# A VIEW FROM THE INSIDE

**Andrew Wilde, Principal Engineer, ROSEN UK, talks monitoring subsea pipelines using internal inspection technologies.**

As the number of subsea pipelines continues to increase and both the internal and external environments that they are subjected to become more severe – deeper waters, higher operating temperatures – the requirement to monitor them for unexpected movement is an increasingly critical aspect of subsea pipeline integrity management.

Subsea pipelines are often designed to withstand movement up to a certain magnitude caused by factors such as thermal expansion or challenging metocean conditions. However, excursions from intended operating limits, extreme environmental conditions, or accidental damage through external force can all result in pipeline movement that exceeds any design limits and therefore requires some form of intervention, be it further assessment, more frequent inspection, or repair.

It is a regulatory requirement in many countries to regularly monitor subsea pipelines for signs of external damage or movement so that any issues can be identified early and addressed before an ultimate limit state is reached and potentially catastrophic failure occurs.

This article will discuss the common causes of movement in subsea pipelines, how a pipeline operator may identify, measure and monitor out-of-straightness and what actions may be required upon the discovery of movement outside of design limits.

## Out-of-straightness in subsea pipelines

Out-of-straightness in a subsea pipeline may be part of the original design and therefore does not pose a threat to pipeline integrity. The following are examples of out-of-straightness that have their origins in the design and installation stages:

- Directional changes due to pipeline routing and installation conditions.
- Seabed topography and features (e.g. potholes, boulders and coral outcrops).
- Gravity pull where a pipeline lacks support (e.g. freespans and catenary risers).
- Crossings of existing infrastructure (e.g. pipelines and cables).
- Crossings of buckle trigger structures.
- Tie-in to pipeline inline or end termination structures.
- Crookedness of the pipejoints as per fabrication.

Many of the above upfront expected out-of-straightness situations introduce static, and in some cases dynamic, loads to a pipeline that need to be compared to stress or strain-based limits, as well as other limit states such as fatigue. Providing the pipeline is operated within its design limits, these loads should not impact the integrity of a pipeline during its design life, but may require further consideration if the life of the pipeline needs to be extended.

However, other sources of out-of-straightness may be unexpected and associated with pipe movements due to operational or environmental loadings or external impact. Examples include:

- On-bottom instability in inclement metocean conditions (e.g. severe currents during storms).
- Soil movement (e.g. by soil transportation, scour, slope instabilities and seismic activities).

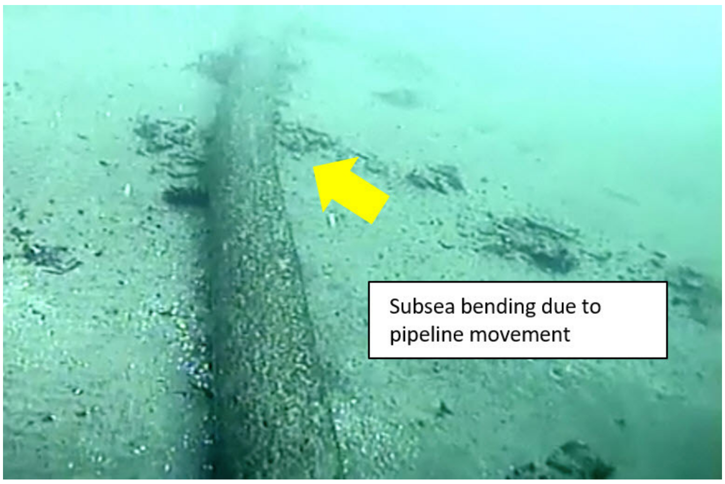


Figure 1. Pipeline out-of-straightness caused by external impact. (Photo courtesy of US Coast Guard)

- Impact by trawl boards, anchors and icebergs.
- Lateral or upheaval buckles caused by thermal expansion.
- Pipe walking (also referred to as pipe ratcheting) due to cyclic pressure and temperature loading, and gravitational pull or axial tension from, for example, catenary risers.

As pipeline movement during operation is a known phenomenon, pipeline integrity management programmes should include measures for identifying, measuring and monitoring pipeline out-of-straightness where such a threat exists.

