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Dear colleagues,

Dr. Klaus Ritter
President EITEP Institute
Editor in Chief of ptj

the Covid 19 pandemic has overwhelmed us all like a tsunami - unwanted, unanticipated and therefore completely surprising. It has plunged the global economy from a high into a deep crisis in a very short time. Nearly all areas of social and economic life have been affected and have to switch to stand-by or abort in the shortest possible time - or they have to find new ways and instruments to meet their obligations and responsibilities.

The pipeline conference with the greatest international impact - the ptc in Berlin - was about to take place when the pandemic became apparent. Cancellation of the date was unavoidable - but the question remained:

How can we secure as many preparations, expectations and investments as possible?

The organiser EITEP decided to turn everything into an online conference, which was made available to all registered participants, sponsors and exhibitors on the scheduled conference days.

It was important to ensure that as many of the expectations that are associated with an attendance conference as possible were also met with the online conference.

Expectations are in particular:

1. Description of the state of the art in science and technology

2. Promoting the exchange of experience

3. Creation of a market place for suppliers and buyers

To be honest, the expectations of 1. and 2. can be achieved to some extent by a well thought-out online conference. The point 3. on the other hand is less easy to present.

In addition to the possibility of guiding visitors to the homepage of sponsors and exhibitors within the online programme, EITEP places all presentations and advertisements - if they are freely available - on the ptc homepage, adds the abstracts to their knowledge database and publishes the papers in the Pipeline Technology Journal (ptj) in several special issues. This is the first of these issues. This gives an idea of the quality of the 15th ptc - whether an attendance or online.

We have received much encouragement in the preparation of the conference. Regarding the transformation into an online conference, the response was almost even more positive, because almost everyone has had to accept cuts in their economic activities during the pandemic. All our partners know that imagination, motivation and energy are needed to continue to meet the existing challenges in the future.

In any case, we at EITEP are ready to continue providing a ptc that focuses on **safety, reliability and cost-effectiveness** of pipelines.

I would like to thank all of you who are at our side now and in the future, and I look forward to seeing you all again at the **16th Pipeline Technology Conference in Berlin from 15 to 18 March 2021.**

Sincerely yours,

Dr. Klaus Ritter,
President EITEP Institute
Editor in Chief of ptj

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MARCH 2020 / SPECIAL EDITION

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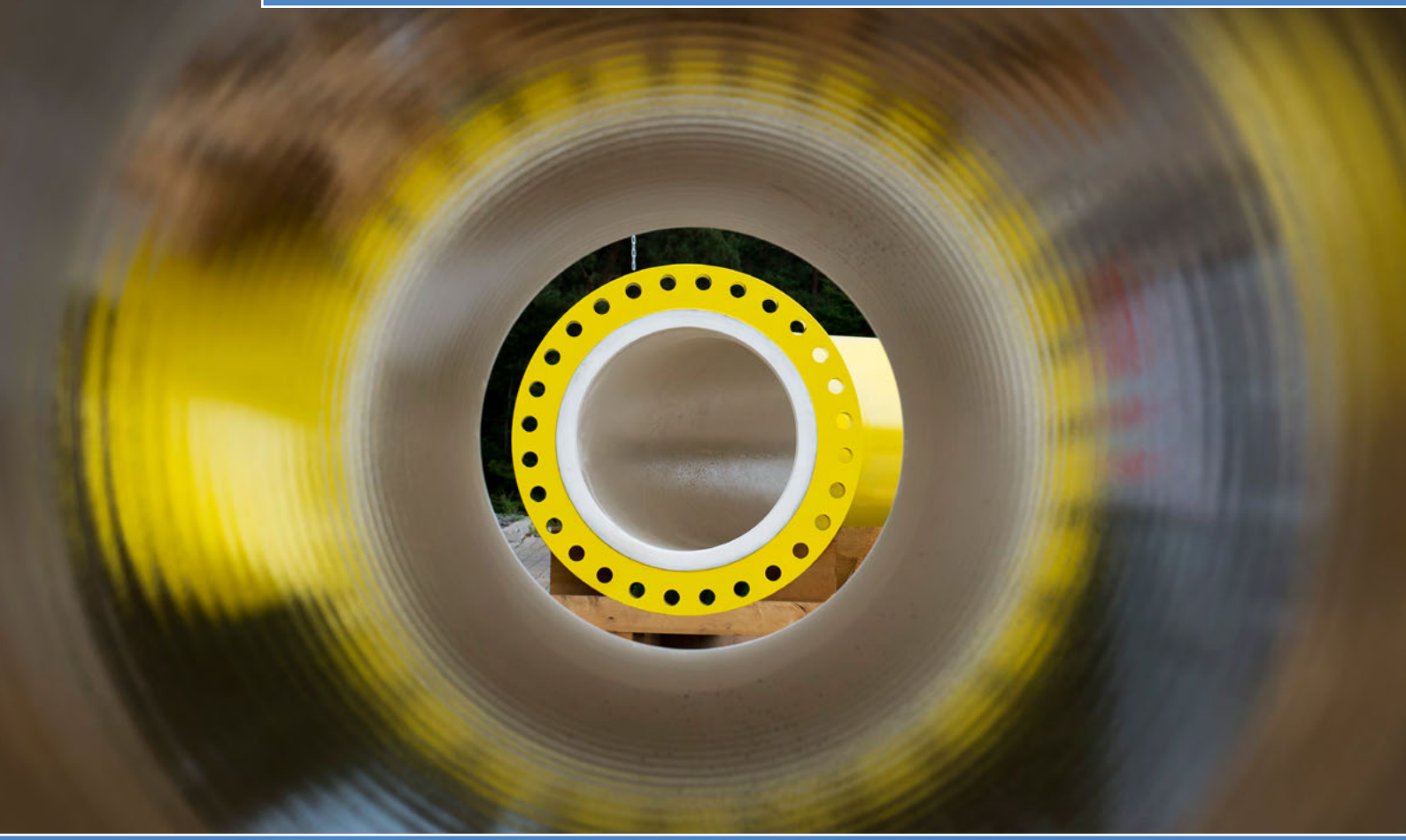
An Exploratory Data Analysis Of Pipeline Coating Degradation



Michael Smith, Matthew Capewell, Ian Laing > ROSEN Group

Abstract

Pipeline coatings can be constructed from a multitude of materials, all of which aim to provide a physical barrier between a pipeline and the external environment. Naturally, understanding the degradation characteristics of these different coating materials is critical, as with the onset of coating degradation comes metal degradation, i.e. corrosion. External corrosion remains as one of the major threats to the integrity of pipelines worldwide.

Since coating degradation can occur for many reasons (from discrete events such as impact damage during construction, to age related processes such as embrittlement or loss of adhesion [ ]), modelling and prediction of degradation is a challenging task. In practice, it is more common for pipeline operators to measure the condition of a coating periodically (using visual inspection, or above ground survey techniques) in order to monitor its degradation over time. Unfortunately, these coating survey data are distributed across multiple pipeline operators, inspection vendors and service providers, meaning that there is no single data repository from which population trends can be established.

As an alternative, we present a brief exploratory data analysis (EDA) conducted on a large repository of historical in line inspection (ILI) data for around 5,000 unique assets with known coating materials. The purpose of the EDA is to investigate whether the prevalence of external corrosion – as observed over a large population of pipelines – can be used to infer the degradation characteristics of the materials. The EDA makes use of 18 million instances of external corrosion detected in over 6,000 metal loss inspections

EXPLORATORY DATA ANALYSIS (EDA)

COATING CATEGORIZATION

Although many different coating materials are recorded within the data repository, we group the coatings into five broad categories: Asphalt, Coal Tar Enamel (CTE), Tape, Fusion Bonded Epoxy (FBE) and 3 Layer Polyethylene/ Polypropylene (3LPE/PP). Note that coatings applied exclusively to the field joint area of a pipeline (approximately 200 mm either side of the girth weld) are not considered in this analysis.

Figure 1 shows the distribution of the coating categories according to decade of construction and reveals a clear trend – namely, the gradual phasing out of the "first-generation" coatings (Asphalt and CTE) and the concurrent introduction of the "second generation" and "third-generation" coatings (FBE and 3LPE/PP). Tape coatings stand the test of time and retain a sizeable proportion of the population throughout the years.

CONDITION METRICS

Condition metrics are single valued, numerical descriptors for the condition of a pipeline. In the present case, two condition metrics are selected as proxy variables for the coating condition.

The first is the anomaly density, defined as the number of external corrosion anomalies divided by the total pipeline surface area. High anomaly densities imply that the coating has degraded in multiple locations, while low anomaly densities suggest more sporadic coating degradation. The second metric of interest is the relative corroded area, defined as the total corroded area (with each individual anomaly area approximated as length × width) divided by the total pipeline surface area.

While anomaly density correlates strongly with relative corroded area, each metric is useful in its own right. There are cases, for example, where a pipeline has a relatively low anomaly density, but where each individual anomaly has a high surface area (this may occur due to coating disbondment over an extended area). The use of both condition metrics also accounts for differences in ILI technology. Magnetic Flux Leakage (MFL) technology, for instance, tends to report a greater number of individual anomalies (each with a relatively small area) compared to Ultrasonic (UT) technology, which is more likely to report an extensive corroded area.

Note that in the present analysis, all external corrosion anomalies are counted, irrespective of their distance to girth welds. While it is acknowledged that different external corrosion activity can occur in the pipe body and field joint areas, further investigation of the dataset shows that this is relatively uncommon. When the two populations are separated and the condition metrics are recalculated for each population, the metrics are strongly positively correlated, implying that a pipeline with significant corrosion in the pipe body is more likely to have significant corrosion in the field joint area, and vice versa.

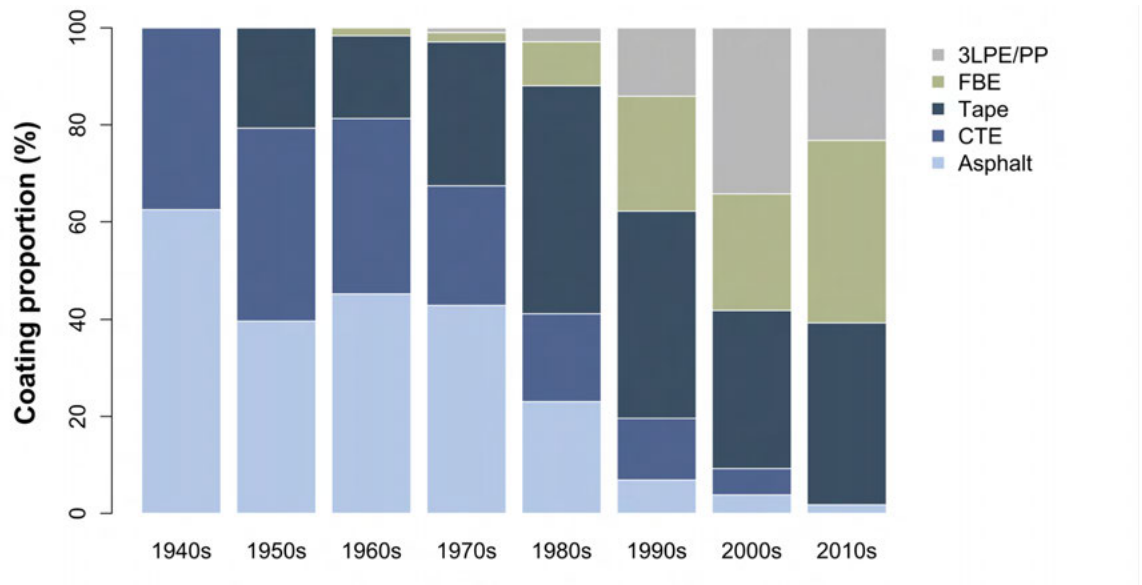


Figure 1: Distribution of pipeline coatings by decade

The distributions of the condition metrics are shown in Figure 2, on a logarithmic scale. The scale highlights that the pipelines vary extensively in their condition, with the lower orders of magnitude representing pipelines in an almost perfect condition, and the higher orders representing pipelines with extremely pervasive corrosion. Nevertheless, there are comparatively few pipelines in the latter category. The median values lie at only 0.0126 m 2 for anomaly density (¬approximating to one anomaly for every 80 m2 of pipe surface area) and 2.51 × 10-5 for relative corroded area (less than 0.003% coverage).

The next step is to understand how these distributions vary according to the coating category (Figure 3). The box plots show the positions of the minimum, lower quartile, median, upper quartile, and maximum condition metric values for each category, in addition to any outliers (defined as 1.5 × interquartile range above or below the upper and lower quartiles respectively).

Notable in Figure 3 is the high variance in each distribution. This variability is entirely expected, however, since the problem is multivariate; the condition of a pipeline depends on far more than just the coating. Confounding variables arise due to cathodic protection, local ground conditions (e.g. soil resistivity), electrical inference, locations of crossings, and a host of other environmental and economic factors.

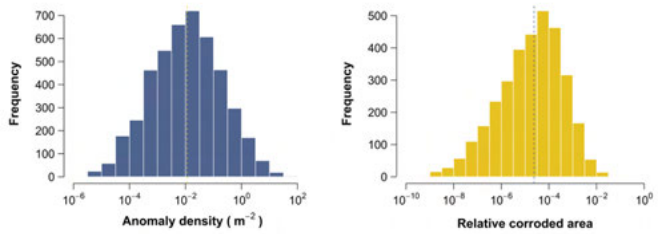


Figure 2: Condition metric distributions (medians superimposed as dashed lines)

Nevertheless, visualizations such as those in Figure 3 can reveal interesting trends. For example, it is clear that the pipelines with first-generation coatings (Asphalt, CTE and Tape) have generally higher values of condition metrics, compared to the more modern second-generation (FBE) and third-generation (3LPE/PP) coatings. This agrees with our intuition, since we expect second and third-generation coatings to provide better protection than firs- generation coatings, due to advances in materials and application methods.

Of course, this does not imply that all future pipelines should be designed with second or third-generation coatings. All coatings have their advantages and disadvantages. The second and third-generation coatings are, for example, far more susceptible to mechanical damage, which can result in localized corrosion at the site of the damage. Since mechanical damage typically occurs at the beginning of a pipeline's life during storage, transport or construction, the exposure time for the corrosion is maximized. This could explain some of the high outliers observed for these coatings.

We must also be particularly careful about the influence of age, which correlates strongly with the coating type (Figure 1) [1]. Due to this correlation, it is difficult to establish whether the trend in condition is caused by the coating itself or the age of the pipeline. All other things being equal, an older pipeline is more likely to have experienced adverse conditions that led to corrosion.

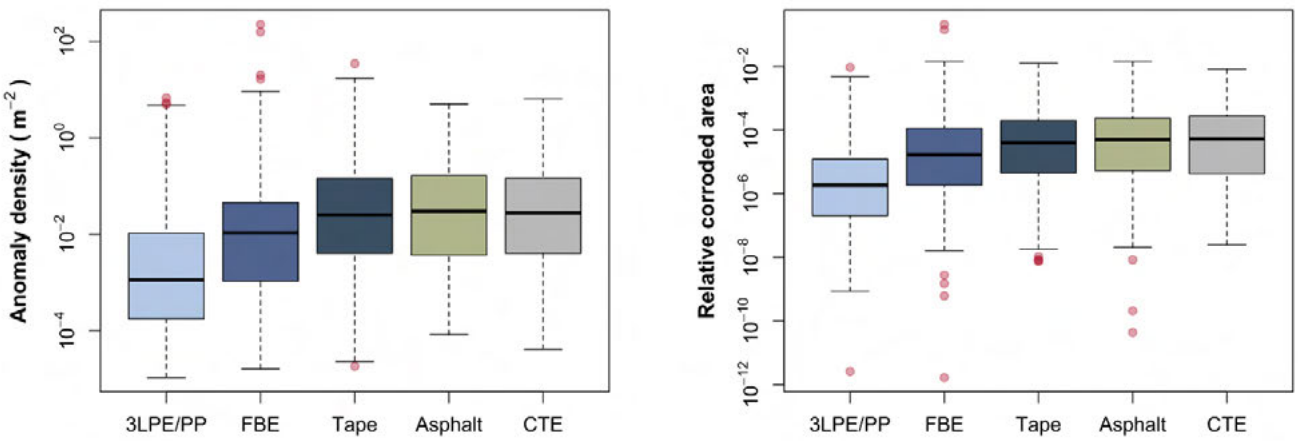


Figure 3: Condition metrics vs. coating type

COATING DEGRADATION

In order to measure degradation, we use the concept of a "degraded" pipeline coating, defined using condition metric values seen in the general population. An intuitive choice is the median value of each metric. Therefore, we set two thresholds, and assert that a pipeline must exceed either one (but not necessarily both) in order for the coating to be defined as "degraded". Explicitly, a pipeline is considered to have a "degraded" coating if either the anomaly density exceeds 0.0126 m 2 or the relative corroded area exceeds 2.51 × 10-5.

After labelling pipelines in this manner, we analyze how the proportion of "degraded" vs. "non-degraded" coatings changes with the age of pipelines (the age of a pipeline is calculated as the difference between the inspection date and the construction date). The proportions are visualized in Figure 4 across five 5 year bins and a final bin for pipelines aged 25 years and over (there is rapidly diminishing representation of 3LPE/PP coatings beyond this age). Note that CTE and Asphalt are combined into a single group as they share similar distributions of age and condition metrics (evidenced in Figures 1 and 3).

At first glance, the poorest performing coating type appears to be FBE, with the probability of observing a degraded FBE coating increasing steadily with pipeline age. While this may be unexpected evidence of time dependent degradation, we should be cautious about jumping to this conclusion. Naturally the ages of pipelines within the database are highly correlated with the construction dates (older pipelines were constructed longer ago), meaning that the trend may simply reflect improvements in construction practices and material properties over time. It remains plausible that the majority of coating damage for these pipelines actually occurred at the beginning of their service lives, with minimal or no degradation thereafter.

By contrast, the best performing coatings are the third generation 3LPE/PP systems, which are minimally degraded and exhibit no clear evidence of time dependent degradation prior to the 25 year mark. Again, the increase in degraded coatings after 25 years may reflect construction practices and material properties from the corresponding time period, rather than time dependent degradation. It may also be a consequence of small sample size.

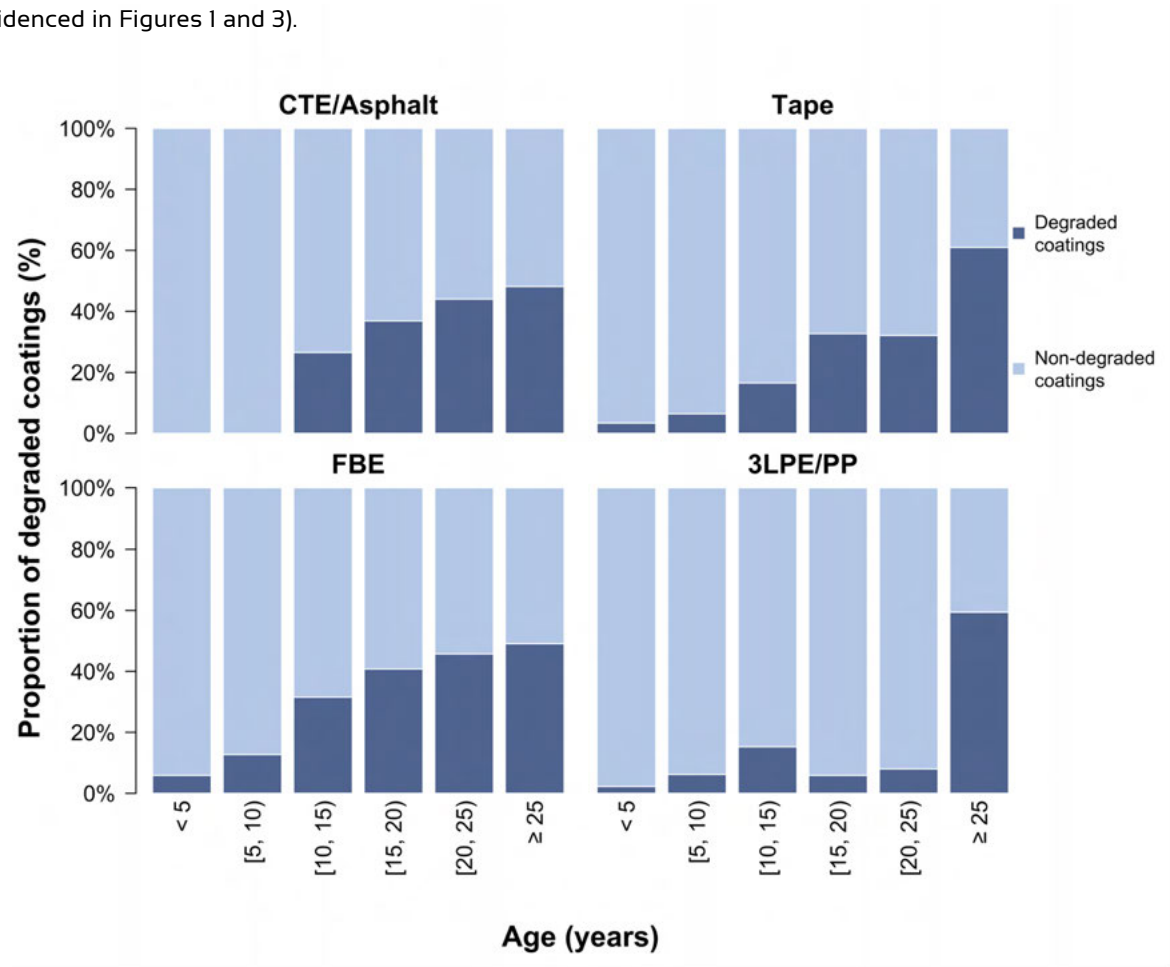


Figure 4: Proportion of degraded coatings vs. pipeline age

While the same confounding effect of construction date may also be at play for the CTE/Asphalt and Tape coatings, prior knowledge of these coating materials gives more credibility to the observed trends. Specifically, the coatings are less susceptible to mechanical damage during construction, but after a time lag are more prone to in service degradation. It is certainly plausible that the absence of degraded CTE/Asphalt coatings less than 10 years of age – followed by a decade by decade increase in degraded coatings thereafter – reflects a 10 year time lag prior to the onset of degradation. Likewise, it is plausible that the trend for Tape coatings reflects degradation without a measurable time lag. Further investigation is required before either of these trends can be verified (and quantified) with confidence.

CONCLUSIONS

Despite the highly confounded nature of the problem, the EDA reveals some interesting trends amongst different coating categories. Most notably, pipelines with first-generation coatings (Asphalt, CTE and Tape) are observed to be in a poorer condition than those with second and third-generation coatings (FBE and 3LPE/PP), and while this trend may reflect the age of pipelines, it is considered highly likely that it also reflects the efficacy of the coating system itself.

The results also hint at time dependent coating degradation amongst Asphalt, CTE, Tape and FBE coatings, although the influence of construction date may be confounding this interpretation. The same cannot be said for third-generation coatings like 3LPE/PP, however, for which there is no clear evidence of degradation with age.

External corrosion and coating degradation are complex phenomena, and fully inferring the causal chain at this stage proves difficult. However, with an expanding data repository (expected to exceed 20,000 metal loss inspections within the next year) and ongoing efforts to obtain higher resolution data, it is inevitable that variability will reduce and trends will become more distinguished. We conclude that the use of ILI data for understanding and characterizing coating degradation is a promising avenue for exploration, with implications for design, construction and integrity management of pipelines.

