HIGH-QUALITY GEOMETRY MODULE DATA FOR PIPELINE STRAIN ANALYSES

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ABSTRACT

The as-laid position of pipelines is not always constant, since movement can occur for several reasons. Earthquakes, permafrost thaw or heave, landslides, ship anchors and other third-party influences can move and bend pipelines. Any movement of the pipeline position can lead to regional strain which can in turn impact pipeline integrity.

Pipeline bending can have regional or local character. Both defect classes can be detected and analyzed with specific in-line inspection modules. The latest geometry sensors developed by ROSEN can be combined with proven inertial navigation systems. This combination improves sensitivity, repeatability and confidence when detecting pipeline bending strain while also taking into account the influence of strain around ID anomalies.

Repeatability is important to establish the reasons for increasing strain values detected at specific pipeline sections through in-line inspection surveys conducted in regular intervals over many years. Moreover, the flexibility resulting from a combination of different sensor technologies not only makes it possible to meet specific operator needs but also provides a more complete picture of the overall situation.

INTRODUCTION

The seaquake in December 2004 caused a tsunami with terrible consequences for human lives. GPS measurements of the earth's rotation showed a displacement of the rotation pole of 8 cm in the period of the seaquake [1]; an enormous effect considering the earth's mass of $6 \cdot 10^{24}$kg. If a seaquake can cause an entire planet to shift, regional and local ground movement and the resulting strain certainly have a strong impact on pipelines. In order to maximize pipeline integrity, it is therefore vital to take into account and carefully analyze any ground movement. Apart from the danger of earthquakes, pipelines built on permafrost, as is the case in Alaska, may be exposed to differential ground movements due to frost heave or thaw settlement. The differential ground movement can lead to pipeline bending strain. ExxonMobil's interests lie in the capability of an in-line inspection tool to reliably measure change in strain level as a result of pipe movement. This is why establishing high repeatability and accuracy at different strain levels with a focus on measurement capabilities in the plastic deformation regions are of high importance.

The combination of the latest geometry sensor technology (consisting of caliper and proximity sensors) developed by ROSEN [2] with inertial navigation systems provides curvature information as a basis for strain calculations. The relative proportions of strain and curvature as well as known data on wall thickness and diameter enable the indirect calculation of regional and local strain values. In addition, direct strain measurements can be taken by means of gauges which are in constant contact with the pipe wall (see Fig. 4).

REGIONAL STRAIN

Bending strain was simulated and analyzed in a series of tests conducted at the ROSEN Technology & Research Center in Lingen, Germany, in cooperation with ExxonMobil Development Company.

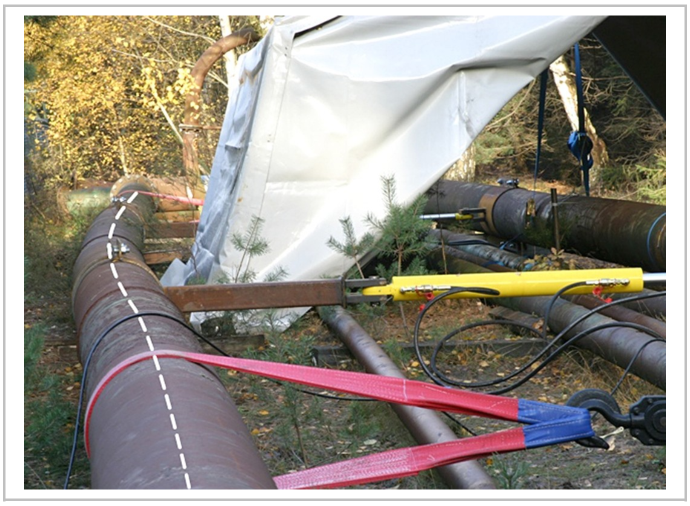

Figure 1: 4-point bending with hydraulic jacks

A 16" pump–test pipeline was placed into a 4-point bending frame for the purpose of gradually inducing low-level strain in the pipeline. While the pipeline was being bent by means of hydraulic jacks, the deflection distance was constantly measured (Figure 1). With the induced curvature, strain values ranging from 0.01 % to 0.1 % were generated over a distance of about 25 meters. The deflections were changed successively beginning just below the detection threshold and ending at a predefined point just below possible mechanical damage in order to analyze sensitivity and repeatability. Moreover, three consecutive factory bends (5D-25D-5D) were installed for the analysis of strain due to severe bending possibly accompanied by plastic deformation (Figure 2). This bend combination was placed in a vertical plane and is equivalent to a 2 % strain in the 25D bend section.