## Methods for identifying, measuring and monitoring out-of-straightness

Where the operating environment of a pipeline indicates that movement is a credible threat, the integrity management plan should set out a range of mitigation measures. Key to any effective movement monitoring plan is a baseline route profile that is established immediately following installation which can be used as a reference for future inspections. The accuracy and resolution of this baseline survey should be sufficient to allow subcritical levels of pipeline movement to be differentiated from measurement errors that result in apparent change in pipeline position indicated by future surveys.

After pipeline installation, the offshore pipeline trajectory is traditionally recorded through inspections by ROVs, towed sensors, and more recently also by AUVs. These inspections may involve a myriad of tools such as cameras, single beam, multi beam, and side scan sonar systems or sub-bottom profiling with high resolution multi-channel/multi-component seismic, magnetometers and gradiometers.

No single tool is perfect when it comes to measuring pipeline out-of-straightness, and increasingly operators are using a combination of methods in a complimentary manner. All methods have their particular advantages and limitations. The main challenges with ROVs are that they are time consuming inspections to perform, and costly because they require a sizable support vessel and skilled operators. Challenging environmental conditions can also limit their successful application and limit the quality of data that is gathered. A cost-effective alternative that overcomes these limitations, and has the prospect of providing superior measurements, involves the use of inertial measurement units (IMU) mounted to inline inspection (ILI) tools. Since the IMU will run internally within the pipeline, it is capable of recording the out-of-straightness throughout the full length of the pipeline from launcher to receiver, and its accuracy is not affected by environmental conditions, e.g. poor visibility. ILI is a fundamental aspect of most pipeline integrity management programmes and for subsea lines these systems are most commonly used to detect, size and monitor corrosion activity within the pipeline. IMUs can be mounted to those inspection tools, to cleaning pigs and, unless more frequent inspections are desired, do not require a dedicated inspection run.