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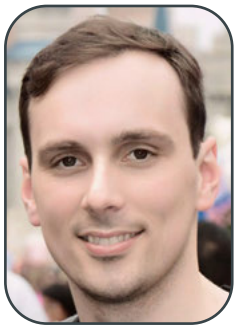

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References

Thompson, I and Saithala, J. R. (2013). Review of Pipe Line Coating Systems from an Operators Perspective. Paper No. 2169, NACE CORROSION 2013 Conference and Expo, March 2013, Orlando, Florida, United States of America

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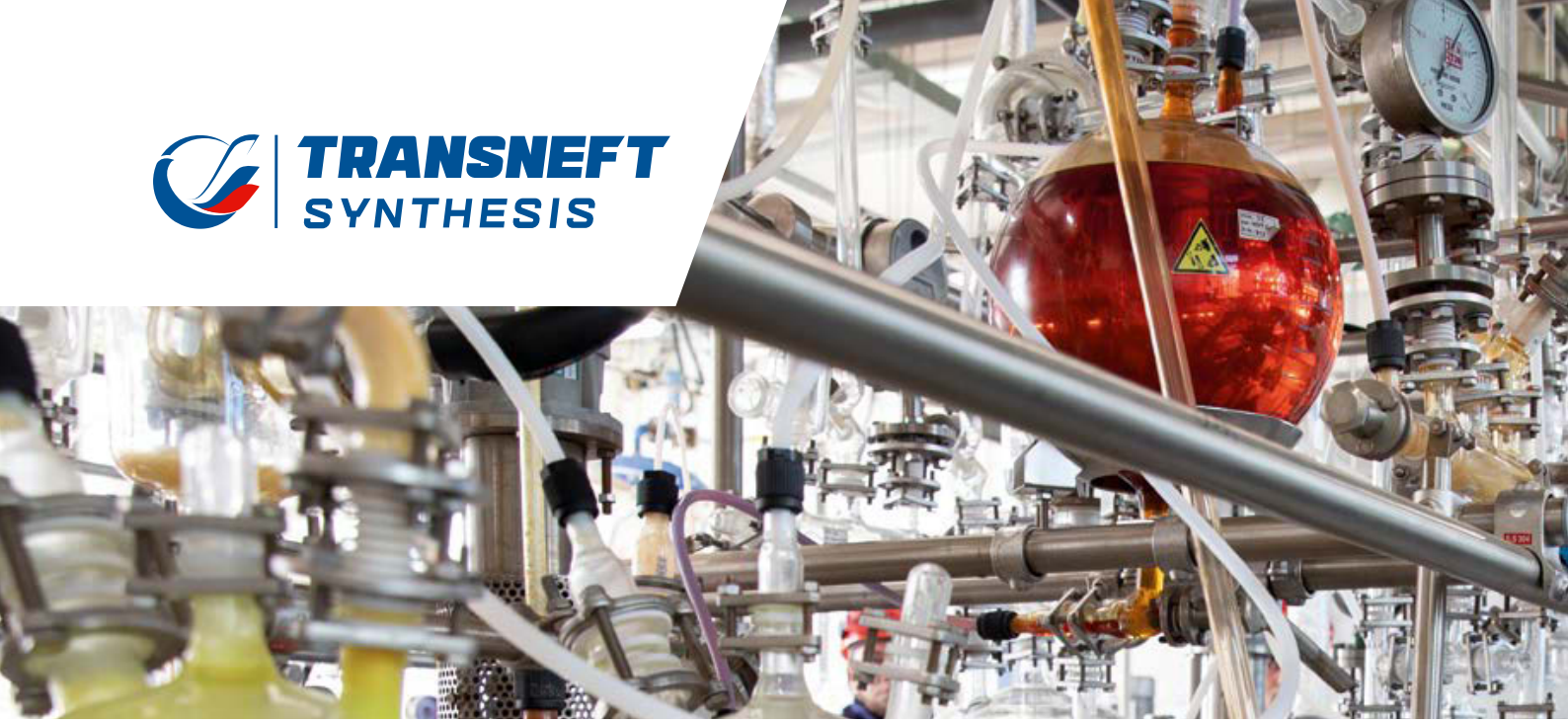

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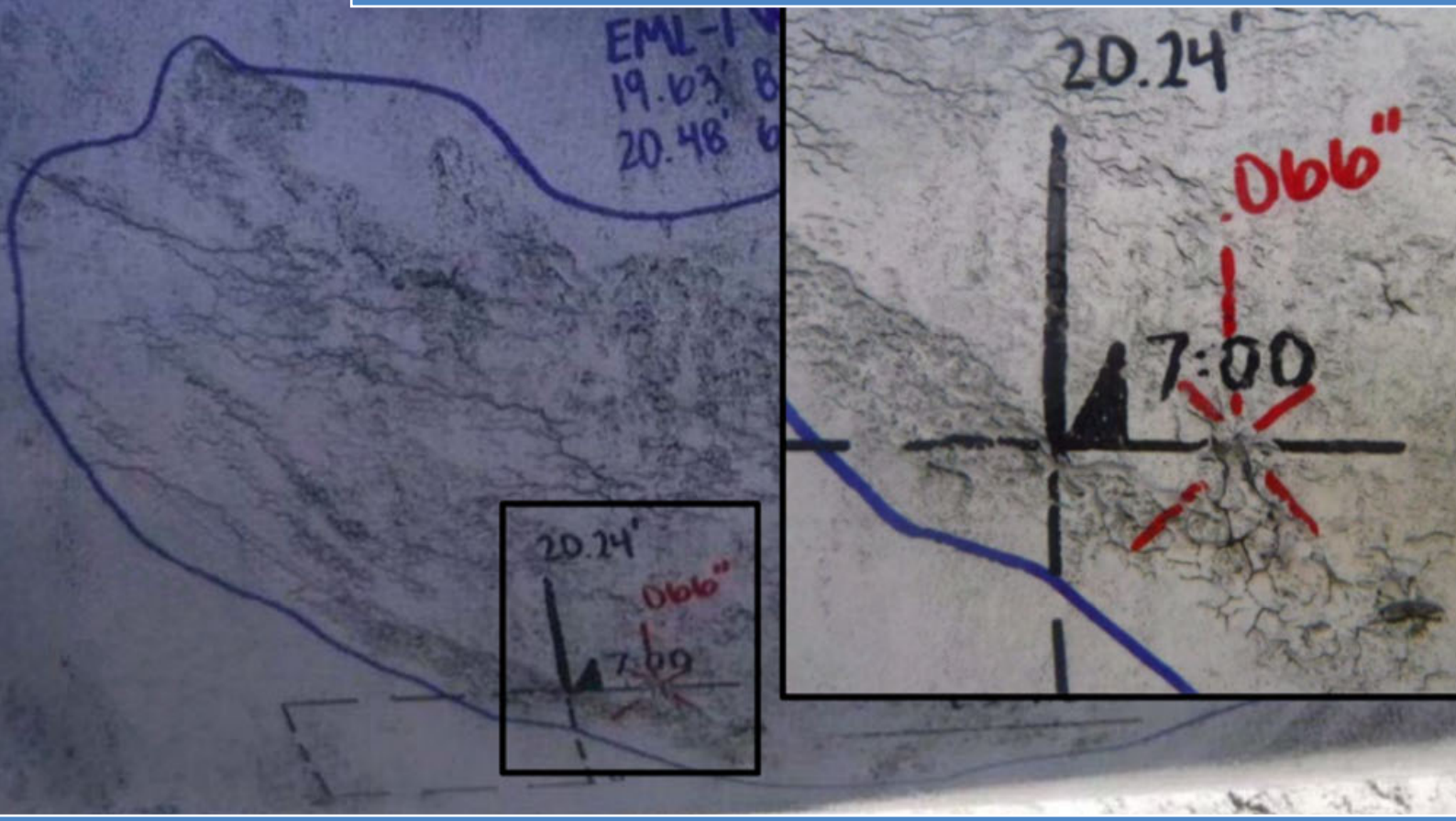
Detection Of Non-Axial Stress Corrosion Cracking (SCC) Using MFL Technology



Matt Rommney, Dane Burden, Dr. Mike Kirkwood> T.D. Williamson

Abstract

Many factors affect how and when line pipe will experience a pipeline integrity threat, including materials, vintage, environment and loading conditions. An integrity threat of particular interest is stress corrosion cracking (SCC). SCC is a type of environmental assisted cracking (EAC) that can occur in line pipe under a very specific set of conditions. First, the material must be conducive to corrosion, which in general is true for common grades of line pipe. Second, the material must be subjected to a corrosive environment. And finally, the material must be subjected to tensile stresses.

The most common appearance of SCC results in colonies of cracks parallel to the axis of the pipe. This is expected, as the principal stress due to internal pressure results in a hoop stress. The in-line inspection (ILI) industry has responded to this threat with crack detection technologies that are specifically designed to detect and size axially oriented SCC and other crack features. However, additional pipe loads associated with external forces, such as line movement, can introduce additional stresses, resulting in non-axially oriented SCC. Under these circumstances, the crack detection technologies specially designed for axially oriented cracking will not be able to accurately detect and size these features.

In response to this gap, research has focused on leveraging existing technologies that can infer the presence of non-axial SCC. Existing technologies can detect the presence of corrosion, determine the additional strain caused by pipe curvature and, given the right conditions, Magnetic Flux Leakage (MFL) technologies have demonstrated the capability to indicate regions with crack-like flaws.

This paper will review several case studies where the data from multiple data set (MDS) ILI tools combined with inertial mapping unit (IMU) technology to find regions where non-axial SCC might occur.

INTRODUCTION

One of the primary concerns of the pipeline industry is maintaining the integrity of pipeline assets. Numerous potential anomalies threaten pipeline integrity. Sources of these threats may include anomalies created during manufacturing, anomalies that occur over time, and pipeline anomalies related to environmental conditions.

Time-dependent anomalies progress as the pipeline material interacts with the environment around the pipe material. One of the most common types of a time-dependent anomaly is corrosion. Corrosion is a naturally occurring phenomenon commonly defined as the deterioration of a material (usually a metal) that results from a chemical or electrochemical reaction with its environment [1]. Corrosion can lead to various pipeline anomalies, including conditions often connected with increased potential pipeline integrity risk. One such potential anomaly is stress corrosion cracking.

Stress corrosion cracking (SCC) has been defined as a form of environmentally assisted cracking that is associated with a tensile stress within a corrosive environment and a susceptible material [2]. This definition outlines the three primary factors required for SCC to occur.

First, SCC requires a susceptible material. Pipelines are often constructed from low carbon steel which is a susceptible material.

Second, corrosion must be present. The pipeline industry spends an estimated $7 billion dollars per year to monitor, replace and maintain transmission pipeline assets [3]. Despite these efforts, pipeline corrosion still can occur.

The final factor required for SCC is the presence of loading. The most commonly recognized pipeline loading is often associated with pipeline loads created by the pressure of the pipeline product. The pressure results in a predominant load in the circumferential direction. The result is SCC-related cracking perpendicular to the predominant loading, which leads to axial oriented cracking.

WHAT IS NON-AXIAL SCC?

Although axial-oriented cracking is the most commonly recognized form of SCC, non-axial SCC can occur when additional loading in introduced. Additional loads can be introduced during pipe installation, pipeline settling and pipe movement because of land movement. When these additional loads occur, the predominant load can re-orient to produce non-axially oriented SCC.

Two of the most common additional loading conditions can be a result of bending strain and pipeline tension and compression. Bending strain can be induced when the pipeline is subjected to movement. For example, land movement can lead to lateral and upward pipe movement, creating additional localized axially oriented loading. Pipeline tension and compression loading can be induced during installation and can also be due to post installation pipeline settling.

Another contributing factor to non-axial SCC is the orientation of the related corrosion. For corrosion to occur, the pipeline coating system must become locally ineffective. Depending on the coating type, some coating will fail in a predictive and repetitive manner. For example, tape wrap-type coating will commonly fail along the tape wrap bond line between successive wraps. When failure occurs, the related corrosion will follow the tape wrap bond line resulting in corrosion following a spiral pattern down the pipe outer diameter. Because corrosion is a required for SCC, the related SCC will follow the same spiral pattern.

An example of non-axial SCC is shown in Figure 1. The SCC has formed because of the damage to coating on this circa 1980 spirally tape wrapped pipeline.

Figure 1: An example of anon-axial SCC

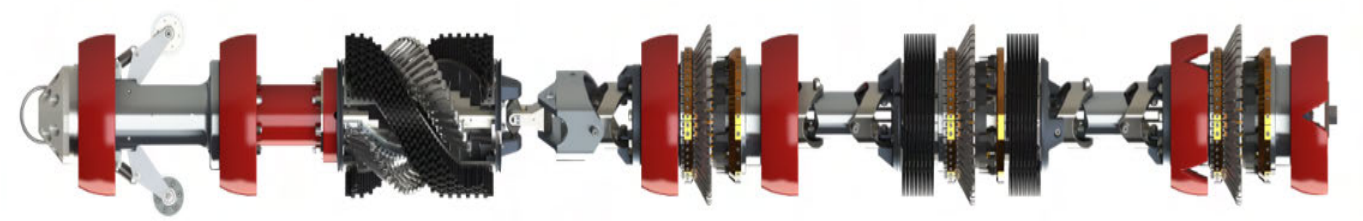


Figure 2: Multiple Datasets ILI Tool

CAN NON-AXIAL SCC BE DETECTED?

A key to accurately detecting, identifying and sizing any pipeline anomaly using ILI technologies is collecting the right data. Each available ILI technology will provide differing views of the anomaly. The combination of data from multiple technologies provides a more comprehensive picture of the total anomaly characteristics. The detection, identification and sizing of SCC anomalies is no different.

The most commonly associated ILI technologies that can identify SCC features are ultrasonic (UT) and electromagnetic acoustic transducer (EMAT). In the traditional arrangement, these technologies produce acoustic waves that travel around the pipe in the circumferential direction. As the acoustic waves encounter a crack-like anomaly, they are reflected. Receiver electronics collect the wave data as it is propagating through the pipe material. With the waves oriented circumferentially, the ILI tool is configured to detect axially oriented crack-like anomalies. However, this wave orientation is not able to properly size circumferentially, or non-axially, oriented crack-like flaws.

Alternative ILI technologies can be used to identify crack-like anomalies under specific circumstances. The multiple datasets (MDS) ILI tool platform (previously published at PTC [4]) incorporates various ILI technologies onto a single inspection vehicle that allows comprehensive identification, detection and characterization of potential integrity threats (Figure 2). The added benefit of the MDS system is that all technologies are collected simultaneously within a single ILI run. Post run correlation and integration of the various technologies is simplified when a system connected to a single odometer is applied. Outlined below are each of the MDS technologies, with a description of the applications of each to non-axial SCC detection.

- Axial magnetic flux leakage (MFL) detects volumetric metal loss, mill anomalies and extra metal within the pipe wall. Changes in the direction of the flux leakage field result in a change in the recorded amplitude in the MFL sensors associated with this disruption.
- Spiral magnetic flux leakage (SMFL) applies the high field MFL field in a helical direction. This field orientation allows for the detection of longitudinally oriented features. Combined with the results of the axial MFL data set, this data can be used to discriminate whether the metal loss feature is circumferentially or axially oriented.
- XYZ mapping (XYZ) provides high resolution mapping of the pipeline routing. This technology contributes information to perform bending strain analysis.
- Low field axial magnetic flux leakage (LFM) identifies changes in material permeability. Permeability changes can be associated with localized strain connected to localized cracking.
- Geometry or deformation (DEF) technology produces a high-resolution profile of the pipeline inner diameter surface.

The magnetic-based technologies have limitations when employed to look for crack-like anomalies in the pipe wall. To provide context to the discussion of MFL-based technology capabilities, version 2016 of the Pipeline Operator Forum (POF) "Specifications and Requirements for In-line Inspection of Pipelines" [5] defines both crack and crack-like features. The primary difference between the two definitions is a minimum crack opening of 0.1 mm (0.004 inches), where anything with an opening of less than 0.1 mm is considered a crack and anything with an opening greater than 0.1 mm is considered a crack-like feature. This coincides with the detection capability of MFL based technologies, where crack features are not usually considered detectable, but crack-like features can be.

Therefore, an approach using MFL-based technologies to identify SCC-type features will need to consider both pipeline anomalies that are crack and crack-like. Since crack features will not necessarily be detected by the MFL technology, the approach will require leveraging additional ILI technologies to infer where a feature may be present but is not detectable by MFL technologies.

The high-resolution centerline trajectory from the XYZ mapping unit provides the opportunity to examine pipeline curvature and the additional bending stresses. The navi-

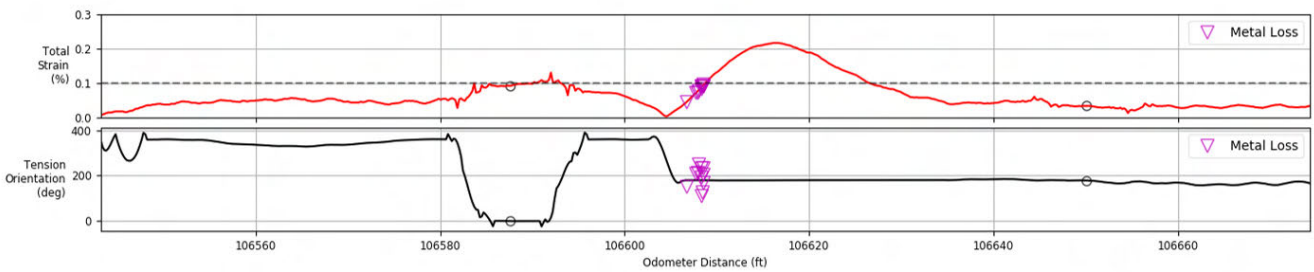


Figure 3: Resultant strain (top), tension orientation (bottom) and MFL identified metal loss plots for an area of unintended curvature

gation of route topography and right-of-way agreements requires intentional curvature to exist, but unknown and unintended curvature is often present. Knowing where unintended curvature exists has historically been utilized to identify the interaction of tensile and compressive load limits associated with girth welds. However, girth welds are not the only pipeline feature that is susceptible to initiate a failure mechanism when additional stress is present. Revisiting the necessary components for SCC initiation, that is, corrosive environment, susceptible material and loading stress, it is possible to isolate the ILI data that may be available to help identify the threat.

An inertial measurement unit (IMU) allows the attitude of an ILI tool to be calculated which can be expressed as pitch roll and azimuth components. Curvature can be calculated by taking the derivative of a component of the attitude, azimuth or pitch, with respect to a specified distance recorded by the odometers. Equation 1 defines the calculations for horizontal and vertical curvature, respectively [6].

$$K_h = -\frac{dA}{ds}\cos(P)$$

$$K_v = -\frac{dP}{ds}$$

Where:
K_h = horizontal curvature (1/m)
K_v = vertical curvature (1/m)
A = azimuth angle (rad)
P = pitch angle (rad)
s = odometer distance (m)

Equation 1: Horizontal and vertical curvature calculations from pitch and azimuth IMU attitude components.

Curvature calculations can be converted to bending strains using Equation 2 [6]. The combined or individual planes of bending contain a compressive and tension state, each perpendicular to one another. Compression on the pipe material fibers resides on the intrados of the bend, that is, the lower or inner curve, while tension is on the extrados, or outer curve; the combination of bending directions can cause the stresses to exist at any orientation on the pipe circumference. Knowing where unintended bending stresses exist, and at what orientation the tensile and compressive stresses are, provides the opportunity to correlate additional ILI data and review interacting threats.

Figure 3 shows the combination of bending strain calculations, orientation of tension in the material fibers and features identified by the associated ILI tool. The red line on the top plot is the resultant strain calculated from the IMU for an area of unintended curvature. It is known to be unintended as no field bend signatures were identified in the associated ILI data and the curvature radii is extremely small. Intentional bending generally has strain values greater than 0.5% which corresponds to a bend radius of 100D (diameter) or larger. The black line in the bottom plot shows the calculated orientation where the pipeline material fibers are in tension. Finally, the purple overlaid triangles are metal loss indications detected and identified by the high field MFL and SMFL datasets. The data can then be used to identify if there is an area of bending strain with associated corrosion that is located at the tension orientation. If the axial stress induced by the bending begins to exceed the hoop stress applied by the internal pipeline pressure, tensile fractures could begin to propagate in a non-axial direction.

$$\varepsilon_h = \frac{D}{2}K_h$$

$$\varepsilon_v = \frac{D}{2}K_v$$

$$\varepsilon_r = \sqrt{\varepsilon_h{}^2 + \varepsilon_v{}^2}$$

Where:
ε_h = horizontal strain
ε_v = vertical strain
ε_r = resultant strain
D = pipe outer diameter (m)

Equation 2: Bending strain calculations for the horizontal and vertical planes and the total resultant strain.

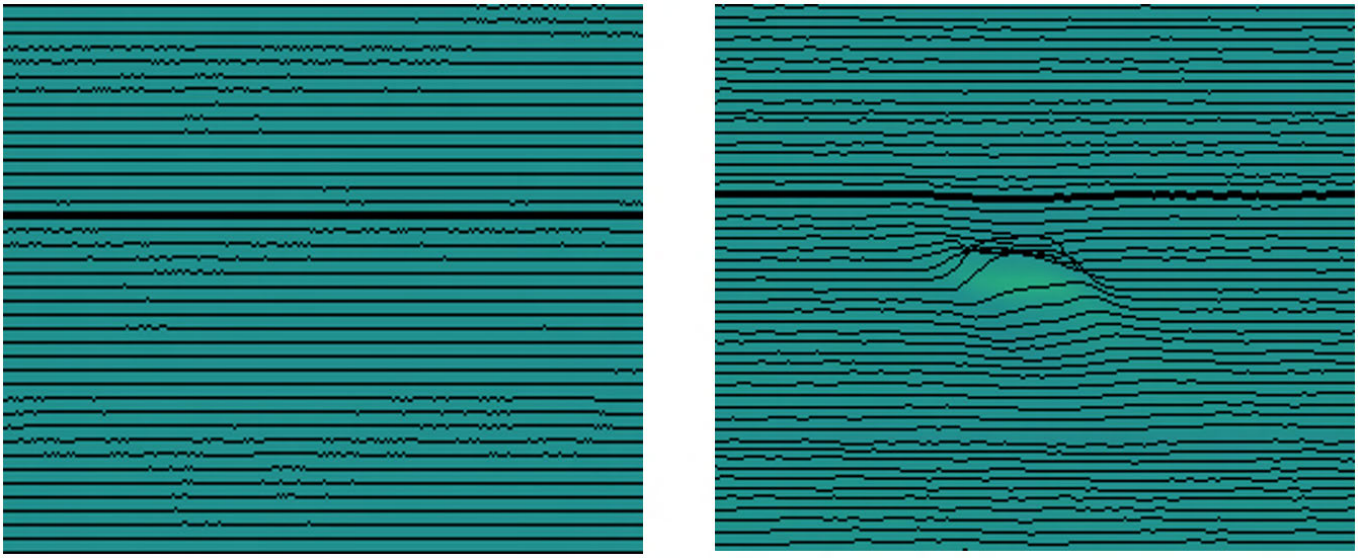


Figure 4: MFL response for an axially oriented crack-like (1.56" L x 0.004" W x 0.25t D) feature

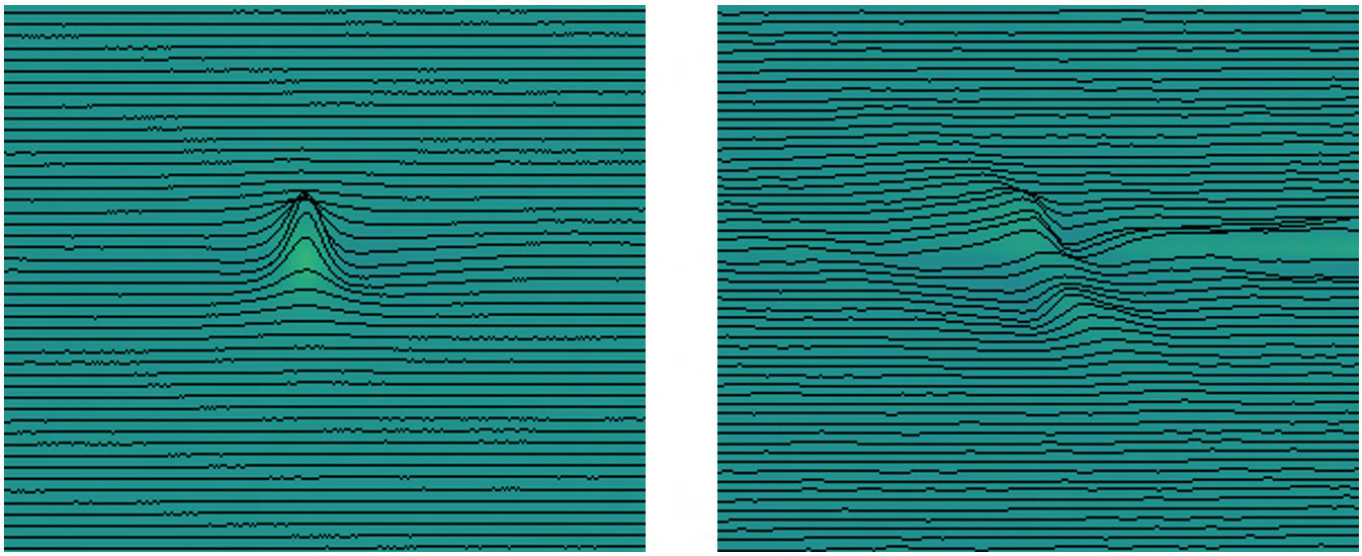


Figure 5: MFL response for a circumferentially oriented crack-like (0.004" L x 1.17" W x 0.26t D) feature

Calculating the total axial stress caused by the bending and comparing it to the hoop stress would not confirm if non-axial cracking was present. However, magnetic discontinuity occurs with extremely small openings, on the order of 0.004", and crack-like indications can be detected by MFL technologies. The use of dual field ILI tools allows both axial and circumferential crack-like indications to be detected and each complement the other to help confirm volumetric from crack-like features.

Figure 4 and Figure 5 demonstrate the power of utilizing dual field MFL ILI tools by showing the response of each field for a crack-like feature at axial and circumferential orientations. The axial feature is 1.56" long by 0.004" wide and 0.25t deep (Figure 4). The circumferential feature is 0.004" long by 1.17" wide and 0.26 of wall thickness (t) deep (Figure 5). Figure 4 shows that the helical direction detected an axial crack-like feature while it is invisible in the axial field direction. Figure 5 shows that the axial field direction detects circumferential crack-like features extremely well while the helical direction detects only some of the tips.

Corrosion features detected and identified by ILI are overlaid on bending strain profiles and any features found to be coincident with areas of unintended curvature are examined. Signal data for each corrosion feature is analyzed in detail to classify the geometry, specifically crack-like features. As MFL is an inferred measurement and signatures cannot be inverted to their true shape, it is more informative to classify the shape into a specific geometry, specifically a crack-like category as defined by the POF.