Figure 2: 5D-25D-5D bend section simulating plastic deformation

Prior to inducing pipeline movement or changing the strain level successively, a baseline survey was conducted for monitoring the as-laid position and to enable direct comparison between affected and non-affected sections. In total, around 50 runs were performed and analyzed. The type of inspection tool used was ROSEN's RoGeo·Xt comprising an inertial measurement unit and an ID mapping module consisting of two inspection planes mounted with inertia compensation geometry sensors (Figure 3). Combining different technologies, this inspection tool is capable of internally detecting curvature and calculating strain.

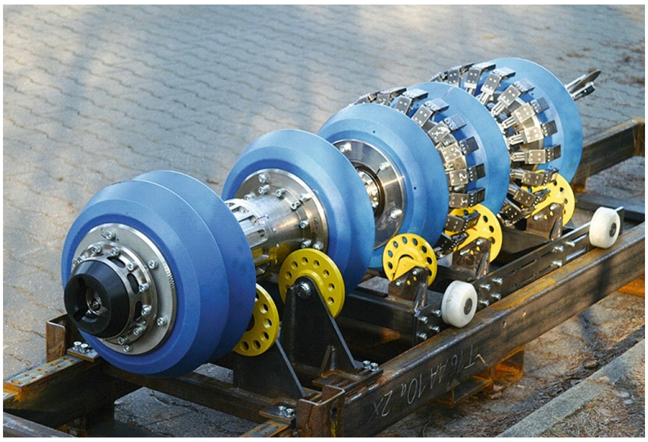

Figure 3: 16" RoGeo·Xt with XYZ mapping and HiRes ID mapping module

Another technique for recording strain is strain gauges. Applied externally, strain gauges consist of a very fine metallic grid which is in direct and constant contact with the pipe wall. When the pipe surface is strained, the strain is transmitted to the grid material through the adhesive. The variations in the electrical resistance of the grid are then measured to determine strain levels (Figure 4).

Figure 4: Integrated strain gauge (red circle) for external strain measurements

METHOD APPLIED

Determining regional strain can be conceived as out-of-straightness analysis. Mathematically speaking, regional strain is a sequence of three curvature areas (see Figure 2) – beginning of movement, area of maximum displacement, end of movement – that produce characteristic amplitudes in the XYZ data recorded by the mapping module. When the RoGeo·Xt inspection tool traverses these three induced bends, the maximum strain appears where the tool is exposed to the highest changes in orientation (or inclination) per recorded distance unit. Figure 5 shows overlaid strain values for the 4-point bending section:

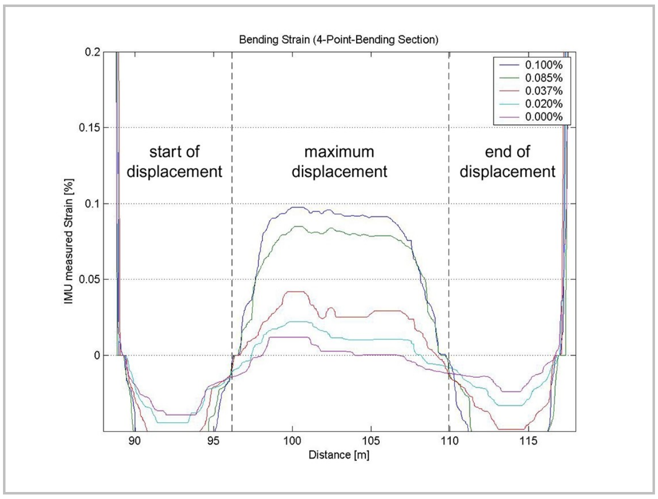

Figure 5: Data distribution typical of a strain area (several strain layers)

Overlaying the different results has the benefit that the strain data of the XYZ mapping analysis can easily be compared with the successive changes of the real pipeline movement. Moreover, the baseline survey must be taken into account, since any offset, wherever it occurs, can skew measurement results. The range of induced strain levels starts close to the tool specification of 0.02 % strain. It must be emphasized that for any level of curvature the strain level strongly depends on the pipeline diameter: the larger the diameter, the more exposed the pipeline is to external forces, since more material is strained compared to a smaller pipeline diameter. The pre-defined trajectory within the factory bends (5D-25D-5D) is clearly out of straightness, as was verified in detail with standard geodetic survey methods in combination with the Gauss-Helmert model which was subsequently used to analyze the geodetic data. The installed strain gauges had been calibrated prior to the installation, and an amplifier later recorded their measurements. Statistical analyses have been conducted incorporating the results of strain gauges, which enables the comparison of internal and external strain measurements.