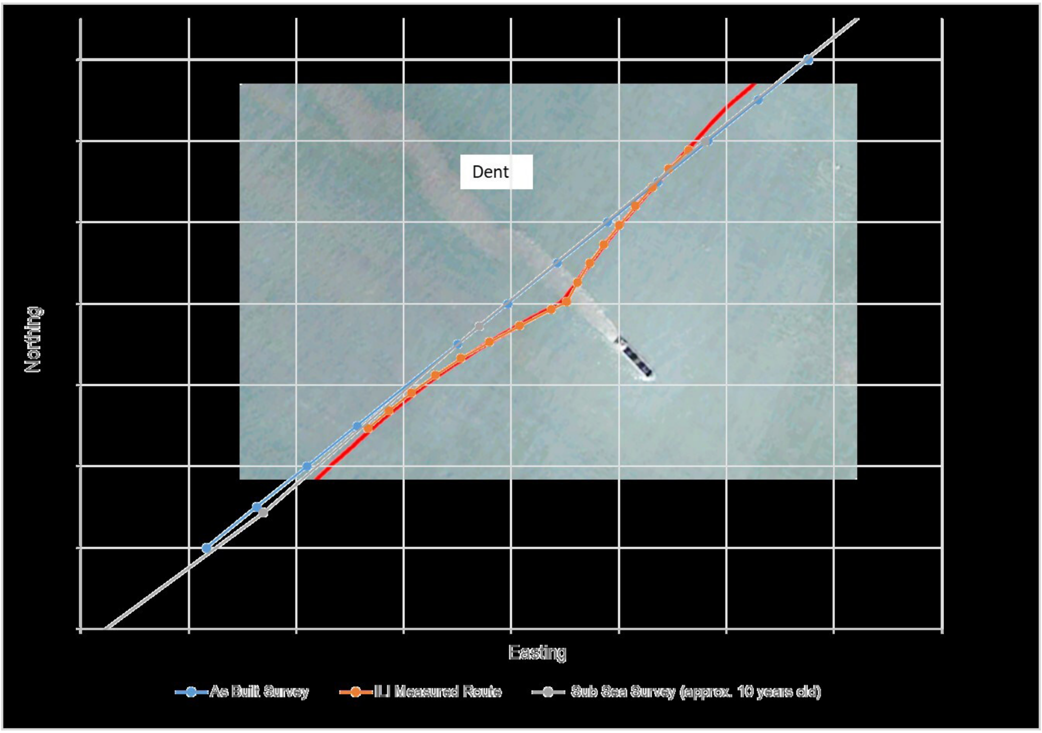


Figure 2. **Comparison of repeat pipeline trajectory data.**

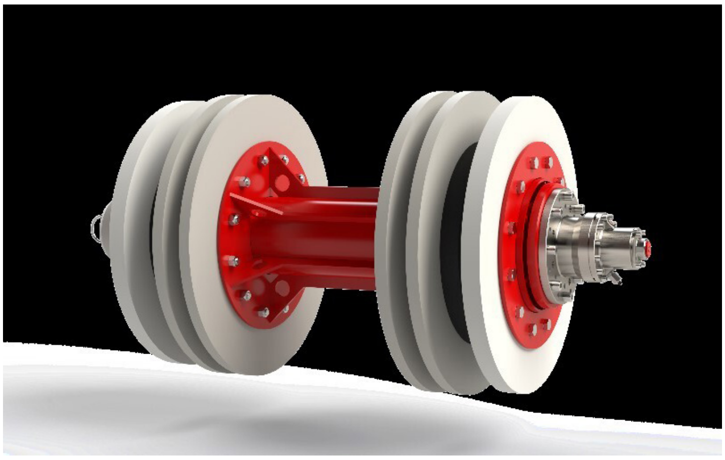

Figure 3. **RoGeo Tool.**

## What is an IMU and how can it be used to monitor subsea pipelines?

An IMU, as used for pipeline ILIs, is an electronic device that measures and reports linear accelerations and rotational rates, using one accelerometer and one gyroscope per axis for each of the three axes: pitch, roll and yaw. As the IMU only detects and records linear accelerations and rotational rates, post processing is required to compute the XYZ data points providing the pipeline profile used in XYZ mapping.

One challenge of using IMU measurements for global pipeline XYZ mapping is that positional errors are accumulated over time, leading to a 'drift': an ever-increasing difference between the calculated location and the actual location. As a result, in order to determine an accurate pipeline route (within say 0.7 m) regular tie-in points are required, typically every 1 - 2 km. For most onshore pipelines, establishing regular tie-in points is economically viable, and so ILI using IMUs has become a standard practice for establishing an accurate profile. For subsea lines however, this requires the use of ROVs which negates many of the benefits of using ILI to map the route of subsea pipelines, and so the use of IMUs for subsea pipelines for pure mapping with high global accuracy is less prevalent.

However, once an accurate baseline route has been established, typically through ROV or AUV inspection following pipeline construction, the focus for future inspections is on identifying and quantifying any changes to the pipeline route that may have occurred due to excursions from design limits or external impact. This requires an accurate indication of the pipeline trajectory/curvature over a localised area, and is not dependent on an accurate absolute position of the pipeline. Where repeat inspections using IMU are available, changes in pipeline curvature can be identified, and these areas can be reviewed in more detail to determine whether the differences in pipe curvature have been caused by pipeline movement. By applying virtual fix points at the start and end of the suspected pipeline movement area, the direction and extent of movement can be determined. Using this approach, movements of the magnitude 0.2 m can be detected. For pipe sections with established pipe movements, the pipeline movement pattern will be assessed for characteristics that may reveal the movement root cause, e.g. pipe walking, anchor drag or freespan developments. By analysing for such characteristic movement patterns, movement of significantly less than 0.2 m can be identified. Furthermore, if the pipeline movement can be determined to be predominantly displacement controlled, the pipe curvature may be converted into bending strains and criticality checked against code allowable strain limits vs the more strict stress limits. Consequently, pipeline movement can be identified, quantified and assessed using IMU without the need to establish regular tie-in points, and therefore provides an effective solution for susceptible subsea pipelines.

## Deployment of IMU tools

IMUs are normally deployed as part of an ILI combo tool including, for example, magnetic flux leakage and geometry sensors. This combination of inspection technologies can provide a wealth of information to support integrity assessments, especially in cases of coincident damage.