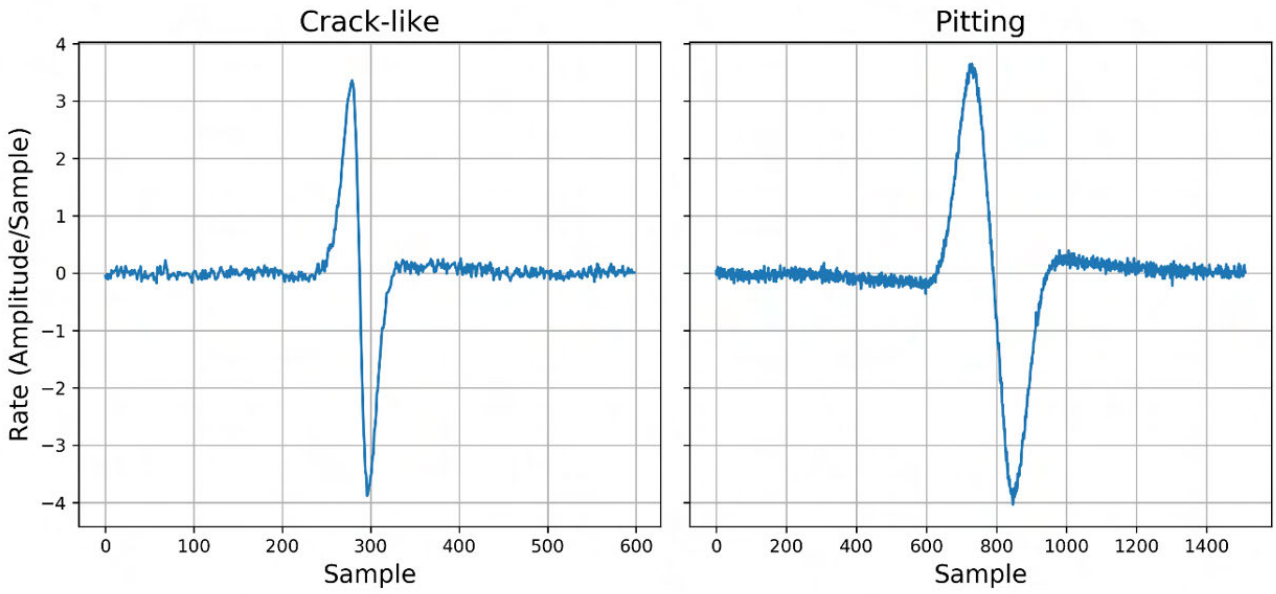


Figure 6: Comparison of the first order derivative profiles for two different POF geometries, crack-like and pitting

This was done by computing the distance between the maximum and minimum numerical derivative across the axial cross section of the corrosion signature. Figure 6 shows two examples of the first order axial derivative profiles for two different metal loss features. The left profile is a 0.004"-long circumferential slot (crack-like) feature while the right is a 1.0"-long pitting (volumetric) feature. Both features have similar signal peak amplitudes but the length between the rate at which they rise, and fall is a significant differentiator.

Using this information, a scoring method was developed to classify circumferential crack-like features from longer slotting and more general volumetric geometries. Figure 7 shows a comparison of metal loss geometries and the calculated score for each feature sorted descending by highest score. There is a significant separation between crack-like and volumetric features that provides a simple way to classify individual metal loss signatures.

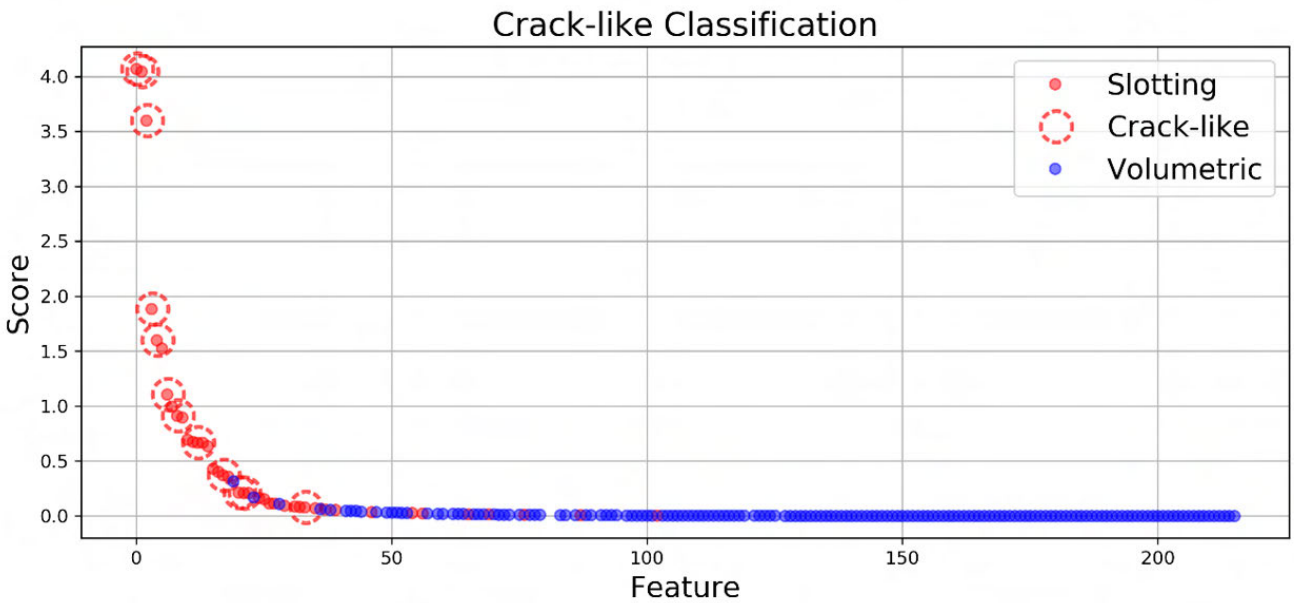


Figure 7: Comparison of circumferential slotting, circumferential crack-like and volumetric feature scores

RESULTS

Using the strengths and weaknesses of each field direction, the associated bending strain computations and the metal loss geometry classification techniques discussed above, a prioritization method was developed to identify areas with potential non-axial SCC. This method has been applied to several pipelines in which non-axial SCC was believed to be present.

In one case, an operator provided a list of pre-selected areas for further review. The initial list was developed using historical ILI data, geographic location and environmental interactions and proximity to system components, such as compressor stations. The goal was to review the provided candidates and prioritize them from most likely to least likely to contain non-axial SCC. The final list included high, moderate and low-ranking categories and a field investigation priority. Figure 8 shows the key decision features from the prioritization method for the area ranked with the highest field investigation priority.

The MFL dataset shows several wide, high amplitude features that were classified as circumferentially crack-like. The corresponding SMFL dataset shows no volumetric response at these areas, further confirming the short circumferential nature indicative of a crack-like features. The features are also located in an area of abnormal curvature with a peak strain value of 0.22% and an associated strain value of 0.1%. Finally, the curvature is a bend up (under-bend) and the features reside at the 6:00 o'clock pipe orientation where the material fibers are in tension.

Figure 9 shows the field results for the general area and a close-up image of the deepest crack-like feature reported. The area included numerous non-axial SCC features and, at the reported location, several prominent circumferential SCC features with the deepest depths.

The results from the highest priority area are quite promising but it is equally important to properly classify the lowest priority rankings. Figure 10 shows the key decision

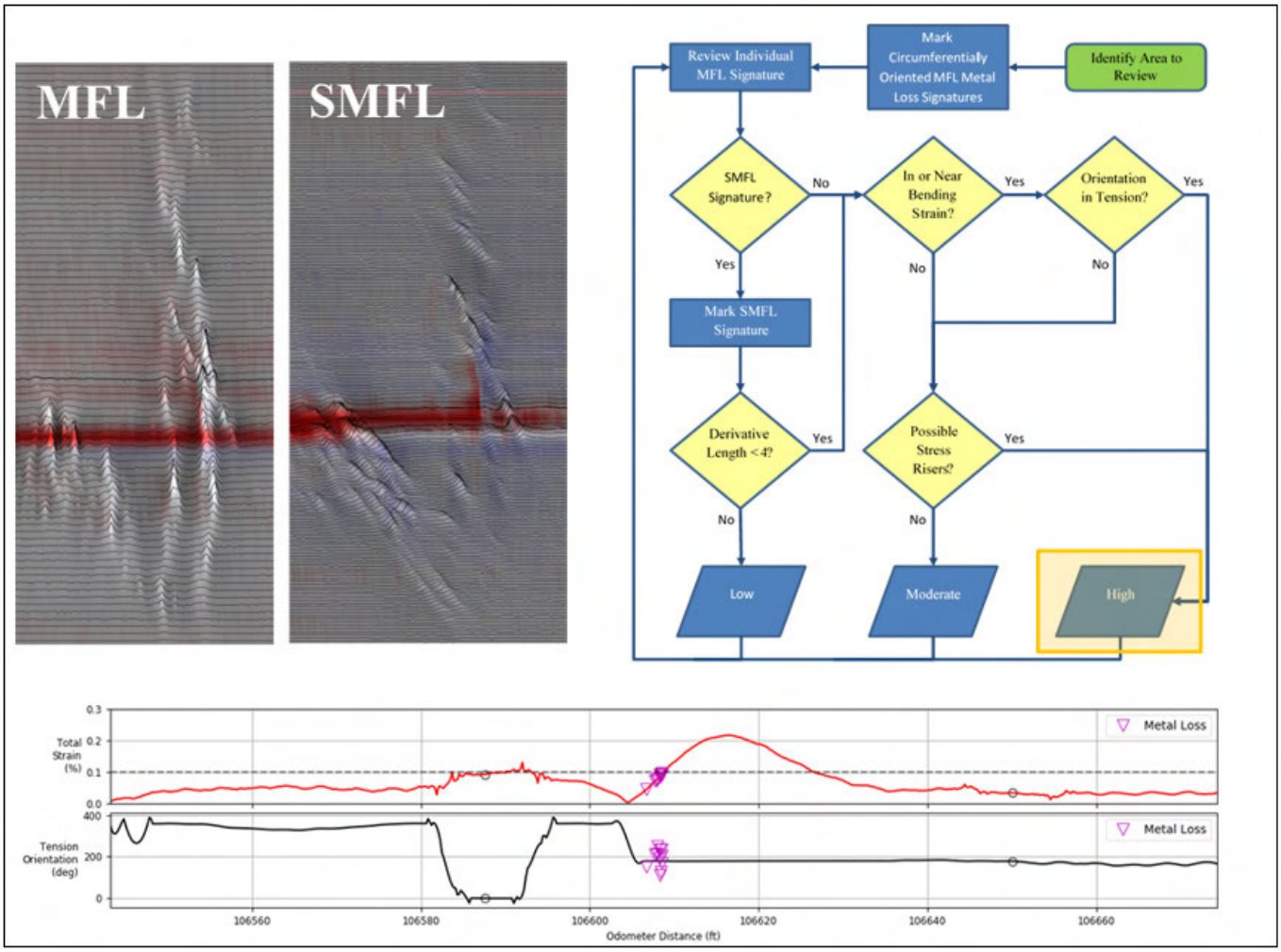


Figure 8: Key features and decision tree for the highest priority area. MFL and SMFL ILI data (top left), prioritization decision tree (top right), bending strain and tension orientation plots with metal loss overlaid (bottom)

features from the prioritization method for the area with the second lowest field investigation priority. This area is the lowest priority that was investigated in the field. The MFL dataset shows several wide, high amplitude features that were not classified as circumferentially crack-like.

The corresponding SMFL dataset shows volumetric responses at these areas that are not indicative of circumferential crack-like features. The features are also located in an area of abnormal curvature with a peak strain value of 0.17% and an associated strain value of 0.14%.

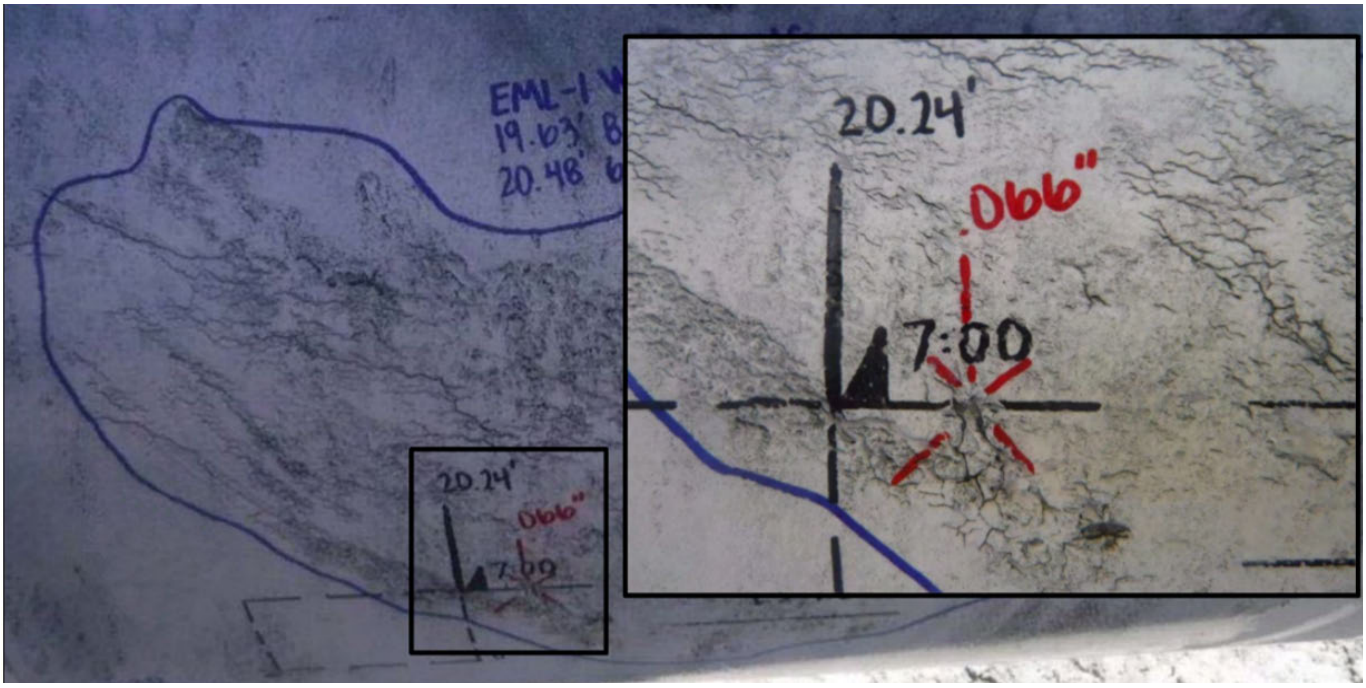


Figure 9: Field investigation results for the highest priority area and close-up image of the deepest reported crack-like feature

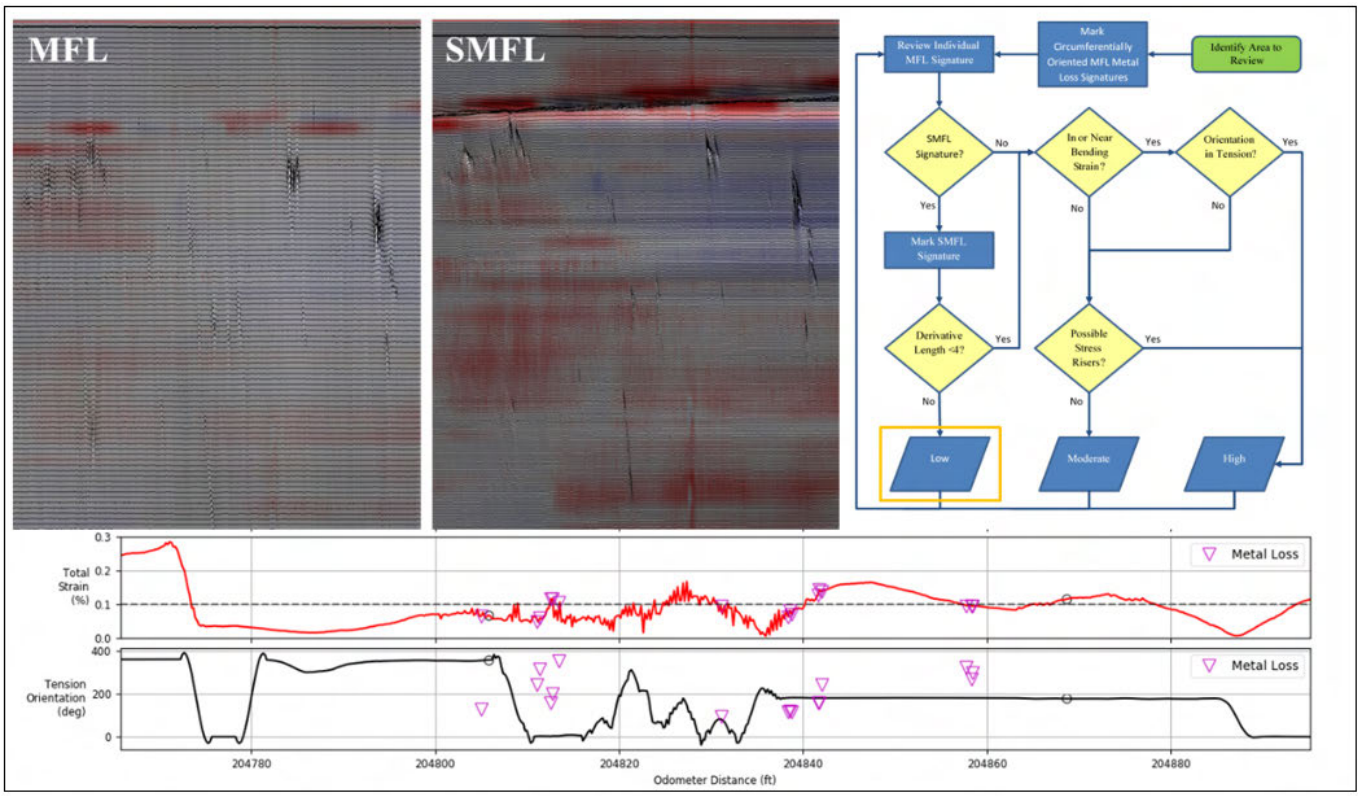


Figure 10 - Key features and decision tree for the lowest priority area investigated in the field. MFL and SMFL ILI data (top left), prioritization decision tree (top right), bending strain and tension orientation plots with metal loss overlaid (bottom)

Finally, the curvature is a bend up (under-bend) and the features reside at scattered orientations generally not associated with material fibers in tension. Figure 11 shows the field results for the area, which included only shallow general metal loss.

The prioritization method has been applied to 109 areas across several pipeline systems and diameters. Figure 12 shows the cumulative field investigation results for the high, moderate and low prioritization classifications. In several instances axial SCC was found. At these locations it is likely that the axial strain induced by bending had not yet exceeded the hoop stress, and crack propagation adhered to the primary stressor. While much of the work focused on non-axial SCC, the field findings of axial SCC are not viewed as negative results because they are still a pipeline integrity concern. Overall, there is a positive finding of SCC with the high category at 75%, the moderate at 62% and the low at 48%.

This is a positive trend but does highlight that more work is needed to further classify the prioritization into non-axial and axial categories. Investigation into including pipeline pressure profile data to identify areas of elevated hoop stress that may dictate crack propagation are being pursed. Additionally, the LFM dataset is being included as a prioritization feature in a focused effort to decrease the number of high priority false positives. Preliminary results show LFM responses in areas of high priority improve the ratio of true positive results.

CONCLUSIONS

The presence of SCC anomalies poses a real threat to pipeline integrity. The most recognized configuration of SCC is the axial cracking. This is a result of pressure loading producing stresses that are adequate to interact with active corrosion to produce the SCC anomalies. The cracking will set up perpendicular to the principal stress state. When the predominant stress is the hoop stress from the pipeline pressure, the axial configuration is expected.

However, additional pipe loads often associated with installation and land movement can produce large stresses in alternative orientation, which, when interacting with active corrosion, can produce SCC anomalies that are non-axial. Traditional ILI crack tools such as UT or EMAT, when configured to detect, classify and size axial cracking, will not be as effective detecting the non-axial cracking.

An alternative to UT and EMAT technologies is to leverage existing ILI technologies such as SMFL, MFL and XYZ. These technologies can be leveraged to identify pipeline locations that have active corrosion and concentrated tensile stresses due to unexpected pipeline bending.

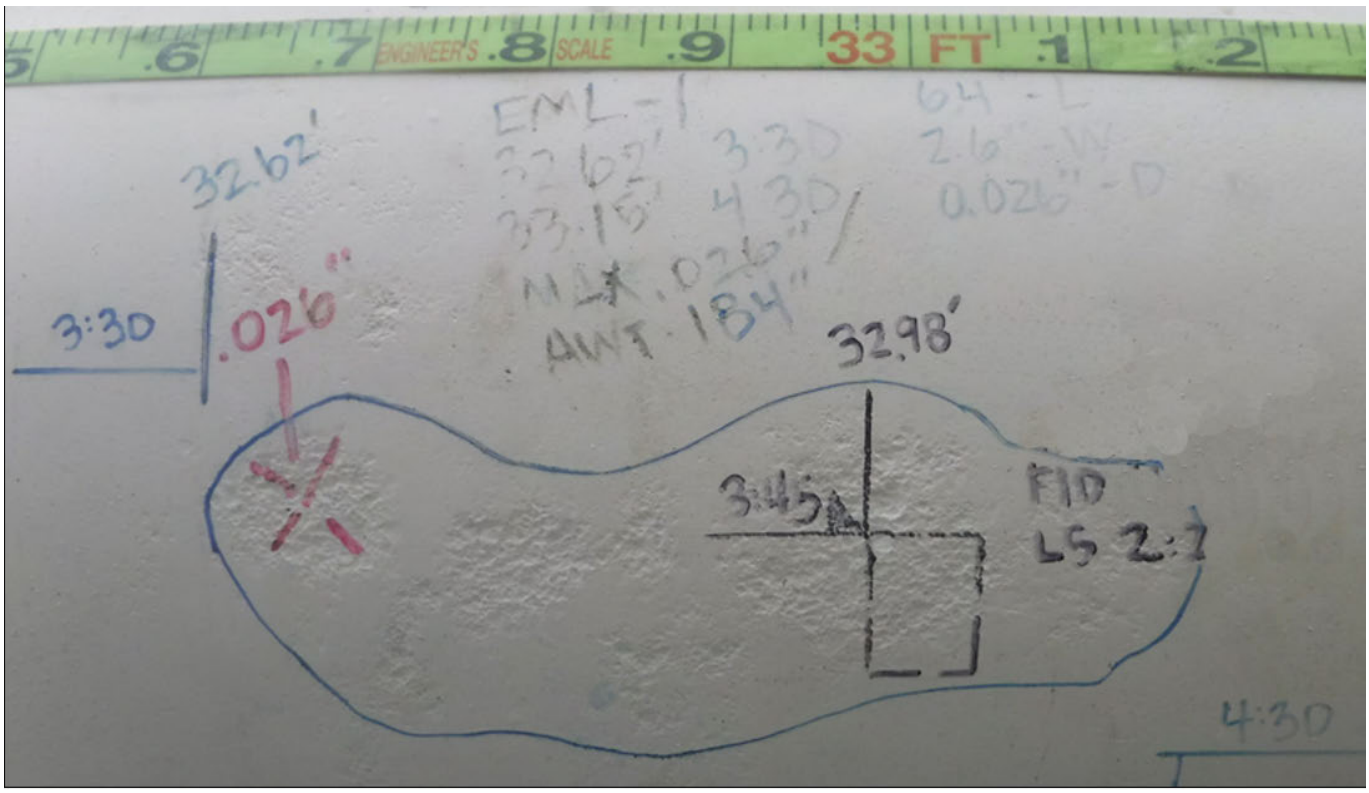


Figure 11 - Field results for the lowest priority investigated in the field

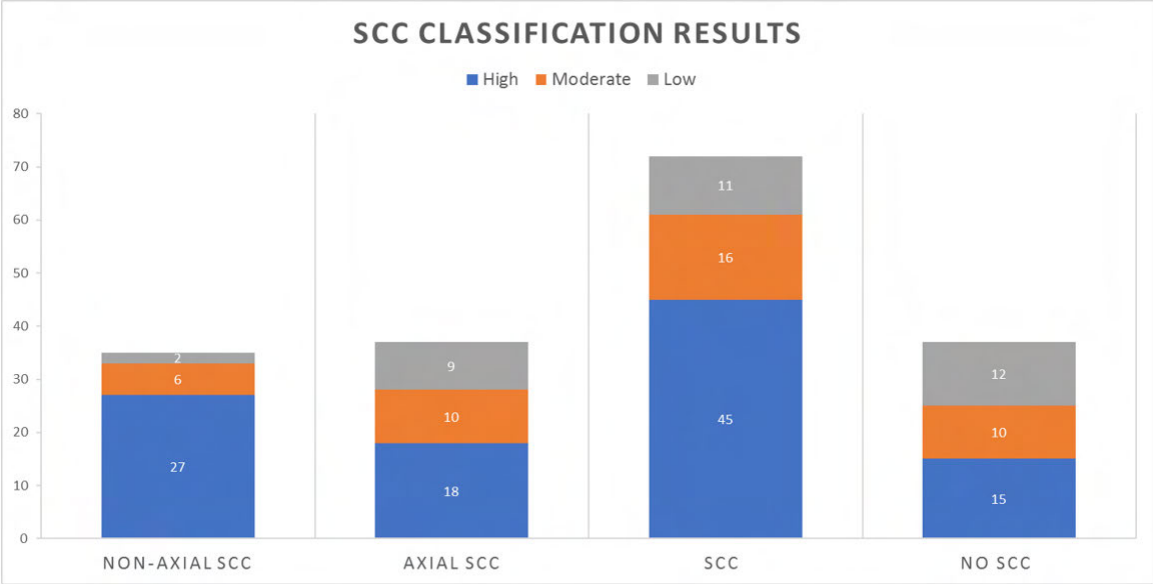


Figure 12 - Field investigation results for high, moderate and low prioritization categories

T.D. Williamson has produced an R&D process that leverages these alternative technologies to identify potential SCC location where active corrosion and tensile stress exists. Further, the process classifies each location as low, moderate or high potential locations. After assessing the field results of more than 100 various pipeline locations, the initial classification process has proven valuable for locating and classifying SCC features, although additional improvements are warranted.

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References

1. L. Van Delinder, „Corrosion Basics, An Introduction," in NACE, Houston, TX, 1984.
2. Anon, „API 1176 Recommended Practice for Assessment and Management of Cracking in Pipelines"." Washington, DC.
3. [Online]. Available: http://www.ipltec.com/news/articles/what-is-corrosion-costing-the-pipeline-industry/.
4. M. Kirkwood, C. Harris and P. Barbosa, „The New 2016 Pipeline Operators Forum (Pof) Specification; A Vendors Experience," in 13th Pipeline Technology Conference, Berlin, Germany, 12-14 March 2018.
5. Anon, „Specification and Requirements for In-line Inspection of Pipelines," Amsterdam, Netherlands, 2016.
6. J. Czyz and J. Adams, „Computation of pipeline bending strains based on Geopig measurements," in Pipeline Pigging and Integrity Monitoring Conference, Houston,TX, 1994.