STATISTICAL ANALYSIS

Prior to statistical analysis of the in-line inspection data, the signal structure and data appearance must be examined carefully due to potentially interfering signals caused by the internal contour of the pipeline. Figure 6 shows overlaid strain signals including weld signals producing contour noise in the data. This example highlights the necessity of carefully sampling the internal contour, as contour signals must be separated from true strain values. This filtering process requires both expertise and a comprehensive picture of the specific situation, especially in low-level strain areas.

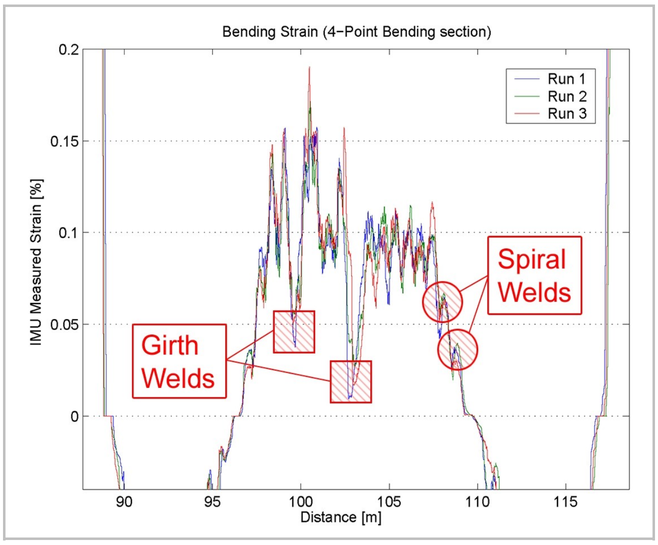

Figure 6: Data distribution typical of a strain area (several strain layers)

The statistical analysis was based on the averaged strain results of all runs through the section with constant strain within the 4-point bending frame. The accuracy and repeatability calculations of the data refer to a confidence level of 80 %. The average accuracy (for the strain levels 0.01 % to 0.1 %) was found to be 0.002 %. An analysis of the results from the strain gauges showed that these external measurements were accurate enough to be compared with the results produced by the Inertial Measurement Unit (IMU). In Figure 7, the strain levels measured by the strain gauges are plotted against the IMU strain results. A tolerance band represents the range within which 80 % of the measurements are located, namely ± 0.0022 %. Using a 48 inch diameter Trans-Alaska pipeline as an example, a deflection of 82 mm on a pipeline section length of 20 m would result in 0.1 % strain.