This was evident following a recent internal inspection of a predominantly onshore pipeline with an estuary crossing several kilometres long, where shipping activity was high. A large dent (>6% of the outer diameter) was reported on the top/side of the pipeline. The dent was subject to an initial integrity assessment which demonstrated a low likelihood of cracking due to localised curvature strain, and showed that the fatigue life of the dent exceeded the design life of the pipeline. However, its location within the estuary warranted further investigation to determine its root cause. The internal inspection had used a combination of MFL, caliper and IMU technologies, although IMU data had been used only to map the onshore pipe section. A comparison of the local pipe profile as indicated by the ILI against both the as-built survey and an in-service ROV inspection showed a clear deviation in pipeline route, centred on the dent location (Figure 2). Subsequent analysis of the pipe curvature indicated global bending strains approaching 2% that were coincident with both the dent and a girth weld. Movement in excess of 20 m was identified. Although no metal loss was identified by the MFL tool, further analysis will be required to fully quantify the peak strains that the pipeline has been subjected to in order to determine the proximity of the pipe to ultimate limits states, such as low cycle fatigue. Such analysis will require accurate data relating to local pipeline curvature, detailed profile information for the deformation, and data on any nearby metal loss. All of this information can be provided from the ILI, meaning that further integrity analysis can progress in parallel with further external inspection that will be required to establish the status of the concrete coating, and to gather any further information relating to the likely root cause.

## The demand for regular movement monitoring

The add-on cost of including an IMU within a traditional ILI campaign is nominal, however the overall cost of the inspection activity and production interruptions mean that IMU tools are rarely used on a frequent basis unless the pipeline is highly susceptible to movement and alternative monitoring methods are flawed. Therefore, a dedicated solution was required that is cost-effective and has minimal operational impact. ROSEN has recently developed a tool that incorporates IMU technology within the body of a cleaning tool which can be used as part of regular operational cleaning runs. The tool, RoGeo PD, can be run at higher speeds compared to conventional ILI tools, and so minimises the impact on pipeline throughput. The short tool length also simplifies tool handling as well as launching and receiving.

The tool has no odometer wheels to measure distance and instead uses the IMU to detect characteristic vibrations that occur as the tool passes over girth welds to enable alignment with a previous ILI. Initial inspection runs using this technology show that almost similar relative trajectory accuracy levels can be achieved compared to traditional IMU inspections, but the simplicity of the tool means that it can be run at a lower cost, thereby supporting the demand for a solution that can be run on a regular basis.

## The value of ILI with IMU in integrity management of offshore pipeline

Undesired pipeline deformation and failures may occur from pipe bending resulting from insufficient engineering, installation mishaps and unintended environmental and operational loadings. As such, it is important that pipeline out-of-straightness is identified, measured and monitored from the day of installation/commissioning to the end of useful life so that the optimal and timely intervention actions may be taken by the pipeline operator. One method of achieving these goals involves the use of ILI with IMU as part of a wider integrity management plan. ILI with IMU has several benefits with regards to the integrity management of offshore pipelines. Achievable benefits from a single IMU inspection run:

- Curvature measurements throughout pipeline. This will, if assessed together with external inspection data of freespans, for example, provide high quality input to ultimate strength checks and span modal analysis.
- Bending strain profile for full length of pipeline, providing insight into unintended forces acting on the pipeline.
- Detect global geometric anomalies such as lateral and upheaval buckles, or anchor drags.
- Combining IMU with Geometry and MFL or UT inspection technology – bending strains can be accurately correlated to other anomalies (e.g. corrosion, dents, gouges, wrinkles) within or in close proximity to the deviated shape. Data collected will support root cause analysis, allow for code compliance checks and detailed finite element modelling.

Achievable benefits from multiple IMU inspection runs include:

- Monitoring changes to the pipeline profile and bending strain levels.
- Early detection of upheaval buckles (not easily detectable by ROV for buried pipelines).
- Measuring the effect of thermal expansion on end terminations, tie-in spools and pipeline buckles.
- Monitoring pipe walking, ensuring that counter measures are installed in a timely manner.
- Early detection and monitoring of pipeline on bottom instability.
- Monitor for changes to span profiles and thereby optimise the need for costly external inspections.

Further developments in ILI technology and post-inspection processing have resulted in an effective solution to run IMU inspections on a regular basis at lower cost and lower operational impact. However, ILI with IMU will not provide a standalone integrity management solution, but is an invaluable and cost-efficient supplement to a wider management plan incorporating other inspection solutions, such as ROV/AUV.