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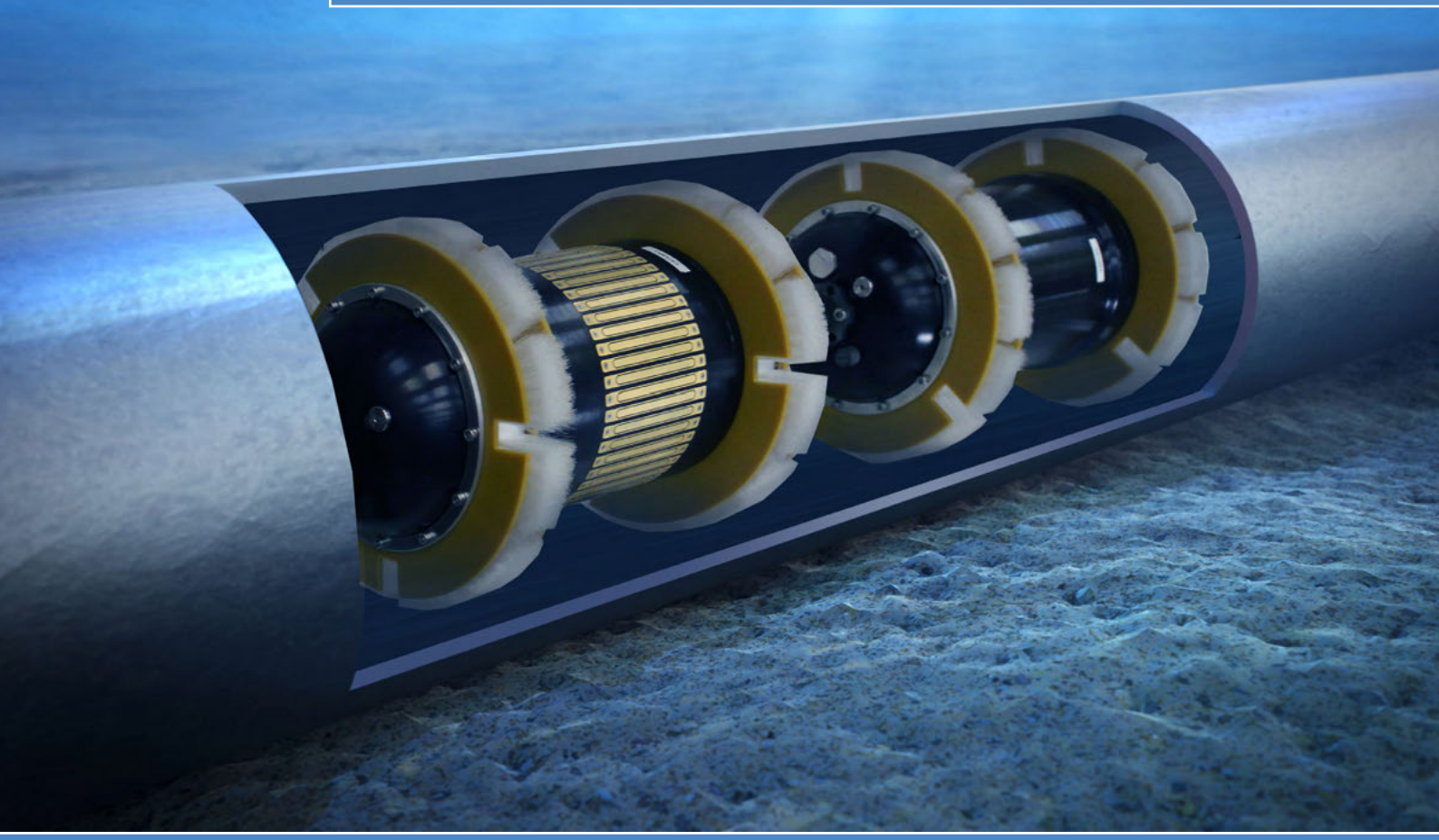
Know Your Deposits – Novel Deposit In-Line Inspection Tool For Quantifying And Characterizing Solid Deposits



Ossi Lehtikangas, Mika Tienhaara, Anssi Lehikoinen, Pasi Laakkonen, Arto Voutilainen, Antti Nissinen, Mika Mononen, Jouni Hartikainen > Rocsole Ltd

Abstract

Pipeline pigging services in the oil & gas industry are of considerable market size estimated to reach more than 14 billion USD by 2025. It is essential for the operators to keep the lines open for smooth flow and the intelligent services are in focus to increase efficiency and cut the overall operational costs. Optimal pipeline cleaning requires exact knowledge about deposit types, thicknesses and build-up locations in the pipeline. This information allows maximizing production throughput and optimizing the usage of chemicals as well as cleaning pig programs from the number of runs needed to the sizes used.

Rocsole Ltd has been developing deposition in-line inspection (DILI) tool based on electrical tomography. This technology is already being utilized for other oil and gas applications. This tool quantifies and characterizes solid deposits in piggable liquid and gas flow lines and pipelines. Current tool sizes cover pipeline sizes between 8"-28" with minimum 1.5D bends and maximum pipeline length of more than 100 km. The risk of the tool becoming stuck in the pipe is minimized since the sensor diameter is significantly smaller than the pipe diameter (tool is non-aggressive). The tool uses safe and cost-effective non-nuclear technology to measure the solid deposit thickness and type while traveling through the pipeline along with the flow without production shutdowns. In this article, deposit inspection results from different deposits tests are discussed.

INTRODUCTION

Deposition formation inside pipelines is a major and growing problem in the oil and gas industry. Paraffin wax deposition alone costs the oil industry billions of dollars worldwide for prevention and remediation. Wax, scale, asphaltene and hydrate deposits are significant challenges, which in some cases can cause a blockage of a pipeline or downhole equipment and stop oil and gas production for months, resulting in significant costs due to remediation and production deferment [1,2]. The industry uses a variety of tools for controlling deposition problems. The main tools are chemical inhibitors, pipeline insulation, heating systems [3], and cleaning pigs [4]. These methods are expensive, but the optimal use of these measures could lead to major savings due to minimized production problems and optimized pipe cleaning costs. This could be achieved if the actual deposits inside pipelines and downhole could be characterized and quantified. Several different methods for the detection and estimation of the deposit build-up have been proposed. These methods include Gamma-ray tomography [5, 6], density mapping [6], radioisotope tracer injection [6] and measuring viscosity of pigging slurry in front of the pig [7]. Wax and other deposit accumulation can also be simulated and predicted using multi-physics software tools [8,9]. For a more comprehensive review of pigs and inline inspection methods, see [10, 11].

ELECTRICAL TOMOGRAHY

Recently, a novel deposition inline inspection (DILI) sensor placed inside the pipe has been developed based on electrical tomography (ET) [12-14]. In [13], a proof of concept ET measurement device constructed for measuring deposit thickness and type inside a pipe segment. In the ET DILI sensor shown in Figure 1, electrical measurements through electrodes around the DILI sensor are made. These measurements are used to determine the electrical properties, such as electrical conductivity and permittivity, inside the detection volume between the DILI sensor and the pipe. Since oil, water, gas and different deposits have different electrical properties, it is possible to detect the thickness and identify the deposit. Measurement principle of ET is shown in Figure 2. The technology used is the same principle as we have already in permanent operations installed for pipelines, tanks and separators.

Current tool sizes cover pipeline sizes between 8"-28" with minimum 1.5D bends and maximum pipeline length of more than 100 km. Current maximum operating pressure during the inspection run is 100 bar and temperature range 0-60 °C with typical flow speed of 0.5-2 m/s.

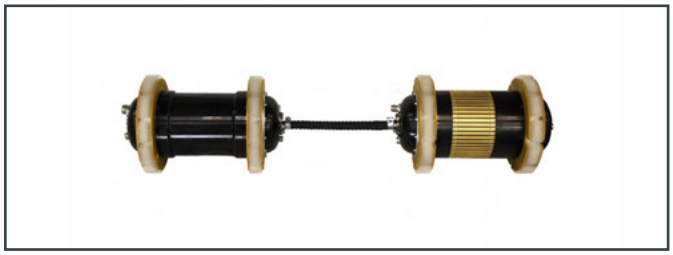


Figure 1: Rocsole DILI tool for 12 inch pipeline. Current tool sizes cover pipeline sizes from 8 inch to 28 inch.

DEPOSIT INSPECTION RESULTS

OIL FLOW SOFT WAX AND CALCIUM CARBONATE DEPOSIT

These tests were carried out in a test facility in a 70 m long 10-inch diameter flow loop, see Figures 3 and 4. The flow loop has a separate sensor launcher and receiver chambers on both sides of the pump. The diameter of the DILI tool for this pipeline was 8-inch. In this test case, the speed of the tool was approximately 0.3 m/s. The pipeline included a 10 m long test section with 15 pipe segments which can be manually moulded with deposit layers of desired thicknesses. The location of the test section is shown in Figure 3 and it ranges from 48 m to 58 m of the 70 m long pipeline. The rest of the pipeline is clean without any deposits. Transmission oil was used to fill the pipeline. Pipe segments 1-4 were moulded with soft wax deposit with a mean thickness of 7.3 mm. The thickness of the deposit was manually measured in several positions. The mean of the measured values for each deposit segment was used as a true reference value. The mean thicknesses of wax deposits moulded in pipe segment 5-8 and 9-11 were 3.4 mm and 1.7 mm, respectively. Pipe segments 12-14 were moulded with a calcium carbonate deposit with a mean thickness of 3.6 mm. A photograph of a clean pipe segment and a segment with wax deposit is shown in Figure 5.

Measured deposit thickness from DILI run is shown in Figure 6. In addition, deposit permittivity indicating deposit type is shown. Figure 7 shows cross sectional electrical tomographic images corresponding a clean pipe segment, segment with thick wax deposit, thin wax deposit and scale deposit. All deposit thicknesses and types can be correctly identified based on the results.

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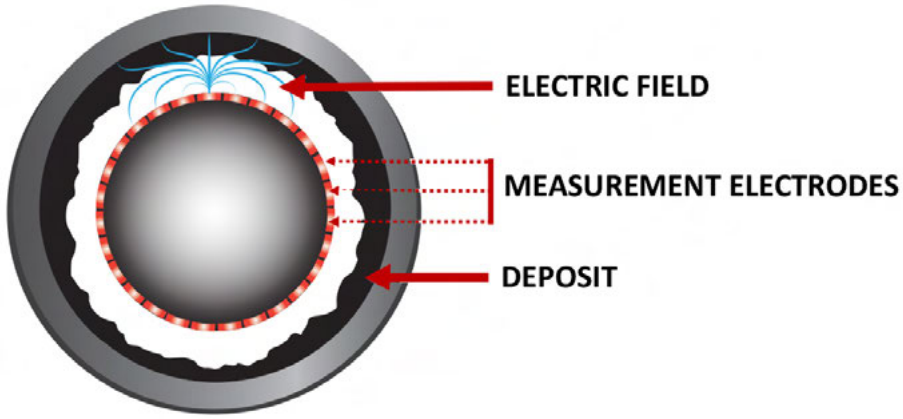

Figure 2: Measurement principle of electrical tomography in DILI. DILI sensor is moving inside the pipeline and making electrical measurements of its surrounding media. Deposit thickness and type can be computed based on these measurements.

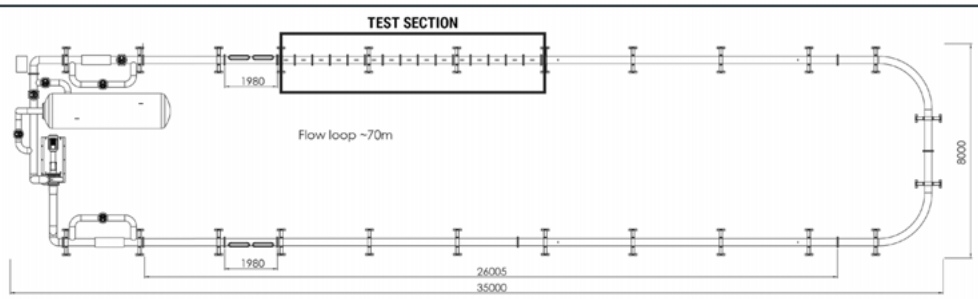

Figure 3: Schematic diagram of the flow loop. Test section containing deposits is marked with rectangle.

Figure 4: Flow loop test facility for 10" DILI tool.

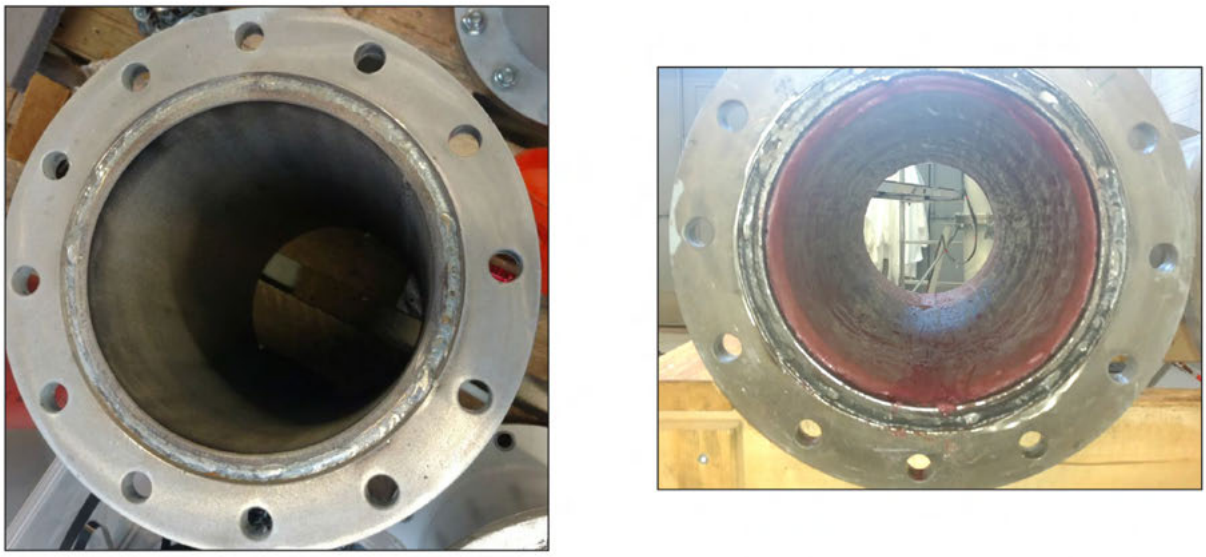

Figure 5: Right: a clean pipe segment. Left: pipe segment with 7.3 mm wax deposit.

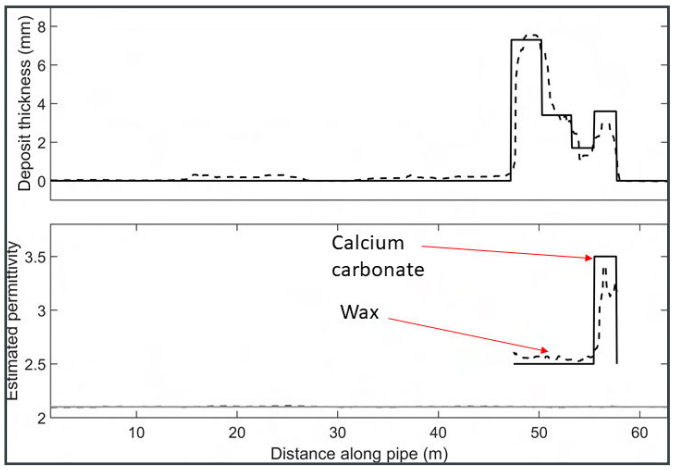

Figure 6: Measured deposit thickness using the tool along the pipe (dashed line) is shown on the top row. Clean pipe and different deposit thicknesses are clearly visible. True manually measured deposit thickness is shown with a solid line. Bottom row shows deposit permittivity estimate indicating the deposit type.

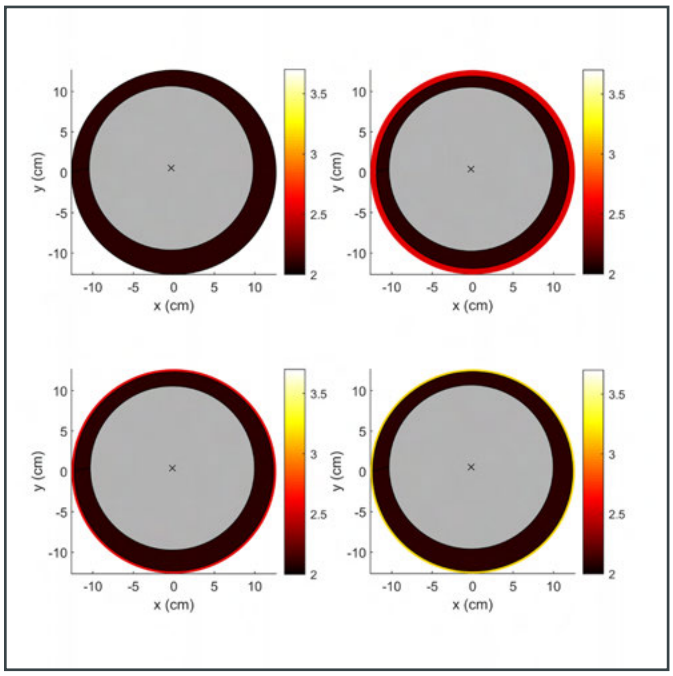

Figure 7: Electrical tomography images corresponding clean pipe (top left image), 7.3 mm wax deposit (top right image), 3.4 mm wax deposit (bottom left image) and 3.6 mm calcium carbonate deposit (bottom right image). Gray area is location of the tool.

CONCLUSIONS

This novel deposit in-line inspection tool can accurately measure deposit thickness and deposit type in a pipeline. This information can be used for optimizing chemical use and cleaning pig programs from the number of runs needed to the sizes used as well as detecting possible blockages and build-up locations of the pipeline in the early phase. Moreover, integrity assessment campaigns can be made more efficient by identifying what deposits are present and where by using the sensor before the pipeline cleaning process and by ensuring cleanliness before integrity measurements take place. This allows pipeline operation and cleaning programs to be optimized. Analytics can be done is a short time frame in minutes or a few hours rather than many days or weeks which is typical for conventional technology, reducing total time and associated costs. Using the tool thus allows for reducing total maintenance costs as well contribute to open pipelines to ensure a stable production. Subsea launch of the tool will take place from Q2/2020 with several oil & gas operators.

References

1. Mokhatab S and Towler B 2009 World Oil 230 55-58
2. Bukkaraju S K, Osorio N F, Annadorai K M, Garduno J L, Golden N K et al. 2016 Practical guidelines for the diagnosis and remediation of pipeline blockages, Offshore Technology Conference
3. Hoffmann R, Amundsen L and Schuller R 2011 Measurement Science and Technology 22 075701
4. Stevenson C J, Davies S R, Gasanov I, Hawkins P, Demiroglu M, Marwood A P et al. 2015 Development and execution of a wax remediation pigging program for a subsea oil export pipeline, Offshore Technology Conference
5. Johansen G 2015 Gamma-ray tomography Industrial Tomography Systems and Applications ed Wang M (Woodhead Publishing)
6. Benson D et al. 2007 Non-intrusive pipeline inspection techniques for accurate measurement of hydrates and waxes within operational pipelines, Offshore Europe (Society of Petroleum Engineers)
7. Wang W and Huang Q 2014 Journal of the Energy Institute 87 196-207
8. Pagliuca G, Riviere R I, Clercq M L, Lisdonk S, Macnair C et al. 2016 Real time dynamic simulator for a multi-phase pipeline system to increase production and reduce operational costs, Abu Dhabi International Petroleum Exhibition & Conference (Society of Petroleum Engineers)
9. Labes-Carrier C, R_nningsen H P, Kolnes J, Leporcher E et al. 2002 Wax deposition in north sea gas condensate and oil systems: Comparison between operational experience and model prediction SPE Annual Technical Conference and Exhibition (Society of Petroleum Engineers)
10. Timashev S and Bushinskaya A 2016 Diagnostics and reliability of pipeline systems vol 30 (Springer)
11. Tiratsoo J 2013 Pipeline Pigging & Integrity Technology (Clarion Technical Publishers)
12. Kjaersgaard-Rasmussen J and Meyer K E 2010 Inside-out electrical capacitance tomography for downhole multiphase flow evaluation Tech. rep.
13. Lehikoinen A, Kaipio J P, Voutilainen A, Laakkonen P, Rivas-Griswold A, Vreenegoor L, Khosla V and Varma Rand Broze G 2017 Technical feasibility study of advanced tomography sensor for inspection in piggable flowlines Offshore Technology Conference
14. Lehtikangas O, Voutilainen A, Lehikoinen A, Nissinen A, Mononen M, Hartikainen J, Kaipio J and Laakkonen P 2018 Flow loop validation of moving electrical tomography sensor for pipeline inspection, 9th World Congress in Industrial Process Tomography

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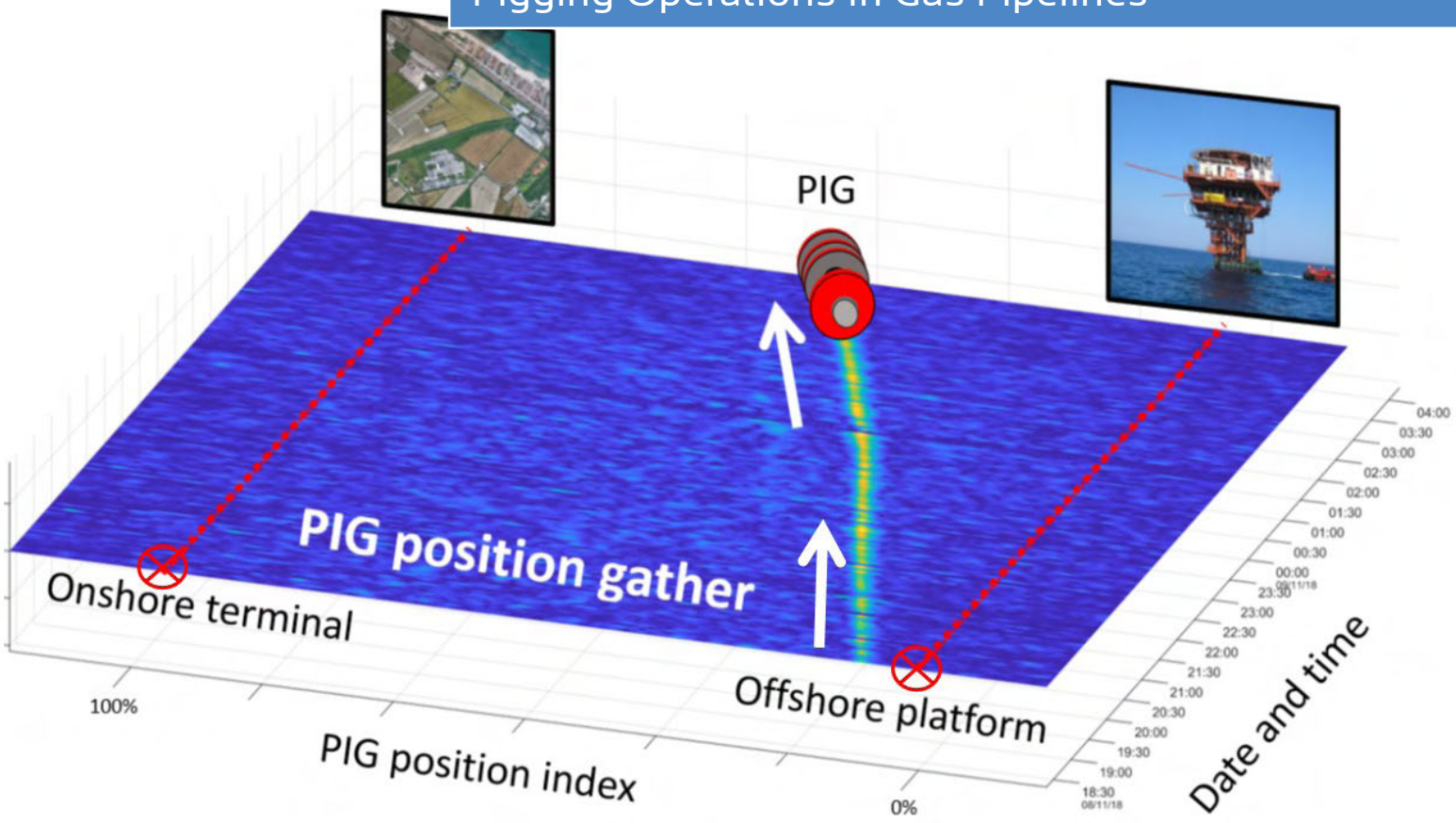

Giuseppe Giunta, Silvia Morrea; Giancarlo Bernasconi; Massimo Signori > Eni S.p.A; Politecnico di Milano; Solares JV

Abstract

This paper presents a procedure for continuous real-time positioning and tracking of a Pipeline Inspection Gauge (PIG) travelling within a pipeline, by exploiting the pressure transients it generates during the displacement. In fact, the PIG produces recognizable sounds when crossing the welding dents and while sliding against the pipe walls. This acoustic signature propagates in both directions along the conduit and it can be recorded by sensors (i.e. static and dynamic hydrophones), at least one on each side of the PIG, in order to locate the gauge. The sound can be also processed to detect pipe branches, local diameter reductions, valve crossings, obstruction buckles. The paper analyzes the acoustic signals collected during a PIG campaign at the terminals of a 10" internal diameter, 57300 m long gas pipeline, from Barbara A platform in the Adriatic Sea to the onshore station in Falconara (Italy). Several PIGs (e.g. clean up, geometrical, intelligent devices, and brushes) have been transferred from the offshore terminal to the onshore one, driven by gas flow. During the inspections the pressure transients received at the acquisition units are cross-correlated in moving windows, revealing a peak that corresponds to the differential propagation time between the "noisy" tool and the recording stations. By tracking the cross-correlation acoustic peaks versus time, it is possible to identify the position of the tool and its velocity. Delay time is converted to absolute distance using the sound velocity in natural gas. The results demonstrate a good accuracy in both detection and tracking. Moreover, the recordings of the differential pressure profiles between the two sides of the PIGs have been displayed versus pipeline coordinate and overlapped, revealing an interesting similarity: the differential pressure variation peaks can be associated to pipe branches, dents, pipe diameter variations and slopes of the submarine line. The presented PIG tracking technique has the advantages of not requiring additional tools mounted on the gauge, although permitting a real time and remotely controlled monitoring.