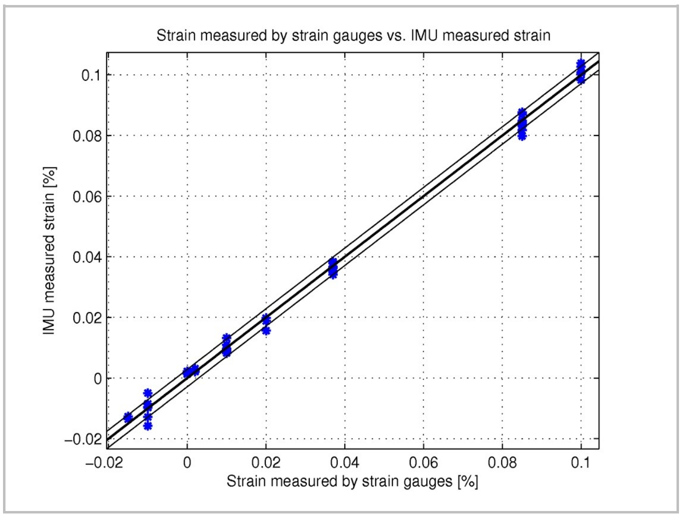

Figure 7: Strain gauge readings plotted against IMU strain results

As Figure 7 shows, there is both high correlation and good repeatability between IMU-measured strain levels and the strain readings produced by the external gauges. The average repeatability (for the strain levels 0.01 % to 0.1 %) is 89 %. In this statistical analysis, repeatability is defined as the percentile standard deviation (subtracted from 100 %). In the area of simulated strain due to severe bending (25D bend equivalent to 2 % strain), the accuracy of strain detection was 0.025 %, whereas the level of repeatability was 99 %. In general, all bends (with bend radii <30D; 15 bends in total) in the pump-test pipeline were detected with a POD of 100 % during an automated search run. Moreover, the good repeatability of regional strain detection enables, especially in conjunction with local strain results, identification of trends – e.g. increasing strain – and threats – e.g. vulnerability of pipeline integrity – at specific locations.

LOCAL STRAIN

Along with regional strain, the appearance of local strain must be taken into account as well. As seen, external forces can induce regional curvature. However, such forces also have a local impact, since ID anomalies such as dents and ovalities can be present near curvature changes where strain typically reaches maximum values. For this reason, it is vital firstly to map the internal contour confidently and secondly to quantify the anomalies with appropriate methods [3].

Combined technologies and data evaluation methods, then, assist in proving and quantifying pipeline integrity. Thus geometry components can be combined with a high- resolution magnetic flux leakage (MFL) unit and other specialized combo tools to identify possible mechanical damage such as corrosion (see Figure 8) in addition to mapping the internal contour and detecting ID anomalies.

Moreover, the integration of an MFL unit ensures, thanks to the tool's ability to magnetize walls to saturation, highly accurate information on wall thickness changes. Data provided by the MFL unit can thus be used as a necessarily contributing basis for calculating strain values in dent areas.

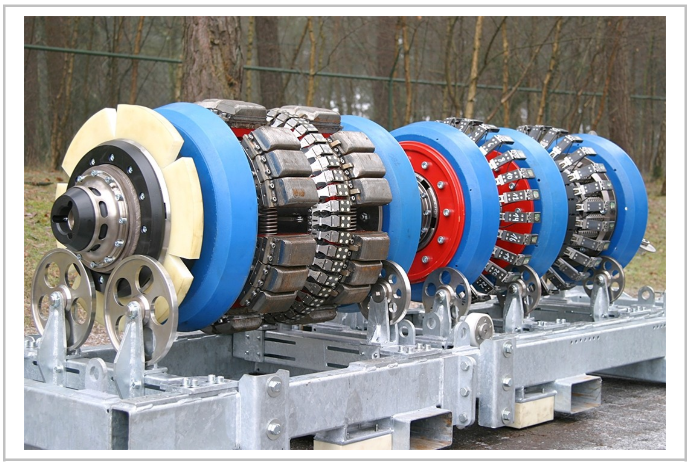

Figure 8: RoGeo·Xt combined with an MFL unit and an XYZ mapping module

ROSEN's modular technology enables the pipeline operator to assemble an inspection tool which flexibly combines EMAT (Electro-magnetic Acoustic Transducer) with UT (Ultrasonic) components and geometry modules to ensure that all the needs arising from a specific situation are met.

CONCLUSION

The pump-test series conducted with the XYZ module indicate that this measurement system is sensitive enough to detect strain levels as low as of 0.01 % (5000D equivalent bend radius). Furthermore, it can be concluded that repeatability improves with increased strain level, the average repeatability being 89 %. The achieved accuracies of 0.002 % for strain levels ranging from 0.01 % to 0.1 % as well as 0.025 % for the 25D bend means that even small amounts of pipeline movements resulting in minor strain changes are revealed. These strain changes can be monitored by regularly comparing the XYZ mapping inspection results recorded over a period of many years. In addition, the established repeatability suggests that the inspection results are a reliable source of pipeline integrity information, especially if the pipeline is exposed to increasing strain levels over a certain period of time. The tests demonstrated that the strain measurement tool has the accuracy and repeatability required to detect strain levels of interest for real world pipeline applications. In summary, multi-purpose tools are an indispensable instrument for detecting strain on the pipeline due to positional movement: while regional strain can be identified with the XYZ module, the RoGeo·Xt tool exposes local dent strain. Modular assembly of different sensor components, then, enables the operator to run combined in-line inspections meeting specific needs for a comprehensive picture of the pipeline under inspection.

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