INTRODUCTION

Pipeline Inspection Gauges (PIGs) are used to perform various integrity operations in fluid transportation pipelines (Tiratsoo, 1999), such as to remove deposits, to inspect the condition of the pipe walls, to collect objects and/or dusts dispersed along the track. PIGs are usually inserted in the conduit in a "launcher" station, and then they are pushed by the flow itself up to a "receiving" trap (Hiltscher et al, 2003). In all cases it is extremely important to know the position of the gauge and to recognise a stuck condition. Moreover, some tools are effective in a limited range of displacement velocity, so that a real time tracking can permit the utilization of active PIG velocity control procedures. There exist nowadays several procedures for locating and tracking a PIG inside a pipeline (McAllister, 2009). In general, these procedures require to deploy a plurality of sensors along the line itself, and/or to mount active systems on the gauge, and are based on:

- measuring the pressure and the volume of fluids upstream and downstream of the PIG to evaluate its position inside the pipeline.
- Detecting the vibrations produced by the PIG during its movement through a network of geophones (Brown et al, 1988) or by an optical fibre acting like a Distributed Acoustic Sensing (DAS) device (Hill and Kelley, 2012) along the pipeline track.
- Mounting active sources on the PIG, e.g. electromagnetic (Brayson, 2001) or acoustic emitters (Alonso, 2009), and deploying along the pipe track a network of corresponding receivers.
- In case of a stuck PIG, generating suitable hydraulic transients within the fluid on one pipe branch where the PIG is blocked, and measuring the return times of the echoes that are generated on the device.
- Using gyroscopic self-location unit mounted on the PIG, in order to tag the position of the measured anomalies. Self-positioning data can be downloaded only when the pigging run has been completed, and it has to be checked with external logs for verification and calibration.

We present here a patented procedure for a continuous PIG localization/tracking that exploits passive vibroacoustic signals generated by the travelling gauge, recorded by stations located at tens of kilometres between each other along the conduit. The key points of the procedure are the accurate synchronization of the measuring units, the use of high sensitivity sensors, the accurate selection of the useful bandwidth, the real time transmission and multichannel processing of the data (Giunta et al, 2017a and 2017b). The method is based on the cross-correlation of the acoustic signals generated by the PIG and recorded at opposite sides of is position, like in a standard time of flight acoustic source location. Taking as time reference the departing station, the cross-correlation peak moves from 0 s (the PIG is departing) to the time corresponding to sound propagation from the departing to the arriving station (PIG at the receiving station).

This method is able to obtain continuously the position of the PIG, and so to compute its velocity as well as to identify a stuck condition. The following sections give details on the tracking procedures, showing real data examples.

PIG TRACKING PROCEDURE

The sound peak produced by the PIG at the welding dents and while sliding against the pipe walls propagates in both directions, and it is recorded at the two sides by vibroacoustic monitoring stations (Figure 1). The PIG location method computes the cross-correlation in moving windows of the pressure signals at the opposite terminals. A cross-correlation peak appears at the differential propagation time between the source position (PIG) and the recording stations. As the PIG travels through the pipe, the delay moves from negative (first arrival at departing station), to zero (equal propagation time, the PIG is in the middle of the pipeline section), and then to positive (first arrival at arrival station). By tracking the cross-correlation peak versus time it is possible to identify the position of the PIG and its velocity, with few minutes of delay, related to sound propagation time within the pipe and to the availability of some minutes of recorded signal at the processing unit. Correlation delay time is converted to distance along the pipeline using the sound propagation velocity.

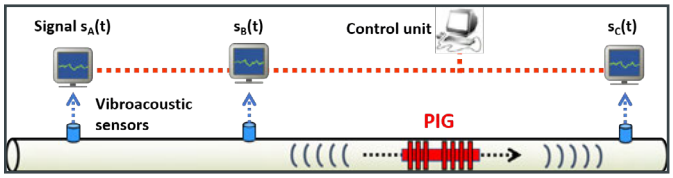

Figure 1: Moving PIG and monitoring system scheme.

Again from Figure 1, sB(n) and sC(n) are the samples at time nT of the vibroacoustic signals reaching the two stations on opposite sides with respect of the PIG: n is an integer index and T is the time sampling interval. The normalized cross-correlation on moving windows of the two sequences is:

$$x(n) = \frac{\sum_{i=1}^{m} s_B(i) s_C(i+n)}{\sqrt{\sum_{i=1}^{m} [s_B(i)]^2 \sum_{i=1}^{m} [s_C(i+n)]^2}}$$

where m is the length (in samples) of the window.

The result is presented as a "waterfall" image of the positive envelope of x(n): for a given window, a cross-correlation peak happens at the time peak corresponding to the differential delay of propagation from the PIG to the recording locations. We have

$$\tau_{BC} = \tau_{PB} + \tau_{PC} = \frac{d_{BC}}{v_{sound}};$$

$$\tau_{peak} = \tau_{PB} - \tau_{PC};$$

$$\tau_{PC} = \frac{d_{PC}}{v_{sound}};$$

$$\tau_{PB} = \frac{d_{PB}}{v_{sound}}$$

where

- τ_{BC} is the total time of propagation for a distance dBC from station B to station C;
- τ_{PC} is the total time of propagation for a distance dPC from PIG position to station C;
- τ_{PB} is the total time of propagation for a distance dPB from PIG position to station B;
- V_{sound} is the sound speed in the fluid.

The position of the PIG with respect to the measuring stations can be obtained with:

$$d_{PB} = \frac{d_{BC} + \tau_{peak} \cdot v_{sound}}{2};$$

$$d_{PC} = d_{BC} - d_{PB}.$$

The sound speed in the fluid is computed experimentally by tracking some important pressure variation along the line, possibly before the pigging campaign. In this way the time axis of the cross-correlation is converted in distance along the line, and the position and velocity of the PIG can be obtained continuously and remotely.

CASE HISTORY: BARBARA A-FALCONARA PIPELINE

Six PIG operations have been carried out by Eni DICS on November 2018 from the platform Barbara A in the Adriatic Sea and the receiving station in Falconara (Italy). The pipeline conveys natural gas, has an internal diameter ID of 10" and a length of 57300m (Figure 2).

Proprietary recording vibroacoustic stations (e-vpms® technology) have been installed at the two terminals (Bernasconi et al., 2013, 2014, 2015; Dalmazzone et al., 2016; Giunta et al., 2017c).

Figure 2: Barbara A (A) to Falconara (B) pipeline (Eni Upstream).

	Type	Departure from Barbara A platform (GMT+1)	Arrival at Falconara terminal (GMT+1)
PIG1	Dual Module Brush Magnet	Not tracked	Not tracked
PIG2	Dual Module Heavy Brush	16:49 of 8/11/2018	9:44 of 9/11/2018
PIG3	Dual Module Pin De Scaling	15:33 of 9/11/2018	7:50 of 9/11/2018
PIG4	Dual Module Brush Magnet	15:05 of 13/11/2018	7:25 of 14/11/2018
PIG5	Dual Module Brush Magnet	14:10 of 14/11/2018	6:20 of 15/11/2018
PIG6	Smart PIG	14:30 of 15/11/2018	6:10 of 16/11/2018

Table 1: PIG departing and arrival times (GMT+1) obtained from vibroacoustic recordings.

Figure 3: PIG2 Dual module heavy brush arrived at Falconara terminal.

ANALYSIS OF THE PIG NOISE

The analysis of the acoustic noise generated by the moving gauge is shown for PIG2 (see Table 1). The sound recorded within the gas filled pipeline versus time (travelled distance) decreases in amplitude on the departing station Barbara A and increases in amplitude in the approaching arrival station Falconara (Figure 4.top). Pressure on the back and on the front of the PIG varies in opposite

direction (Figure 4.bottom): when the PIG is moving, there is a "decompression" on the back and a "compression" on the front of this one. When the PIG is stopped, pressure increases on the pumping side (A in Figure 5); when it starts moving, the "accumulated" pressure decreases (B in Figure 5).

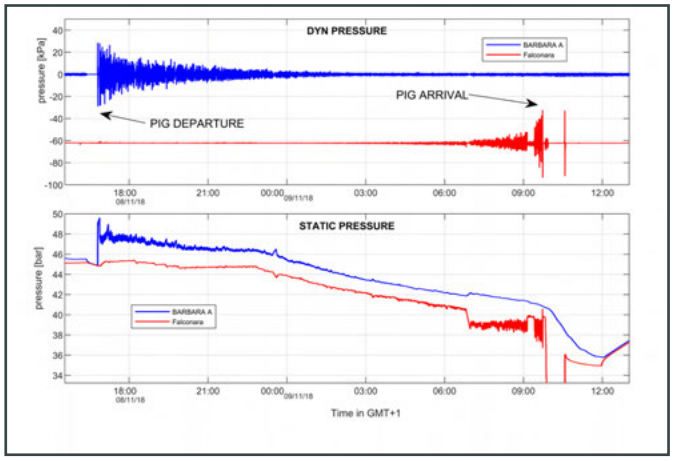

Figure 4: PIG2 vibroacoustic recordings: pressure transients (top) and absolute pressure (bottom). In top figure the transients measured at Falconara have been shifted along the vertical axis (their mean value was 0kPa) to help the visual comparison between the curves.

Figure 5: PIG2: vibroacoustic recordings (zoom of Figure 3). The PIG is stopped (A) and pressure increases on the pushing side (Barbara A absolute pressure), until the PIG starts moving again (B).

Figure 6 displays the pressure measurements for the whole pigging campaign: it highlights the acoustic events are repeatable, opening the door to very interesting applications of predictive maintenance and data driven monitoring strategies (Giunta et al., 2019).

The differential pressure for different monitored operations can be overlapped and plotted vs. pipe coordinate (Figure 7). Some positions along the pipeline reveal anomalous peaks, which can be related to pipe joints, diameter change, buckles. The correct classification of these irregularities is in progress with Eni Upstream.

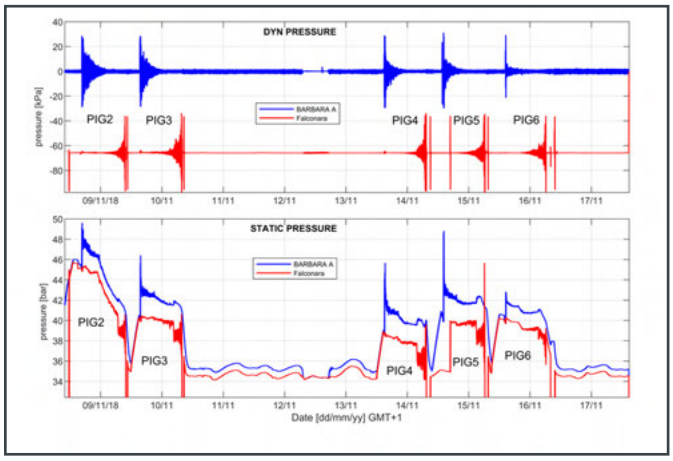

Figure 6: Dynamic (top) and static pressure (bottom) at Barbara A (PIG departing station) and Falconara (PIG arriving station), for the whole PIG campaign.

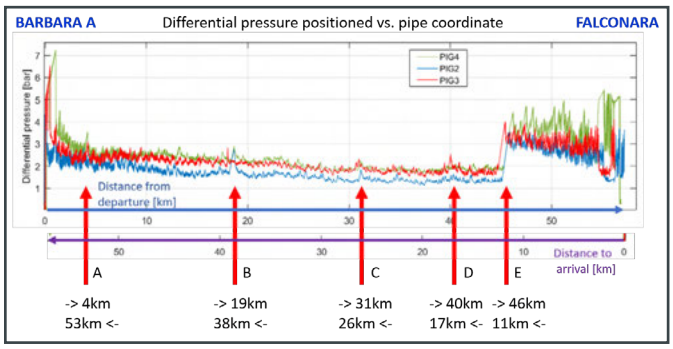

Figure 7: Differential pressure between the two sides of the PIG, positioned vs. pipe coordinate, for three complete recorded operations.

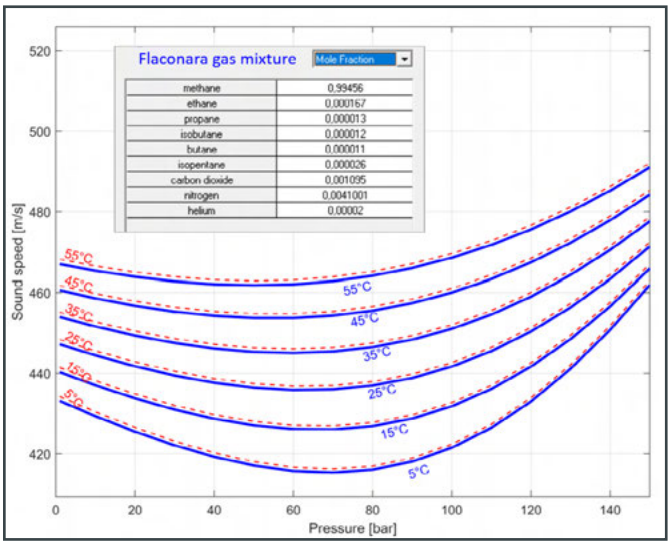

Figure 8: Sound speed in the Barbara A - Falconara natural gas mixture (blue solid line), compared with the sound speed for pure methane (red dashed line).

From the composition of the natural gas transported on the line, we have computed the sound velocity versus pressure and temperature with REFPROP (National Institute of Standards and Technology (NIST), REFerence fluid PROPerties): the results are shown in Figure 8. The appropriate velocity value is used to perform the time to distance conversion. We are using here an average pressure between the two sides of the PIG. A further validation of the sound speed value is obtained from the time of the correlation peak between the pressure transients at the two stations, before/after the pigging operation.

PIG DETECTION AND TRACKING

Figure 9 shows the procedure for detecting and tracking the PIG during the inspection. The upper panel is the (absolute value) cross-correlation waterfall between the pressure signals at the departing and arriving stations. The horizontal axis is shown in the bottom for the two figures, and it is the recording date and time. The top figure contains the whole pigging operation: in the real-time analysis the figures are updated every few minutes, as soon as new data becomes available, "growing" along the horizontal axis.

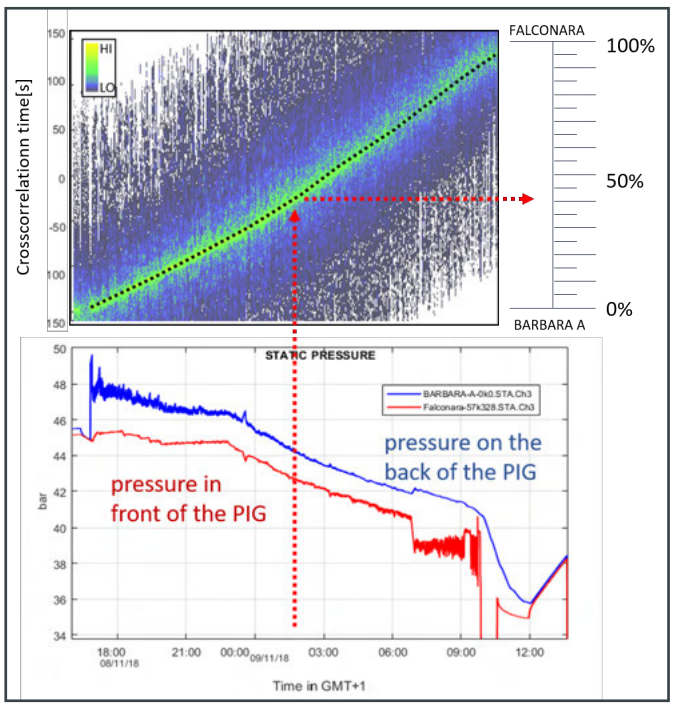

Figure 9: PIG2 and how to obtain the PIG position at a given time (follow red dotted lines with arrows).

The yellow/green areas correspond to maxima, and the procedure automatically tracks (black dots) the main peak produced by the PIG. The vertical axis (cross-correlation time, on the left side of the panel) is converted to PIG propagation distance between the departing station and the arriving station (on the right side of the panel). The bottom panel is for an advanced analysis and it displays the absolute pressure at the two measuring stations, so that it is immediately visible the differential pressure at the two sides of the PIG.

Following the red arrows in Figure 9, for a given instant of the pigging operation (a value along the horizontal axis, usually the current time), the cross-correlation peak in the top figure identifies the position of the PIG. The velocity of the PIG is computed as the ratio between the traveled distance and the corresponding time interval.

CONCLUSIONS

PIG tracking is an available technology, and it uses active systems mounted on the PIG or sensors deployed along the line that are triggered by the nearby passage of the device. On the other hand, travelling PIGs generate vibro-acoustic transients while they slide against the pipeline and at the crossing of the internal welding dents. These transients, of the order of 1-5 kPa (10-50 mbar) and guided by the fluid line, can be sensed at tens of kilometres from the originating location.

We have presented a strategy of processing the PIG noise detected by vibroacoustic units in order to remotely track its real time position and velocity during the inline inspection, without special tools mounted on the gauge. The case history demonstrates the efficacy and the operational advantages of the technique in offshore scenarios, where the measuring locations are only at the onshore terminals. The analysis of the acoustic signature related to periodical PIG campaigns could be used for innovative data driven asset integrity management.

ACKNOWLEDGEMENTS

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References

1. Alonso, J. R., 2007, System for locating pigs in single phase and multiphase fluid transport pipelines, Application Patent WO2009067769A1.
2. Bernasconi, G., Del Giudice, S., Giunta, G., Dionigi, F., 2013, Advanced pipeline vibroacoustic monitoring, Proceedings of the ASME 2013 Pressure Vessels & Piping Division Conference, Paris, PVP2013-97281.
3. Bernasconi G., S Del Giudice, G Giunta, 2014, Advanced real time and long term monitoring of transportation pipelines, Proceedings of the ASME 2014 International Mechanical Engineering Congress and Exposition. IMECE2014-36872.
4. Bernasconi, G., Giunta G., Chiappa F., 2015, Gas filled pipelines monitoring using multipoint vibroacoustic sensing, Proceedings of the ASME 2015 Ocean, Offshore and Arctic Engineering, St. John's, OMAE2015-41265.
5. Brayson, A.T., Ignagni, M. B., Touchberry, A. B., Anderson, D. W., Glen, S. J., Gilman, J. M., 2001, Method and apparatus for determining location of characteristics of a pipeline, Patent US6243657B1 (2001).
6. Brown, R. C., McIntyre, J. D., 1988, Pipeline PIG tracking, Patent EP0122704B1 (1988).
7. Dalmazzone, G. M., De Lorenzo, G., Giunta G., 2016, System and method for the continuous detection of impacts on pipelines for the transportation of fluids, particularly suitable for under-water pipelines, ENI S.p.A, Patent US9267648B2 (2016), EP2483656B1 (2017).
8. Giunta G., Bernasconi G., Del Giudice S., 2013, Vibroacoustic Monitoring of Gas-Filled Pipelines, ASNT Fall Conference and quality testing show, 79-86, Las Vegas, Nevada, USA, 2013, ISBN-13: 978-1-57117-317-1.
9. Giunta, G., Bernasconi, G., Del Giudice, S., 2015, Pipeline Monitoring with Vibroacoustic Sensing, Materials Evaluation, Vol.73 (7), pp. 979-986.
10. Giunta, G., Bernasconi, G., 2017a, Method and system for the remote detection of the position of a pig device inside a pressurized pipeline, EP2935969B1 (2017), US9897243B2 (2018).
11. Giunta, G., Bernasconi, G., Del Giudice, S. 2017b, Method and system for the continuous remote tracking of a pig device and detection of anomalies inside a pressurized pipeline, EP2944857008 (2017), US10132823B2 (2018).
12. Giunta, G., Bernasconi, G., 2017c, Method and system for continuous remote monitoring of the integrity of pressurized pipelines and properties of the fluids transported, Patent EP2936106B1 (2017), US10401254B2 (2019).
13. Giunta, G., Nielsen, K. L., Bernasconi, G., Bondi, L., & Korubo, B., 2019, Data Driven Smart Monitoring for Pipeline Integrity Assessment, Abu Dhabi International Petroleum Exhibition & Conference. Society of Petroleum Engineers, SPE-197327-MS.
14. Hill, D. J., Kelley, C. J., 2012, Distributed acoustic sensing, Patent Application WO2012114077A3.
15. Hiltscher, G., Muhlthaler, W., Smits, J., 2003, Industrial Pigging Technology- Fundamentals, Components, Applications, Wiley VCH, Weinhem.
16. Tiratsoo, J.N.H., 1999, Pipeline Pigging Technology, Gulf Publishing Company, Houston.

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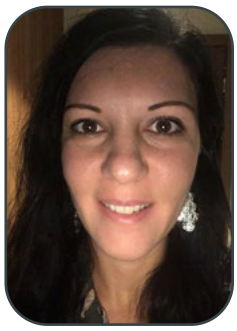

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Get To Know Our Neighbour In The East

TRANSNEFT

Rasim F. Mingazetdinov > Head of the Strategic Development Directorate

Transneft is one of the largest pipeline companies in the world. It operates nearly 70,000 km of pipelines. To increase the pipelines' throughput capacity, Transneft consumes some 1,000-2,000 tonnes of drag reducing agents (DRA) a year.

In 2014, the company made an important step forward, as it started a research and development work (R&D) on the drag reducing agent technology in cooperation with NIKA-PETROTECH company and leading R&D agencies, such as the Institute of Organic Synthesis, the Institute of Petrochemical Synthesis, and Lomonosov Moscow State University, which resulted in a technology of production of a drag-reducing agent involving a customized titanium-magnesium catalyst.

In 2018, the construction of Transneft Synthesis' plant in the Alabuga Special Economic Zone (the Republic of Tatarstan) began. In September 2019, the Transneft Synthesis drag-reducing agents plant was commissioned.

The plant's target capacity is 3,000 – 5,000 tonnes of DRA per year, with a possibility to further expand it up to 10,000 tonnes a year. In 2019, the domestic DRA production under the Transneft technology reached 3,148 tonnes.

Implementation of this project is aiming to replace imported DRAs with competitive, highly efficient Russian products, as well as to satisfy the industry's demand for polymeric additives and to provide wider export opportunities for the Russian petro- and gasochemical industry.

The Transneft Synthesis plant will produce two types of drag-reducing agents: PT FLYDE-H for crude oil and NGL, and PT FLYDE-L for crude oil having viscosity lower than 30 cSt, diesel fuel and NGL as well. Transneft's experience in DRA application suggests that the pipelines' throughput capacity may be increased by 30-35%.

Though the plant is a relatively new one, Russian oil companies and IAOT members already show their interest to the product.

Figure 2: Aerial view of the Transneft Synthesis plant

Figure 3: Polymer producing unit

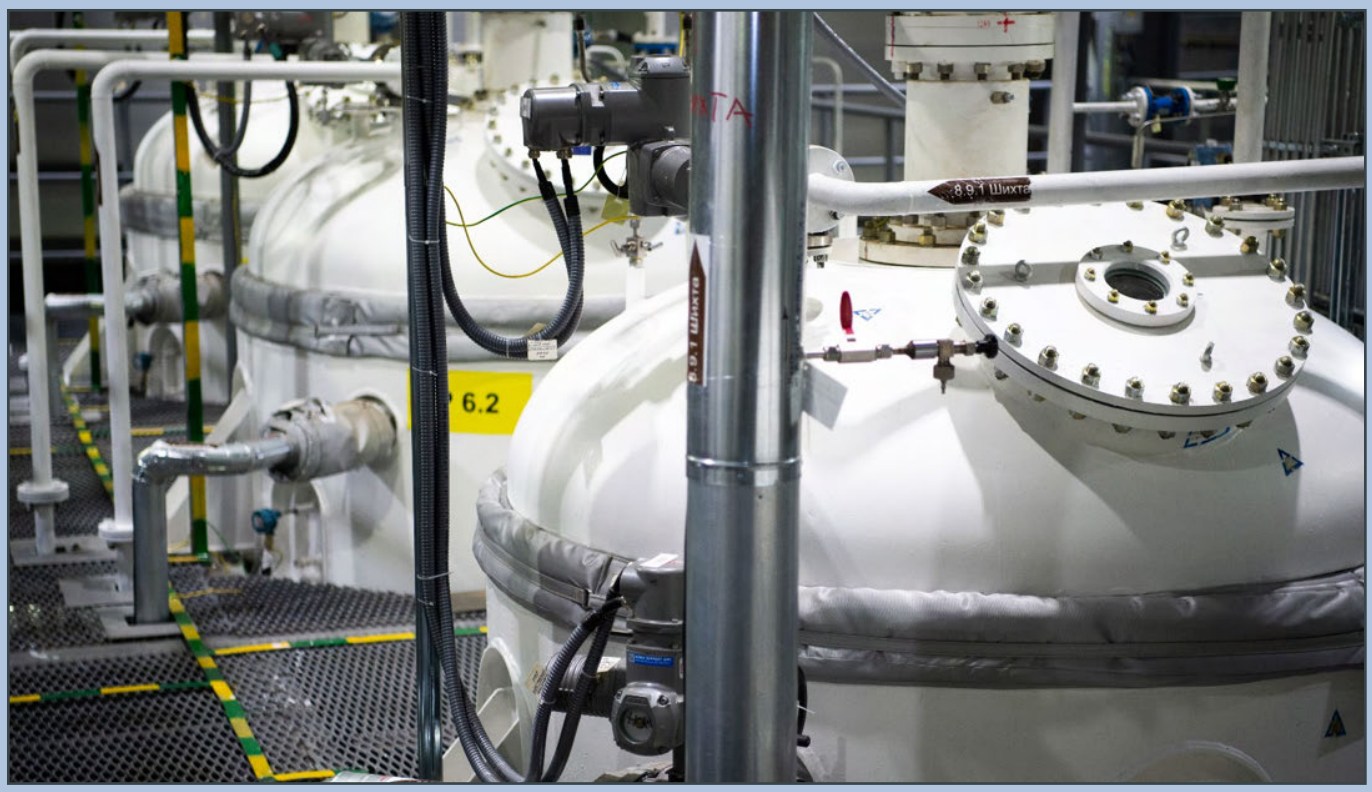

Figure 4: DRA producing unit

Figure 5: Catalyst producing unit

Figure 6: The first batch of Transneft Synthesis DRA.

We control all stages of DRA production from raw materials to finished products. The plant has a laboratory equipped with cutting-edge equipment for DRA samples' analysis. We also take arbitrary samplings and keep them for two years.

The plant creates new types of drag-reducing agents, for example, for cold fluids, and seeks to make raw materials for polyalphaolefin-based DRA more easily accessible. They conduct research on new technologies of homogeneous catalytic trimerization of ethylene and applicability of direct tandem synthesis of DRA from ethylene.

As for expanding the range of products, the chemicals used in pipeline transport are not limited to drag-reducing agents only. So, the plant is still seeking new opportunities for creating chemicals with complex effect and active components for depressor-dispersant additives for fuels and for removing asphaltene-resin-paraffin deposits, which shall make easier the in-line inspection at challenging sections of oil pipelines and pumping crude oil when depressor additives are required.

Innovations and development of new technologies are the company's current priority.

TRANSNEFT

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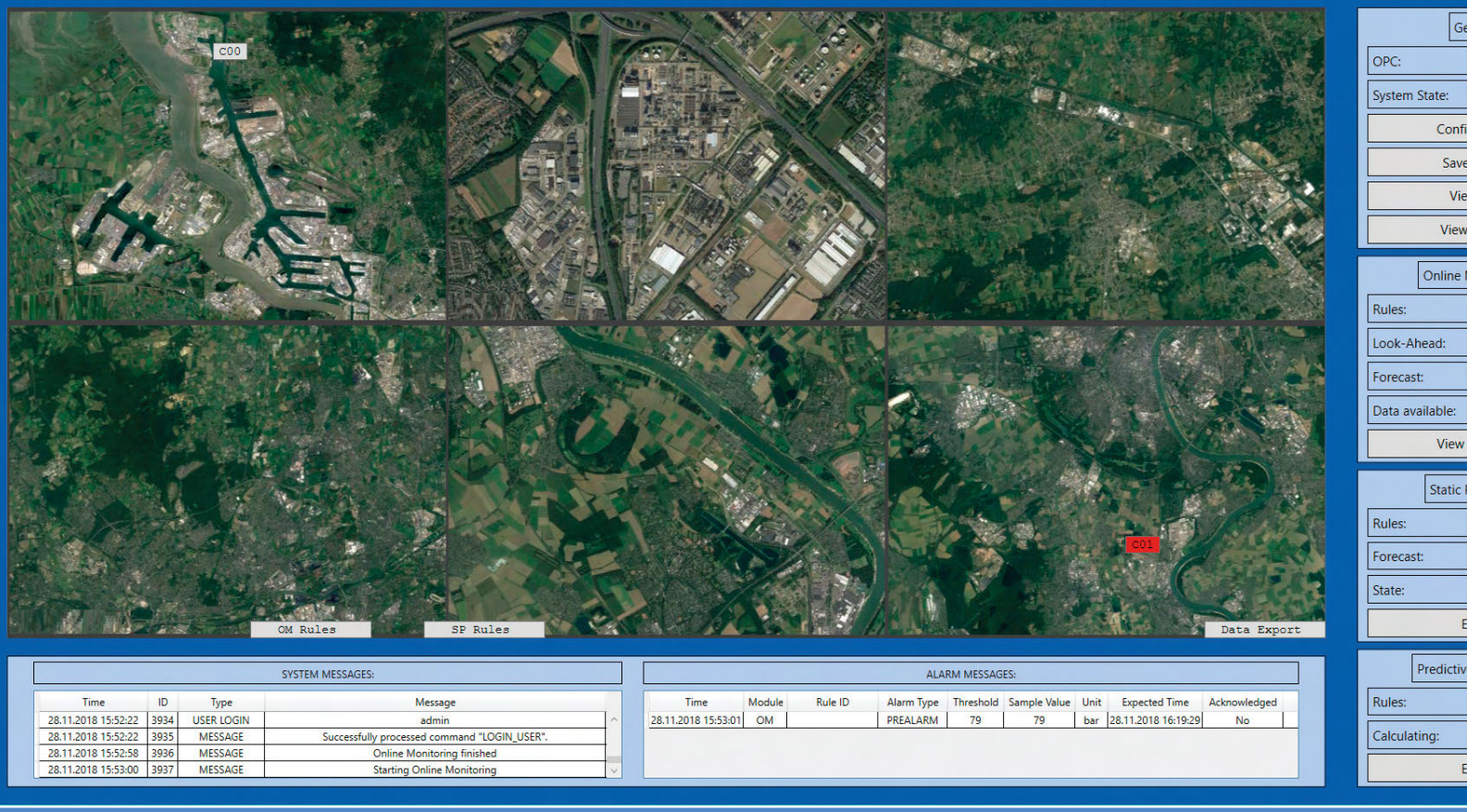
Additional Functionalities Of Model Based Leak Detection Systems To Improve Pipeline Safety And Efficiency



Kai Brünenberg, Daniel Vogt, Max Ihring> KROHNE Oil & Gas BV

Abstract

The main purpose of a leak detection system is of course the reliable and sensitive detection and localization of leaks in a pipeline. Nevertheless certain systems such as those that are based on a pipeline model (e.g. E-RTTM based system, i.e. extended real-time transient model) deliver additional information of the pipeline operation and behavior. This includes for example information used for Predictive Maintenance of pipeline segments, survival time analysis of gas pipelines and Predictive Modeling.

After a short introduction of the leak detection model and its adaption to a pipeline, the paper describes how such a model is used for Predictive Modeling. The basic principle is presented and it will be explained how such a system can be implemented on pipelines and pipeline networks. Furthermore it will be shown how the system's capability of forecasting benefits pipeline operation and maintenance activities. Finally a real example will be presented of how predictive modeling is set up on a gas pipeline network and how it is practically used to improve pipeline operation.

INTRODUCTION

Transportation of fluids in pipelines is increasing all over the world, and with good reason: pipelines are among the safest and most economical transportation systems over long routes.

Pipelines and especially pipeline networks are very complex objects. To operate them safely and efficiently a certain amount of knowledge of the processes within and around the pipeline is required. With increasing complexity of the pipelines it becomes disproportionately harder to understand what impacts operational changes of the pipeline system can have to its current and future behavior.

At this point the most recent development of KROHNE LDS, the PipePatrol Predictor provides a solution for pipeline operators that enables them to define a sequence of operational changes on a timeline and to run a very fast simulation of the temporal hydraulic reactions and behavior of the fluid over time. A set of rules can be defined that will be continuously evaluated during simulation. For the case that a rule (a minimum pressure that has to be maintained at a certain point for example) is violated, the software will alert via OPC, e-Mail and/or by visual notification. This functionality is what we call "Predictive Modeling".

Another module of the PipePatrol Predictor has been implemented to continuously evaluate the current state of the pipeline and its expected behavior based on that state in the near future. For that reason the software uses an OPC-interface to retrieve process data from a real pipeline and to run its model based simulation in parallel in order to keep the pipeline and its digital twin always at the same state. In user-definable cycles this state is used as the initial step for an accelerated simulation into the future. Another set of evaluation rules might be defined for this functionality that we call "Online-Monitoring".

The underlying model will be tailored to the customer's pipeline topology, instrumentation and fluids to guarantee a maximum accuracy of the simulated process values. It incorporates a number of differential equations needed to describe the fluids behavior while being transported through a pipeline. It is furthermore optimized for computation speed which is crucial when being used for simulations that need to be much faster than real time.

2. VERIFICATION OF THE MODEL ACCURACY

As stated before, the PipePatrol Predictor provides alarms if it detects a future violation of a predefined rule which is normally the case if a process value exceeds or falls below a threshold. For that reason it is important to run a model that has a proven accuracy with data coming from the real life, ideally directly from that pipeline, the model is applied to. For verification purposes of the model accuracy, it has been used to have a virtual pipeline simulating some days of pipeline operation and comparing the results to the reality. A subset of the process data from the field was used as boundary conditions for the simulation performed by the model as shown in Figure 1 in a simplified way.

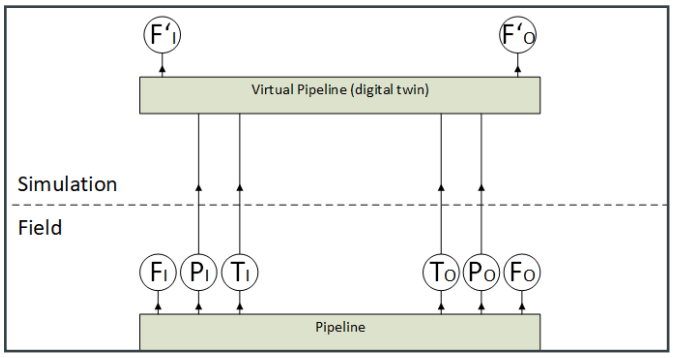


Figure 1: Process values from field as boundary conditions for simulation

It becomes clear that the field values for pressure and temperature at the inlet, P_I and T_I together with P_O and T_O at the outlet of the real pipeline are injected to the virtual pipeline and thus to the model. With these data and with all parameters that define the pipeline and the fluid as well, the simulation can compute the flow.

Then the output of the simulation (computed inlet/outlet flow F'_I and F'_O) can be compared against a disjoint subset of the field data F_I and F_O.

So the verification of the models accuracy is reduced to the question how far F'_I deviates from FI and F'_O from F_O respectively. The result of that comparison is shown in Figure 2 where the computed flow from the simulation is plotted against the measured flow that is NOT part of the boundary conditions.

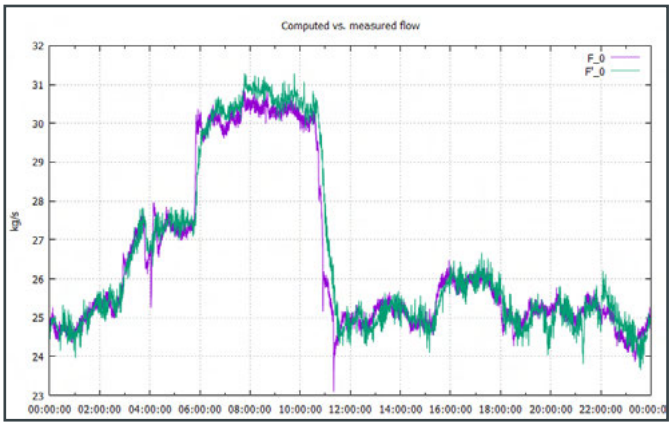


Figure 2: Measured flow is plotted against computed flow for 24h

Obviously the simulation follows the real physical behavior of the flow which has been proven for different operating states over a time span of 24 hours.

For the pressure the same verification has been performed. Here the outlet flow has been used as boundary condition to get a computed pressure P'_L from the simulation. The comparison of P'_L against measured P_L at the outlet is displayed in Figure 3.

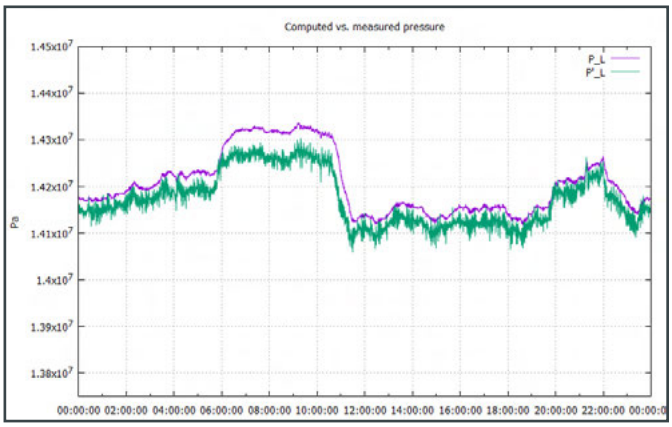


Figure 3: Measured pressure is plotted against computed pressure for 24h

As a result of the verification of the models accuracy it can be stated that the model in principle is suitable for the intended purposes.

3. HOW TO USE THE MODELS CAPABILITY FOR ONLINE-MONITORING?

As the PipePatrol Predictor is a software that retrieves process data from a pipeline in real time, these data can be provided to the model in regular cycles to keep the model up to date to the real physical conditions within the pipeline. This process is called synchronization.

At the beginning (T_N) of each cycle a copy of the model is created and is used to keep a snapshot of all process values as an initial state for a simulation that starts at T_N and is stopped before the next cycle starts at T_{N+1}. To enable the model to predict future states, the simulation between TN and T_{N+1} has to be accelerated as much as possible. Then, depending on computing power, complexity of the pipeline topology and □T between T_N and T_{N+1}, the simulation is able to run up to several days into the future.

Figure 4 illustrates the procedure that is performed by PipePatrol Predictor when doing Online-Monitoring. F denotes the entirety of process values that can change in time as shown by one single green curve in Figure 4.

The red curves show two results of a predictive simulation. They have been initiated at times T_N and T_{N+1}. Based on the initial state F_N (T_N) the model has at time T_N, the simulation has a time frame of □T to run as far into the future as possible before the simulation is stopped and the next one is triggered at time T_{N+1}.

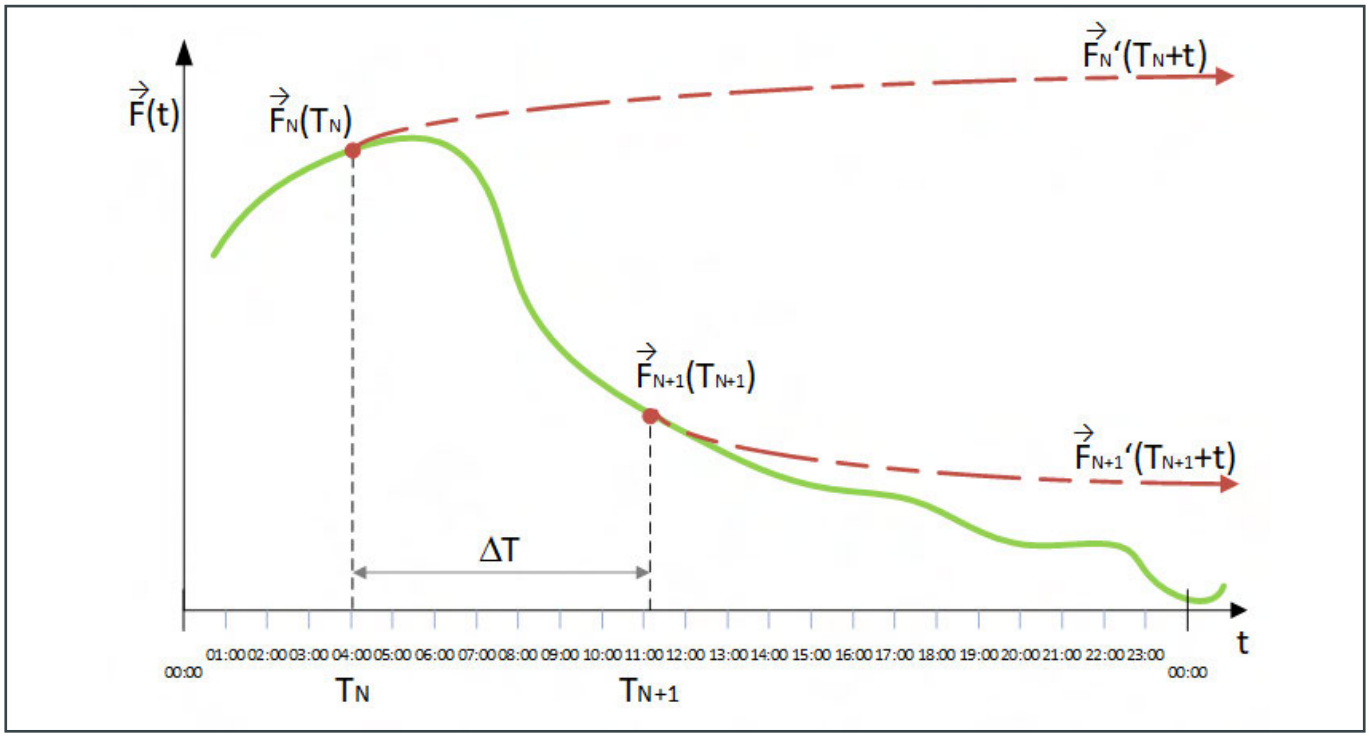


Figure 4: Nonlinear predictions of process values

It is quite important to understand that the red curves do not show just a linear extrapolation of the local derivation of F_N (T_N) but show the model-based predictive simulations of the pipeline as it would behave after T_N and T_{N+1} considering all necessary aspects of thermodynamics and fluid mechanics!

4. SIMULATING AN ARBITRARY SEQUENCE OF OPERATING POINTS (PREDICTIVE MODELING)

Unlike the previously described Online-Monitoring, the Predictive Modeling is not based on an initial operating point, formed by a set of measurements from the pipeline. The starting point for the simulation can be freely defined by the user and so can a number of additional points that must be placed on a timeline interactively. As Figure 5 shows, by this way the user can apply a temporal sequence of N boundary conditions F to the model (red dots within figure).

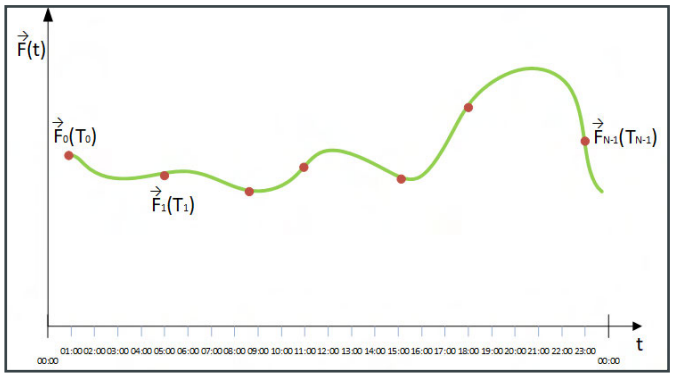


Figure 5: User-defined operating points

After simulation starts, the software will predict the behavior of the pipeline between the N points and beyond the last point as well. In the final result the user will get a trajectory of computed process values (green curve) that can be analyzed under security or economical aspects.

As the Predictive Modeling functionality is based on the same model as the Online-Monitoring, the simulation is also considering all aspects of thermodynamics and fluid mechanics.

Entering boundary conditions F that are physical implausible is not allowed. If any computed value runs out of physical plausibility during simulation between the specified boundary conditions F, a model warning will be provided.

5. HOW TO IMPROVE PIPELINE OPERATION AND MAINTENANCE ACTIVITIES

The PipePatrol Predictor incorporates the two modules Predictive Modeling and Online Monitoring. Both of them provide an independent set of freely definable rules that will be evaluated during simulation. Violations will be logged using their expected timestamp.

Within PipePatrol-Predictor there is a comfortable rule editor available. Figure 6 shows an example how a rule must be set if a pre-alarm event is desired when pressure transmitter 'SimP_Chevron' falls below 65 bar and a main-alarm event when falling below 60 bar. Rules can be created for any kind of transmitter connected at any location at the pipeline or at the pipeline network.

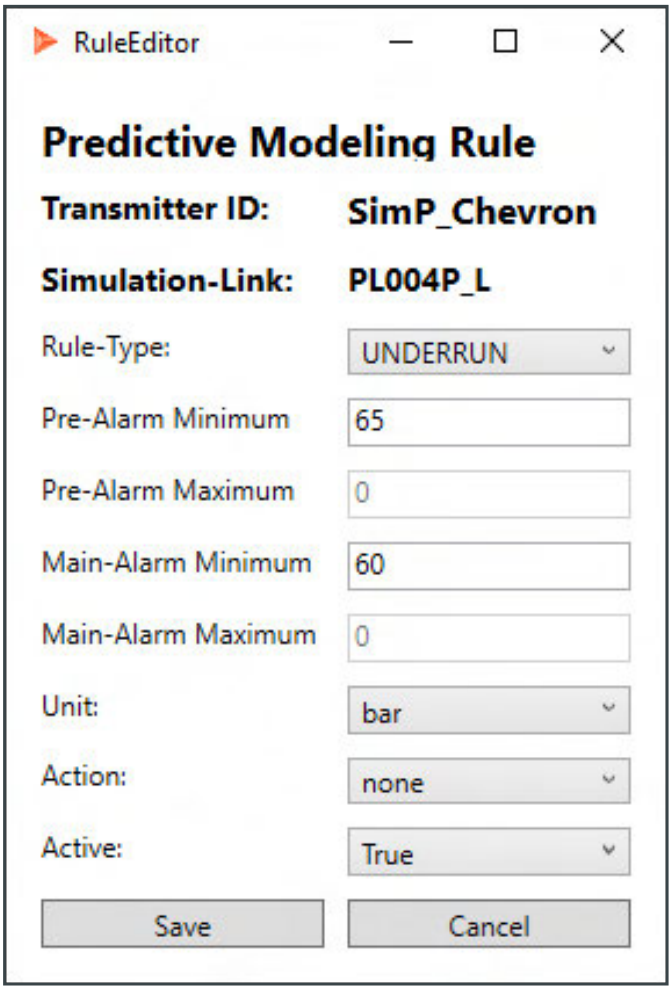


Figure 6: Rule-Editor

These rules may be defined according to following typical questions in pipeline operation:

- How long can the minimum pipeline operation pressure be maintained at certain delivery points?
- How can I maintain secure pipeline operation and fulfil contractual delivery guarantees?
- What corrective actions are necessary to guarantee the minimum pressure?

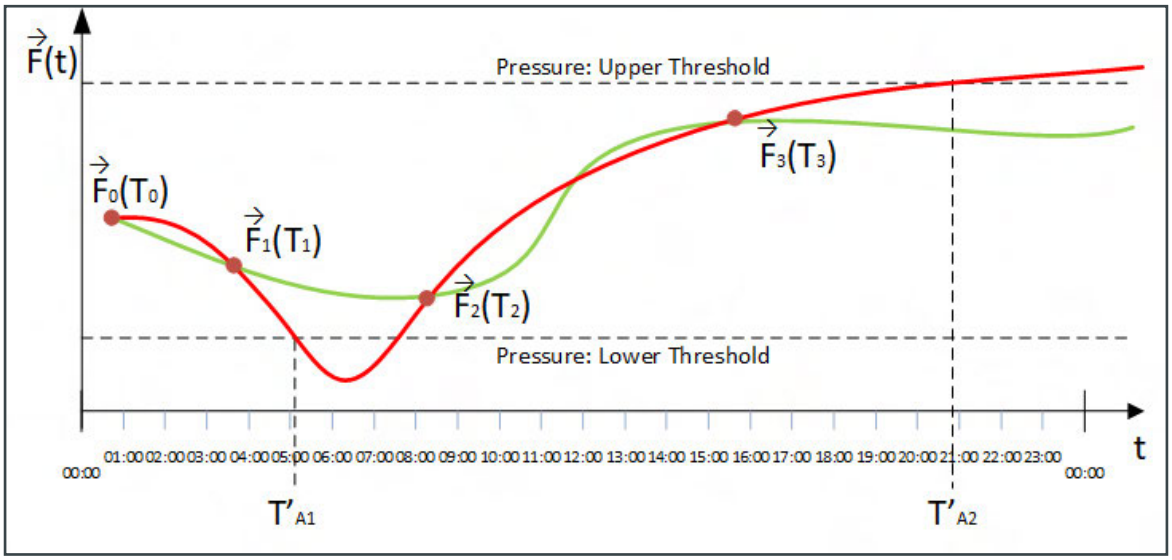


Figure 7: Violation of rules

Figure 7 shows an example how PipePatrol-Predictor can help to maintain secure pipeline operation: Assuming that the displayed sequence of operating points F(t) is planned by pipeline operators, they might expect the pipeline to behave as shown by the green curve hence remaining within the secure area defined by the pressure range between upper and lower threshold PU and PL.

The reality probably looks different. The red curve in Figure 7 shows how the actual behavior of the pipeline could differ from the expectations. Here the PipePatrol Predictor would alarm and tell the operators that, if they should run the sequence F(t), the pressure at a certain delivery point will fall below PL at expected time T'_{A1} and will exceed PU at expected time T'_{A2}. Now it is the operator's decision to take the risk of boundary violation or to define altered operation points and run another predictive simulation for verification.

6. USE CASE FOR PIPEPATROL PREDICTOR

In 2018 KROHNE implemented the PipePatrol Predictor at a pipeline network that connects Germany, Belgium and the Netherlands with a total length of approximately 495 km. It is the backbone of Central European ethylene production and is accessible for several ethylene producers and consumers.

In this use case the pipeline operator has to manage situations where certain producers might reduce or even stop their production but at the same time the minimum pressure at those positions where ethylene is taken out has to be maintained. Without a model based simulation as shown here it is impossible to predict how long minimum pressure can be guaranteed to consumers in the case that the production rates decrease somewhere. It is also impossible to give a reliable estimation whether a certain corrective action can compensate the loss of ethylene production in terms of keeping the pressure above the minimum.

In the shown example the user of PipePatrol-Predictor created and simulated a scenario with a producer at location 'Wesseling', which normally delivers 50 t/h but stops his production at time 01:42:05 in the morning. A consumer taking out 20 t/h and even increases his consumption to 40 t/h marks the second change of the operation state in that (imaginary) scenario. Figure 8 shows an integrated editor for modeling scenarios like this. The two changes in flow rates highlighted by the dashed line have been interactively designed by the user. Here all other flow rates (production and consumption) remain constant but may also be object of modification of the simulation scenario.

Based on the behavior of the edited flow rates, Figure 9 shows the results of the simulation as a screenshot of the graphical user interface. Here the forecasts of the pressure at several locations is plotted over a temporal axis that points into the future. Furthermore a table with alarm message is displayed from which the user can receive information about the critical value that triggered the alarm, the transmitter and its location and in particular the future time when the alarm is expected.

Comparing Figure 9 against Figure 8 it becomes obvious that the changes in flow rate modelled by the user are responsible for the discontinuities of the pressure at all locations. It is also worth mentioning that the shaping of those discontinuities becomes smoother with increasing distance of the pressure transmitter to the location where the flow rate changed. This was to be expected considering the hydraulic characteristics of a pipeline (red curve shows pressure at 'Wesseling' where the flow rate falls to zero).

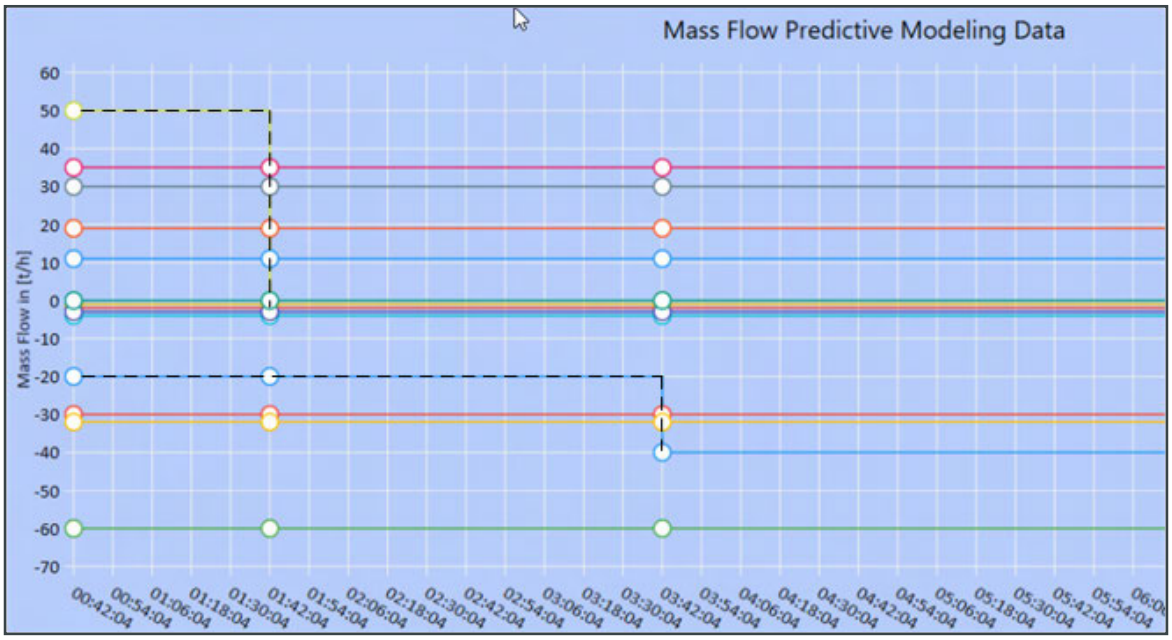


Figure 8: Interactive Simulation Editor

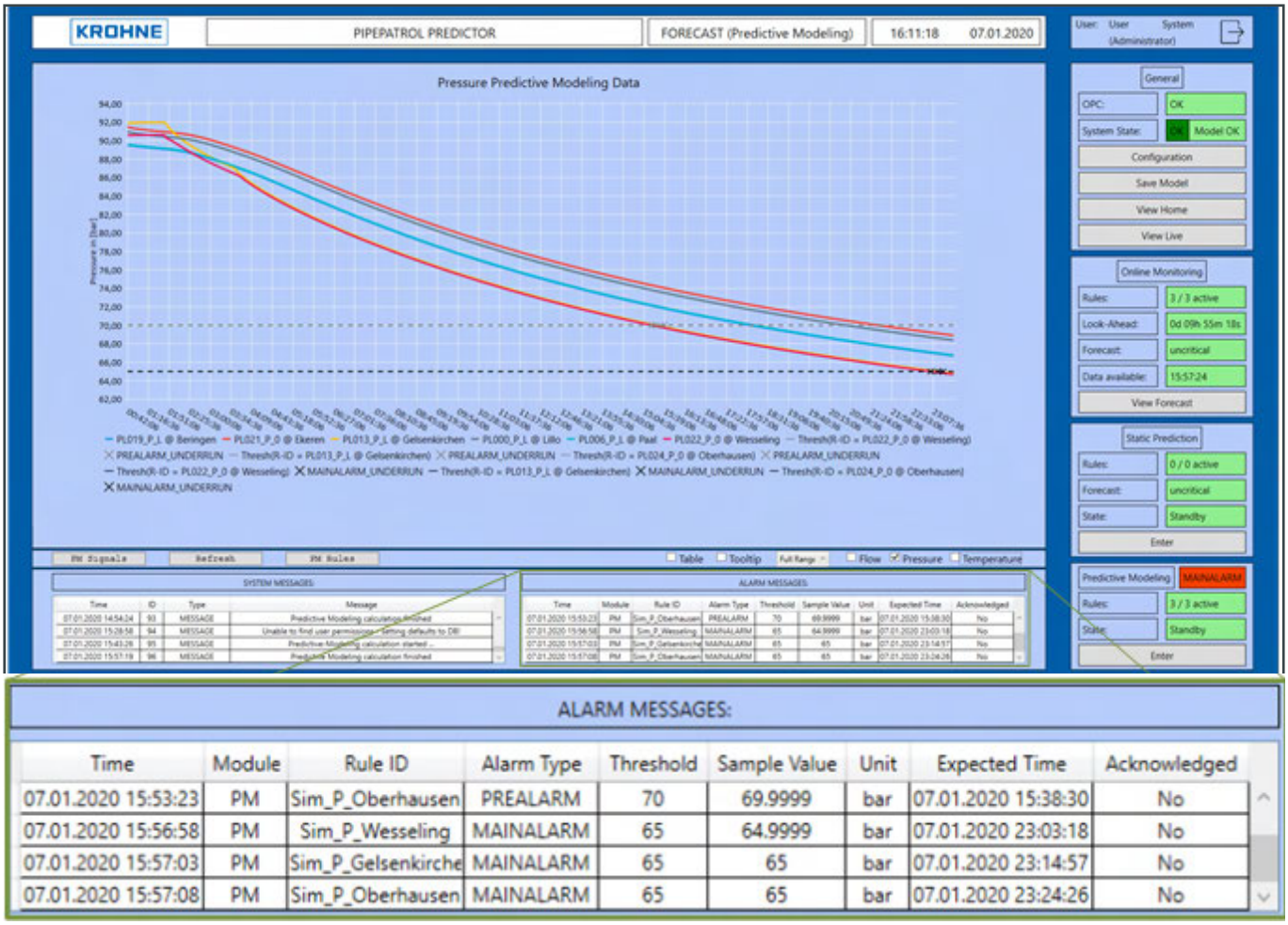


Figure 9: Forecasts from predictive modeling for pressures

For internal analyses a number of real scenarios, i.e. changes of operating points that have been performed in reality, have been reconstructed virtually with the predictive modeling. Then it turned out that the computed forecasts showed a very high congruency against the archived data that have been recorded after the change point. Thus the reliability of the predicted behavior could be proven.

7. SUMMARY

KROHNE, a manufacturer of measuring technology and established supplier of systems to the oil and gas industry, with more than 30 years of experience in leak detection and localization, introduced PipePatrol Predictor, an outstanding technology for continuously analyzing the future behavior of pipelines based on its current state. Additionally PipePatrol Predictor enables pipeline operators to simulate planned operating scenarios and to evaluate their safety and efficiency with high accuracy solely by using the digital twins of their pipelines.

PipePatrol Predictor consists of one backend application that is designed as windows service which incorporates all algorithms for simulation and evaluation. The second part of the package is the Predictor-GUI which contains all controls and data displays. At least one instance of the Predictor-GUI is required to enable the user to interact with the system, i.e. defining rules, selecting signals, modeling operating scenarios, etc.
As the Predictor service is accessible by the GUI via network, even multiple instances of the GUI software can be installed on Windows-PC's available within the LAN. A well elaborated user management provides user roles with definable permissions and ensures exclusive operating of the service only by one user at the same time.

Moreover PipePatrol Predictor is extremely valuable when designing infrastructures or components of a pipeline as well as when creating production and consumption plans. Finally PipePatrol Predictor helps to run a pipeline safely and efficiently and therefore reduce environmental risks and also costs.

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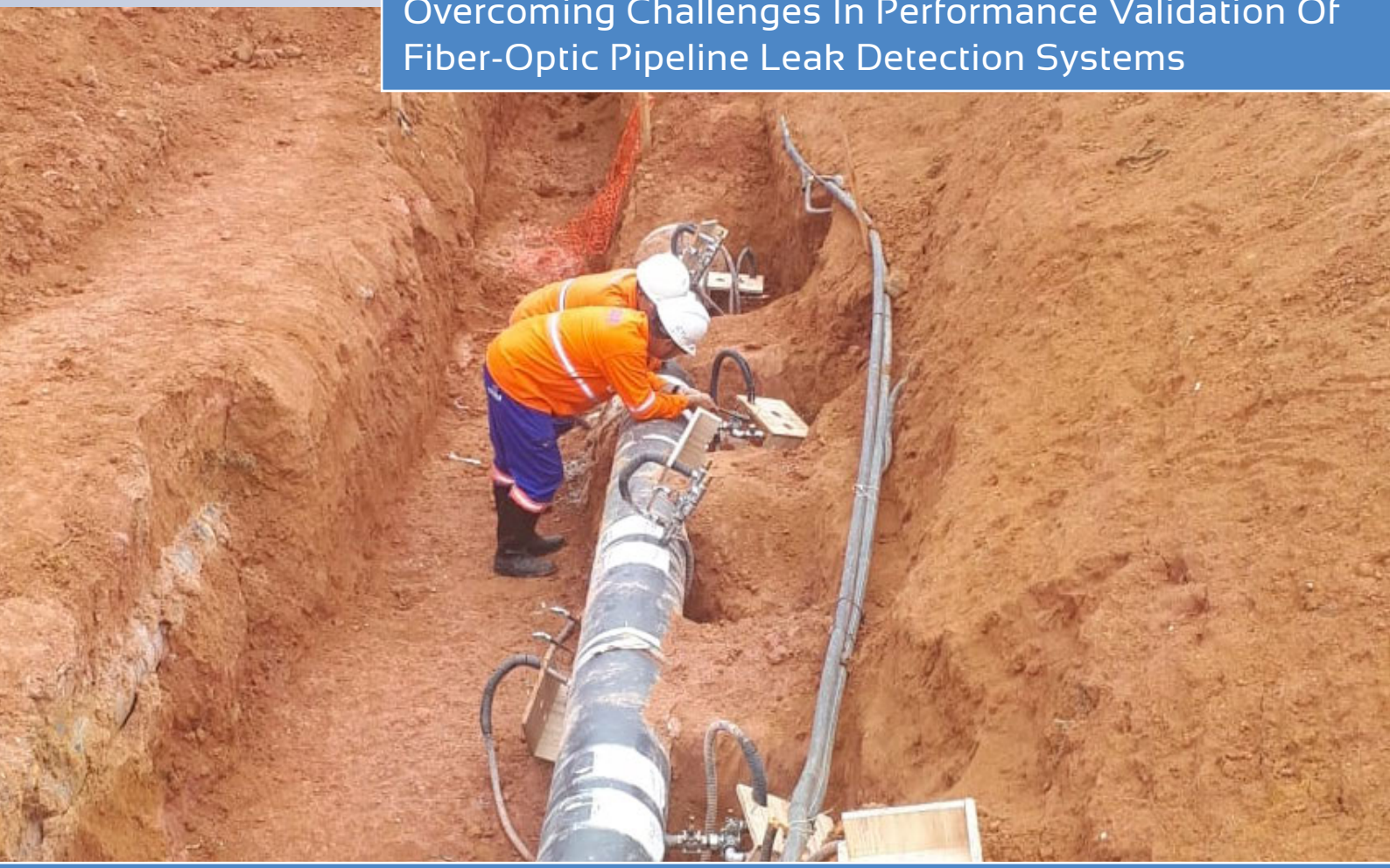
Overcoming Challenges In Performance Validation Of Fiber-Optic Pipeline Leak Detection Systems



Chris Minto > OptaSense Ltd

Abstract

External Leak Detection systems based on distributed fiber optic sensors (DFOS) offer the exciting potential to significantly reduce the overall amount of spilled product before a leak is detected and localized. As an external system, the validation of system performance and equally the verification of an operational installed system is a known challenge since, unlike in a conventional system, leaks cannot easily be simulated. As an example, the detection of a negative pressure pulse – a key detection mode for a Rayleigh based system requires test facilities >500m extent with leaks created at operational pressure in a full-bore pipeline. As a result, industrial focus has traditionally been deployed on lower level research-oriented test data rather than full scale validation.

OptaSense® have worked with the industry test facility CTDUT in Brazil to establish a unique test bed where realistic pipeline leaks can be created in full flow conditions. The results from this have been used to validate a realistic performance basis of small 15 lpm leaks detected via their negative pressure pulse in ~10 seconds and larger 150 lpm leaks detected by multiple modes in ~1 minute. Valid automated detection of NPP was observed down to 1mm holes in the pipe – a leak rate of only 1.5 lpm. The use of the negative pressure pulse is shown as a compelling detection method but needs care to deploy in testing since the use of a valve to create a pulse is shown to be inferior in comparison to burst disks due to the increased valve-opening time that gives rise to a reduced amplitude pressure pulse. This paper argues for the necessity of large-scale validation approaches to performance bound acoustic-based leak detection systems and presents established options for in-field verification on customer owned systems.

INTRODUCTION

Pipeline leak detection is traditionally provided by mass balance techniques or as they are known "computational pipeline monitoring" (CPM) – other techniques also exist and are used in parallel. These are trusted and in widespread use with a well characterized operational envelope. In general, the technique is very reliable and is supported by a wealth of open literature and evidence from experienced practitioners (API, 2012). Failures do happen but, in general, when operated from within their established performance envelope the systems operate reliably and help to safely transport millions of barrels per day.

The limitations of CPM systems are well understood and are attributable to the origin of the data (a relatively sparse array of input and output based measurands):

- Poor positional estimation – sensors are normally only placed at block valve stations and therefore the ability to accurately position an observed drop in flow can only be achieved by time-based estimates of when a drop is observed – resulting in a high positional error.
- Large minimum detectable leak size – the statistical nature of CPM has an ultimate sensitivity relating to the performance of individual sensors and the windowing (averaging) techniques used to detect a drop. The smaller the detectable change the longer the averaging needed - this ultimately leads to an ultimate noise floor of around 1% of flow taking many 10's of minutes or indeed hours to detect at that level. The minimum leaked volume before detection will therefore be a product of the percentage of flow rate detectable with the time taken to detect at that size. In large bore pipelines this can be very large indeed.

Test strategies for CPM based "internal" leak detection are well established and suited to the nature of the technique used. A variety of approaches will generally be taken at different operational frequencies that together add up to a comprehensive and integrated approach to verifying the implementation of a leak detection system (and the management of that system). Validation of the underlying techniques has been built up over years starting from individual transducer calibration through to model effectiveness (in effect achieved by similar techniques as verification).

Ultimately, to test a pipeline leak detection system at some point a full fluid withdrawal test is normally programmed in as part of a robust leak management strategy. Due to the cost of a fluid withdrawal test these are normally done sparingly and the preference is to rely on modelling of the overall approach.

Fiber optic-based mechanisms for leak detection have been explored in recent years as a promising method to improve positional estimation of leak from a kilometer scale down to the meter scale and to dramatically reduce the minimum leaked volume before detection. One key difference between CPM and Fiber Optic Sensing (FOS) based systems: the former are classified as "Internal" systems, i.e. their focus is measuring parameters inside the pipeline, the latter are classified as "External" systems – i.e. their focus if measuring parameters outside the pipeline. CPM observes the evidence of a leak by absence of content (e.g. a drop in pressure or flow rate), FOS determines the occurrence of a leak by the presence of new content (e.g. the noise from a leak). The following signals are typically exploited by Distributed Fiber Optic Sensing techniques (DFOS), specifically as in this case: Distributed Rayleigh Backscatter Systems (DRS), often termed "DAS" (Distributed Acoustic Sensing).

- Orifice Noise - the acoustic noise that occurs when a contained product leaks through an orifice and interacts with the local burial medium and/or pipeline wall - experienced as both vibration and noise. Sound waves are picked up by the fiber immediately on generation.
- Negative Pressure Pulse / Pressure Wave – the NPP signal occurs when a fluid constrained at high pressure is suddenly released to a lower pressure over very short timescales. The effect of the pressure pulse (a reduction in the pipeline diameter) travels in both directions along the pipe at the speed of sound in the fluid and is detected by the fiber placed outside the pipeline.

	Fidelity	Coverage / Flexibility	Cost	Frequency
Fluid Withdrawal Testing	High	Low	High	Low
Leak Simulation Model (Full)	Med-High	Med-High	Low-Medium	Medium
Functional Parameter Testing	Low	Low	Low	High

Table 1: Conventional CPM approaches to Performance Verification: a spread of costs vs capability is used to provide a balance of confidence

- Temperature Change – the fluid (liquid or gas) will impact on the environment and make subtle changes to the local temperature – when these propagate to the fiber optic (which may take some time) these changes can be picked up as a change in temperature (temperature gradient) - typically termed Distributed Temperature Gradient Sensing (DTGS). Earlier versions of DFOS exploited solely an absolute temperature change (DTS: Distributed Temperate Sensing) and were successfully deployed on for example above ground LN2 pipelines with a large expected temperature drop. These are less used on buried pipelines as the temperature drop practically measurable at offset equivocates to very large leaks.
- Local Strain Changes - like the temperature change, the gentle pressure change from the fluid on the fiber or the sudden pressure spike from a gas injection into soil will be perceived as a change in strain – again picked up by long term windowing techniques on the fiber.

OptaSense implements leak detection in two modes: Mode 1 comprising solely of NPP detection – offering the fastest possible reaction a leak (and also detection of the smallest leak size). Mode 2 fuses the results of combinations of all detectors and whilst still extremely fast (minutes) requires a larger baseline for detection (~150lpm).

The testing of these systems is considerably more challenging than is the case on a conventional CPM approach for the following reasons:

- To detect an NPP you need >500m of coverage of a pipeline and the ability to make a release – moreover, as we will see in the results section this cannot be easily approximated by opening a valve – a burst disc assembly is required if the signature of a leak is to be replicated.
- To replicate the OFN and Strain signal levels seen in service a representative signal (orifice size, fluid phase, pressure) sustained over the detection periods is needed – without injecting further artificial noise into the system which may inadvertently trigger any sensitive detector.
- In DTGS based systems they are generally very responsive to minute temperature changes but can have difficulty (in a non-quantitative system) to discriminate between large and small signals, similarly the propagation time (and potential lack of propagation) between leak offset and fiber needs to be considered.

In addition to the practical difficulties of experiment design, some logistic constraints also exist for external leak detection with regard to trials conduct:

- Ground relaxation is likely to trigger residual strain or thermal signals after any disruption – test systems should be emplaced with a period of time between emplacement and test to allow relaxation / compacting to complete.
- Typical leak detection systems run on long averaging windows to offer improved Signal to Noise Ratio (SNR) – this means that the test area should be "naturally" quiet for some time preceding tests – this is particularly important for tests aiming to exploit DTGS techniques.
- For a leak system which fuses different leak signals there is a need for significant coordination to see the individual signals taking place within the correct timespan.
- Once used it is likely that a test location will be disrupted for a considerable period of time.
- Test approaches should take into account the wide range of environmental conditions that may be experienced on a pipeline which lends itself to non-static means of testing.

To date, efforts that have taken place have been funded by a mixture of end users, pipeline operators and industry bodies – recognizing the lack of dedicated pipeline test facilities (FOSA 2018). Similarly, the literature on the subject is sparse to the point of non-existence and there exists few detailed reference points on testing methodologies. Testing efforts to date that we have participated in have been limited to a range of levels of proxy tests (either wittingly or unwittingly) carried out at lab scale with often no results publication and often blind.

THE NATURE OF PROXY SOLUTIONS FOR EXTERNAL LEAK DETECTION

Inevitably, a degree of approximation to real life conditions comes out in any test scenario - the utility of derived data is related to a solid understanding of the limitations of the proxy and how directly they can be read across to practical implementation solutions. This problem is experienced less with internal leak detection systems as they are measuring bulk parameters at a single location – e.g. pressure or flow. The performance of the overall system can then be integrated statistically via a model, the efficacy of which is then directly traceable to individual point results – trust needs only to be put into the statistical convergence to a solution.

In fiber optic, external leak detection systems the source data is uniformly distributed in nature, meaning that results from many discrete locations may be utilized in the generation of a leak result and similarly the algorithmic aspects may draw on many parameters rather than a simple single exposed metric. The results are not easily read

across from a proxy situation to the real-life system since the nature of the external sensors is such that they are not solely exposed to the simple, single metric of a confined fluid (liquid or gas) inside a pipe but the complex, dynamic environment outside a pipe.

This mixture of complexity of environment together with the conjugated nature of the solution leads one to the understanding that a proxy as close as possible to real life should be used. To date this has not been the case.

A variety of levels of proxy to a pipeline have been tested for external leak detection and while useful as laboratory scale research exercises they all have drawbacks in their ability to reflect on the true performance output of such systems:

TESTS FROM A LEAKING ORIFICE MOUNTED ON A HIGH-PRESSURE LINE INSIDE A PROXY PIPE SHELL

In these tests a high-pressure line is typically mounted inside an open (air filled / water filled) pipeline shell of characteristic diameter:

- Good at replicating effects of temperature (from leak fluid) and local (but not bulk) effects of orifice noise
- Does not reflect any bulk pressure orifice noise / skin coupling effects
- Does not produce any negative pressure pulse effects
- Generally very poor at reflecting environmental influences
- Limited length of the pipeline shell leads to end effects
- No dynamic effects / No flow effects
- Typical short duration of tests does not lead to the use of real-life parameter settings
- Useful only as research / initial understanding
- Lab tests are generally not trying to illustrate location accuracy

EXTRACTION TESTS FROM A LIVE PIPELINE

In these tests a small amount of fluid is drawn from a pipeline via a valve into an enclosed lower pressure reservoir to simulate a leak.

- Good potential for generating a negative pressure pulse (only in conjunction with a bursting disk) and some orifice noise effects
- Good at reflecting full scale behaviour
- No external effects so no use of mechanisms involving fluid hitting fiber – e.g. temperature / strain
- Mechanical arrangements may prevent such tests reflecting true environmental influences – i.e. artificial involving much above ground machinery and human influence.
- Unable to investigate the potential to detect leaks amongst typical backgrounds
- Limited dynamic effects / flow effects
- Useful only as research / initial understanding

To date most tests undertaken have used either of these two approaches and should be considered to be "research" projects rather than evaluation projects.

TESTS FROM A LEAKING ORIFICE MOUNTED ON A SHORT SECTION OF CLOSED PIPELINE (HYDROSTATIC)

In these tests a full-sized high-pressure line is mounted inside a generally open (air filled / water filled) pipeline shell of typical diameter:

- Benefits of case 1
- Good reflection of bulk pressure orifice noise / skin coupling effects
- Only supportive of negative pressure pulse effects if quite long c. 500m otherwise cannot be resolved adequately.
- End effects still present
- No dynamic effects / No flow effects
- Limited potential to reflect real world conditions
- Significant cost for not much gain
- Again, in this type of test, location accuracy may not always be tested

TESTS FROM A LEAKING ORIFICE MOUNTED ON A SUITABLY REPRESENTATIVE FLOW LOOP

In these tests a mid-sized pipeline flow loop is created where leak orifice mounts can be controlled to release product into a true environment. This level can truly reflect the behaviour of a real pipeline, affords the ability to create true external leaks with the minimum of artificial signal induced and can be used for full scale validation exercises. Depending on the sensing technology used, fully distributed sensing systems are suited to pinpointing leak location and such a flowline with periodic "orifices" can be used to validate location detection accuracy. The only questions of limitation are How Big? What Diameter? What size of Leak? And perhaps most crucially – what product will be flowing? In addition, a further extension will allow dynamic effects from slack lines / start-up / pump noise / pigging to be investigated in parallel reflecting the needs of current guidance.

The main drawbacks of such a system will generally still be related to the lack of exposed length (limited) and the use of a proxy, benign fluid. Pump noise may additionally be a problem. The visibility of NPP suggests that a straight-line distance in excess of 500m and preferably > 1km is required. Pressure ranges should support typical

	Availability	Expense	Flexibility	Performance
High pressure line mounted inside pipeline shell	Bespoke	Moderate	Limited	Limited to external effects only
Full bore tests inside a compact container	Bespoke	High	Limited	NPP tests not possible –no transients
Live pipeline extraction tests	Client Dependent	Moderate	Some	Only fully valid if used with burst disc.
Leaking orifice mounted on a filled shut in pipeline	Bespoke	Moderate	None	Some bulk signals not representative. Hydrostatic only.
Leak tests on a representative flow loop	Low: CTDUT, SINTEF...	High	Some	Most Representative – only solution likely as validation candidate

Table 2: Summary of approaches to validating external leak detection systems

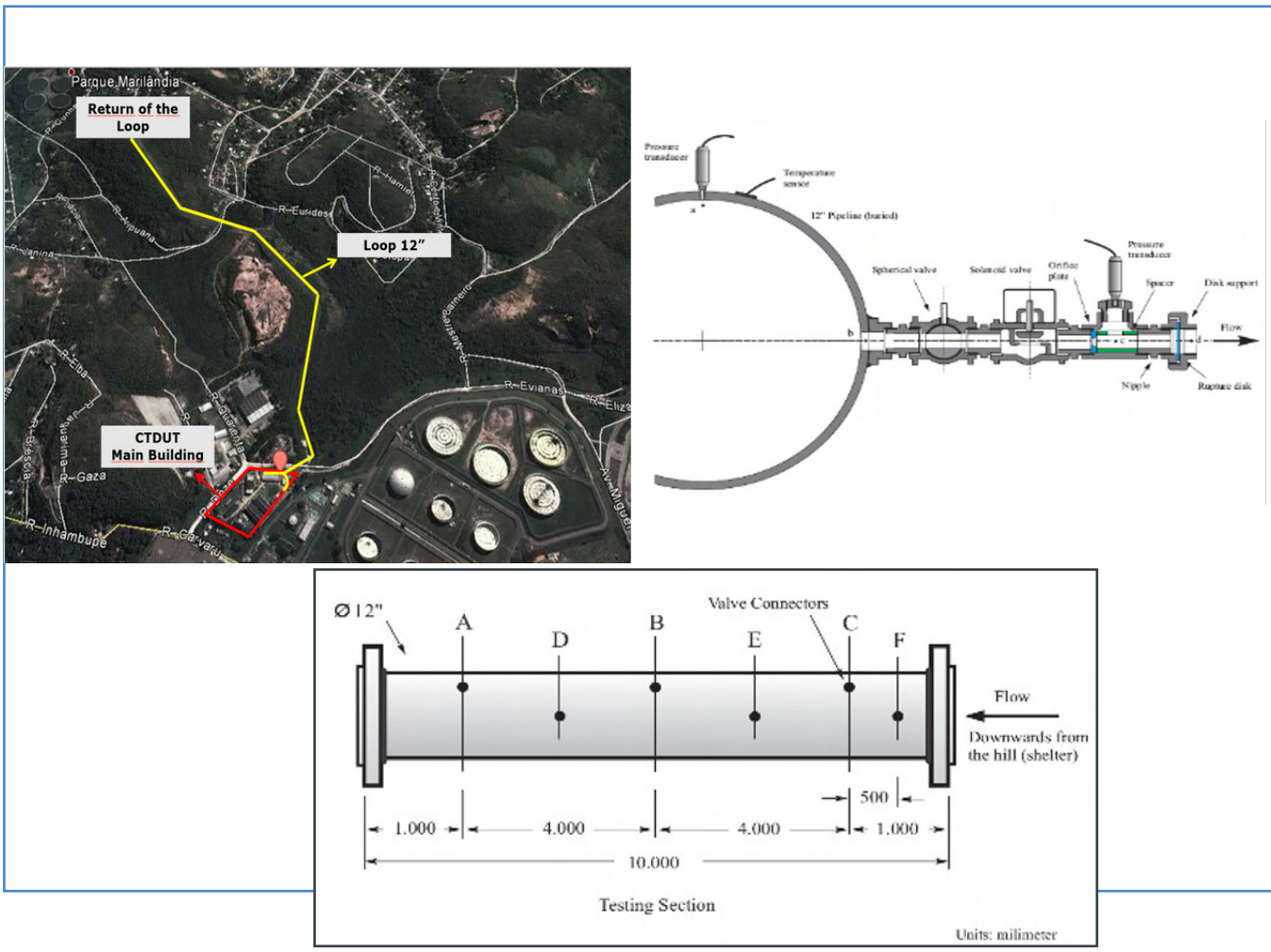


Figure 1: Overview of the CTDUT flow loop and Leak Orifice arrangements

in-service expectations. This paper supports the evidence that this the only practical approach for system validation. The subject of in-service verification is dealt with in the next section.

VALIDATION TESTS UNDERTAKEN AT A BELOW GROUND FLOW LOOP (CTDUT)

Following a similar approach [RIO Pipeline, 2019, OptaSense 2018] to validate Above Ground Leaks, OptaSense commissioned the Brazilian CTDUT flow loop facility to construct a bespoke leak spool piece with manufactured, controlled leak orifices (with burst discs) and controllable actuated valves. CTDUT possesses a 12" diameter, 2.4 km long buried flow loop pipeline with fibre optic cable making it ideal for sensing purposes. An arrangement to protect the pipeline and the measurements with both manual, remotely actuated valves and burst disc was used which allowed both "on/off" measurements as well as a slow escalation of pressure until the bursting disk failed. Pressures of between 9 Bar and 18 bar were used.

Release ports were manufactured with 1,3, 5 and 10mm orifices at different orientations. The leak rates varied between 1 and 110 LPM for liquid and 150 and 15,000 NLPM for gas.

TEST RESULTS

A series of tests were undertaken at the CTDUT facility with data being recorded on a typical OptaSense qualitative DRS system.

The presence of a negative pressure pulse is considered to be one of the key indicators that a pipe has breached due to the rapidity and clarity of signal. As mentioned previously, it is also probably the most difficult to replicate artificially. At the Below Ground Flowloop (CTDUT) tests, OptaSense employed burst disks to replicate the sharp drop in pressure that occurs when pipeline integrity fails. Figure 2 shows two waterfall plots of data: the upper plot shows an NPP that occurs during a leak test with a burst disk and the lower plot shows a much weaker NPP occurring during a leak test employing a solenoid operated valve of the same size. The data in these images was obtained with a DRS system that was monitoring a fiber running up and back down a section of pipeline. As a result, the NPP event is observed twice - originating at channels 912 and 1665, which correspond to optical distances of 912 m and 1665 m. Around channel 1300 the system forms a mirror image. As anticipated for this test, the propagation speed of the NPP is approximately 1500 ms-1 – i.e. the pressure wave speed in water. The key result from this is the significantly increased energy observed in the NPP when test with burst disks as opposed to without. Without these energy levels, the NPP is much more difficult to detect in a simulated testing (or rather implies a much larger orifice is needed). Even though the pipeline at CTDUT is a large-scale facility, the NPP signal can be seen to propagate right round – illustrating the key importance of having sufficient length of pipe to properly observe the NPP signal. This incidentally indicates the potential of this technique where the NPP trace can be very clearly observed on the second arm of the flow loop which is at an extended distance from the fibre.

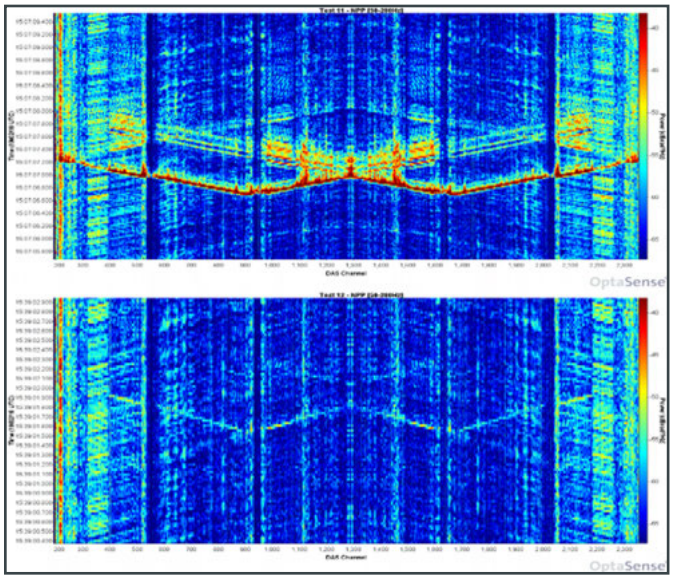


Figure 2: Waterfall plots of DAS data showing NPP events that occurred during (Top) Test 11 and (Bottom) Test 12. Both tests are with a 3 mm orifice and using water as the pipeline fluid. Test 11 employs a burst disc while Test 12 uses a fast-acting solenoid-controlled valve.

Instantaneously after the NPP, fluid will begin leaking from the pipe and this generates orifice noise, which is detectable by the fiber. Figure 3 shows a single channel spectrogram clearly showing OFN occurring during a liquid leak test (left) and a spectrogram obtained during a gas leak test, which, while clear, demonstrates reduced high frequency content.

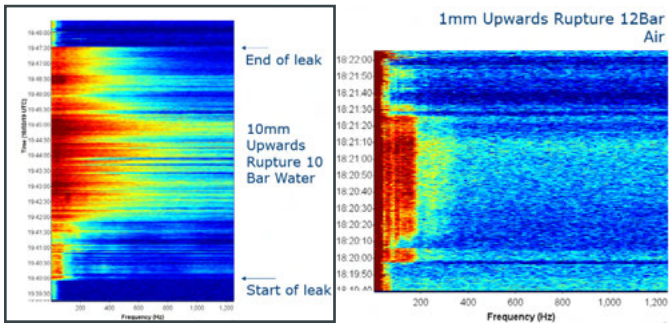


Figure 3: Spectrogram demonstrating OFN during a leak tests at CTDUT, (left) liquid and (right) gas. The onset of leak is clear in this plot as is the later termination. Note that although broadband noise is apparent throughout, the magnitude of the lower frequency content (>50Hz) takes some to build, indicating significant interaction with soil

The final two components of the OptaSense leak detection system are strain and temperature. These are longer timescale effects that require extended leak tests. Data acquired during such an extended leak simulation demonstrates both of these components. Figure 4 plots raw unwrapped phase data obtained during the same test used to demonstrate NPP in Figure 2. Data is plotted for both passes of the leak area from fiber channels centred on the NPP origin. The black dashed line in the image indicates the moment the NPP occurred. After this point in time there is a significant fluctuation in the DC phase of between 5-8 radians observed over a period of approximately 15 minutes. This is followed by a steady decrease in the phase over the remainder of the plot. The initial phase change is attributed to the shifting of the ground around the fiber as a result of water leaking out of the pipe and the later decrease in phase is interpreted as the thermal effect of the water reaching the fiber and having a cooling effect, which appears as a reduction in the DC phase. Without ground-truth it is impossible to verify this interpretation, but these statements are supported by the results of the other leak simulations that were undertaken and controlled laboratory testing. The test that this data originates from was a liquid leak with a leak flow rate of ~30 lpm. This direct observation is not practical in a qualitative system but can be inferred through signal processing as will be shown.

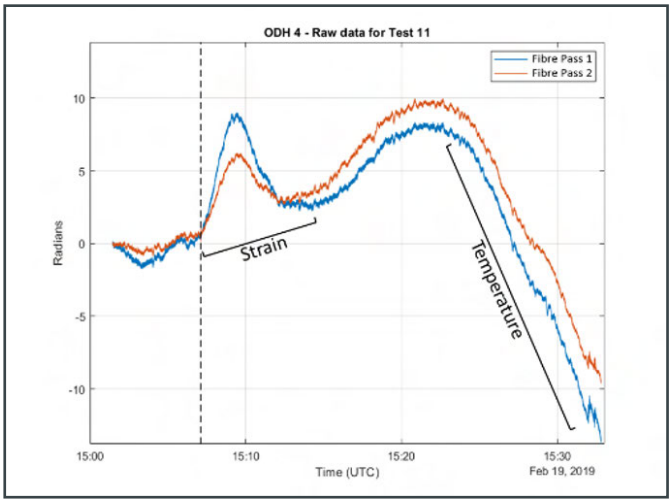


Figure 4: Plot of raw sensor data showing quantitative phase during a leak test at CTDUT. The black dashed line indicates the start of the leak as determined by the origin of the NPP in Figure 3. Regions indicative of strain and temperature-induced behaviour are marked.

Figure 5 shows the output of the OptaSense OFN, Strain and DTGS leak algorithms. The red vertical lines indicate the origin of the NPP as detected by the system and the orange horizontal lines indicate the trigger thresholds for each detector. Shortly after the NPP occurs significant activity is observed on the OFN and strain detectors while the DTGS detector, with a much longer response time, takes longer to reach the trigger threshold.

COMPUTED PERFORMANCE

Table 3 shows the tests and details of whether the system detected the event on each of the three fibre passes (green represents a positive detection). As a result of these tests, a detection confidence is provided for each fibre pass and an overall confidence rating Table 4. Noticeably, the system did not detect any NPPs on any of the three fibre passes during Test 1_5. An investigation into this test suggests that the rupture disk had failed prior to the test and as such there was no NPP generated during the test. The sensor data shows a very weak NPP with characteristics associated with the weak NPP generated during leak tests without a rupture disk. This test is considered an anomaly and is excluded from the calculated detection rates.

The majority of the leak tests undertaken at CTDUT had leak flow rates significantly below 150 lpm. From the full suite of tests, including those undertaken without a rupture disk, where the results from the range of detectors have been fused, we see the results in Table 5. There were no unexplainable alerts generated from fusion of the various modes of leak detection.

CONCLUSIONS

- Full scale tests are a necessary element for the validation of leak detection principles. However, once undertaken, lower order tests may be used for later in-service performance verification. Alternative tests at proxy facilities have all helped build up the general store of validation but have never been able to demonstrate practically "real" leak behaviour – for example the expected nature of travelling pressure waves. With a sufficiently large flow loop and appropriate pumps, pump noise had little impact on the conduct of the tests.
- Travelling pressure waves in liquid from a sudden onset leak are relatively easy to detect because of the well-defined properties and coverage of a large number of channels. When an NPP occurs, this signal is probably the most reliable indicator of a leak for DRS/DAS. All liquid leaks in the experiment set were detectable automatically using this approach. We observed that a rupture disk is needed to simulate such a failure since pressure waves delivered from a fast-acting valve are orders of magnitude weaker (for a given orifice) due to the longer opening times.
- In general, the signatures from the leaks followed expected migration paths through the soil, however there were some unexpected deviations in time and space. This could only have been observed by direct measurement and again is not practical to simulate without recourse to in-ground tests.

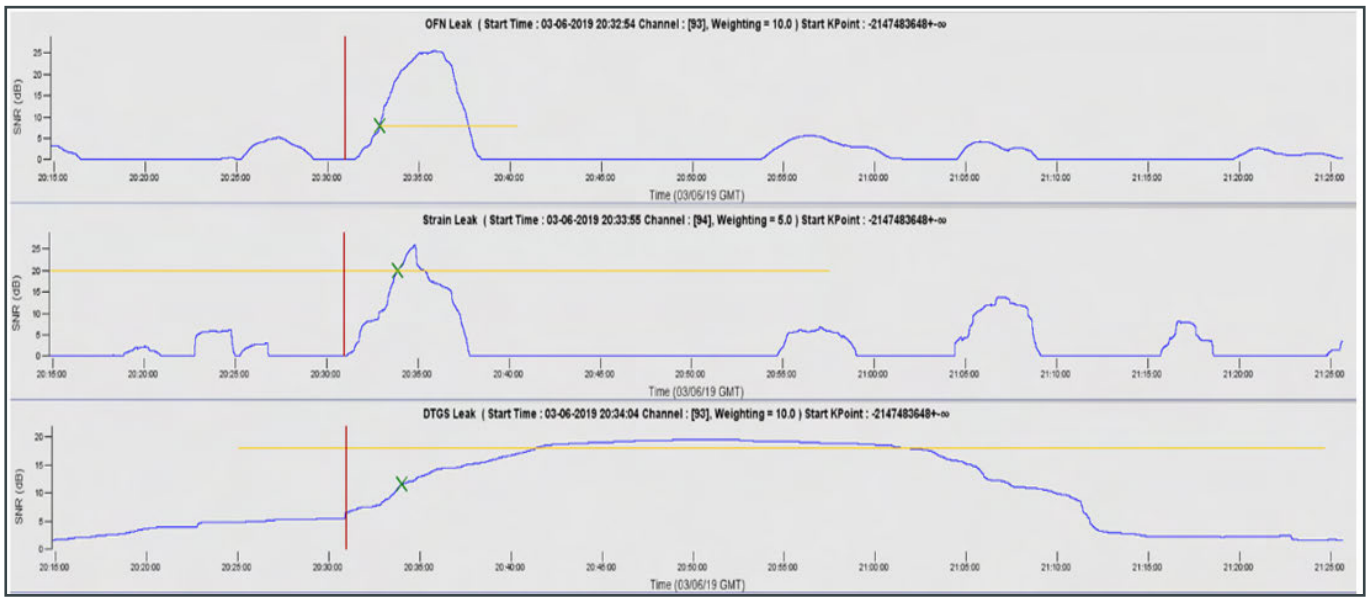


Figure 5: Output of three additional detectors during a leak test at CTDUT, Orange lines indicates the trigger level. The red vertical indicates the start of the leak as a result of the detected NPP (not shown)

TEST	Fibre Pass 1 (0.9 km)	Fibre Pass 2 (1.7 km)	Fibre Pass 3 (20.7 km)	Leak rate (L/min)
Test 1_5				31
Test 1_7				125
Test 1_9				1.25
Test 1_11				11
Test 1_13				1.25
Test 1_15				125
Test 2_5				110
Test 2_4				27
Test 2_6				27
Test 2_7				110
Test 2_8				27
Test 2_9				110
Test 2_13				110
Test 2_12				27

Table 3: Summary of NPP detection performance

	Fibre Pass 1	Fibre Pass 2	Fibre Pass 3	Overall
Detection rate	13/13	13/13	12/13	38/39

Table 4: Overall performance for each fibre pass

	Genuine Leaks	Nuisance Alerts
Test series 1	5	0
Test series 2	11	0

Table 5: Summary of fused performance for larger leaks

- Ultimately a leak modelling tool based on reliable quantitative data is likely to be needed to replicate similar software-based approaches as used in CPM based monitoring. Such a tool could not be developed or implemented without robust validation evidence based on full-scale testing.

ACKNOWLEDGEMENTS

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References

1. American Petroleum Institute. Computational Pipeline Monitoring for Liquids, API Recommended Practice, First Edition, 2007, Reaffirmed 2012
2. Fiber Optic Sensing Association, Fiber Optic Sensing Association calls for US Pipeline Safety Test Facility, News Release, October 2018
3. RIO Pipeline Conference, Challenges in Validation and Verification of External Fiber Optic Leak Detection Systems, September 2019
4. OptaSense White Paper, Above Ground Mixed Phase Leak Detection, April 2018

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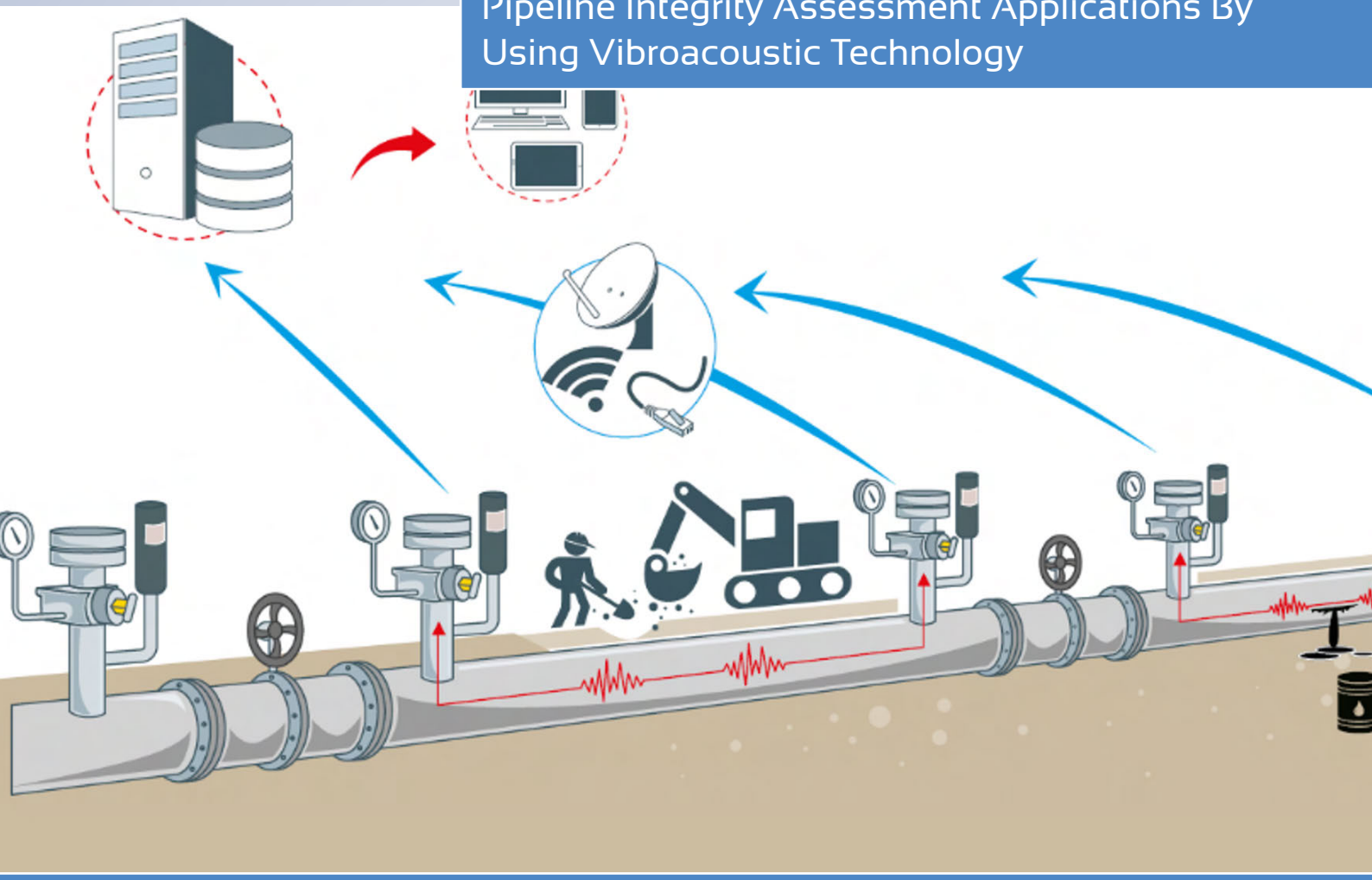
Pipeline Integrity Assessment Applications By Using Vibroacoustic Technology



Marco Marino, Fabio Chiappa; Giuseppe Giunta > SolAres; Eni S.p.A

Abstract

Asset integrity and operation reliability are primary objectives in pipeline management, nevertheless they require often costly methods, system and procedures. The vibroacoustic technology, developed by Eni S.p.A to detect impacts and spillages on Oil & Gas pipelines, already proved to be able to detect illegal tapping precursor events, and recently also to be capable of performing tasks related to integrity assessment.

From a physical point of view, each event or anomaly able to generate a perturbation of the vibroacoustic wave-field into the pipeline can be detected and localized. These kinds of perturbations can be clustered in three main sources. As a Primary one, we mean all the sources of acoustic noise produced by a direct or indirect interaction with the fluid, such as spills, impacts, the formation of degassing bubbles, valve handling/regulations and the jet noise generated by pre-existing breaches.

As a Secondary one, we mean all the signals produced by the interaction of the pump noise or the spill itself (primary sources) with all the geometrical or mechanical anomalies of the duct. The processing and interpretation of these secondary signals is quite complex because of the use of special processing techniques. As a Mixed one, we mean all the noise sources combining the joint effects of primary and secondary sources, such as a PIG (Pipeline Inspection Gauge) travelling into pipeline. In these cases, an analysis of simple pressure data is not enough to provide a correct interpretation of the recordings involved, but efficient and real-time algorithms are required because of the transience of the phenomenon.

By advanced software plugins and system scalability, the e–vpms® system proved to be successfully usable as a digital integrated platform. Additional information gathered using vibroacoustic sensors can be enhanced and automated for the pipeline integrity assessment, with advantages on operational efficiency.

INTRODUCTION

Pipeline networks are the most economic and safest means of transportation for oil, refined hydrocarbons, gases and other fluid products. As a means of long-distance transport, pipelines must fulfil high demands of safety, reliability and efficiency.

If properly maintained, pipelines can last indefinitely without leaks, with most significant leaks occurring because of damage from nearby excavation equipment. If a pipeline is not properly maintained, it can begin to slowly corrode, particularly at construction joints, low points where moisture collects, or locations with imperfections in the pipe. However, these defects can typically be identified by inspection tools and corrected before they reach critical leaking conditions. Other reasons for leaks include accidents, earth movement, or sabotage: this paper is focused on events which are intentionally caused and aimed at illegal tapping.

Third Party Interference (TPI) are the most frequent cause of failure in oil & gas pipelines infrastructures, and they constitute a major risk for safety and environment. When these kinds of event occur, it's fundamental to react as quickly as possible to reduce the environmental impact, reputation damage and the economic loss [1].

The e-vpms® (Eni Vibroacoustic Monitoring System) is a proprietary vibroacoustic sensing technology, for remote real-time integrity monitoring of pipelines.

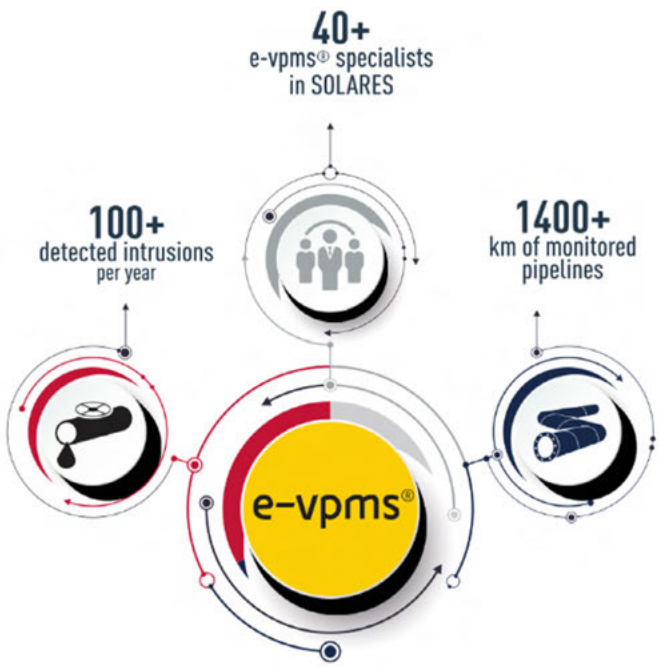
The system has been developed by Eni S.p.A in the framework of the R&D project, with the scientific collaboration of Politecnico di Milano and the industrial support of technological provider SolAres, composed by ARESYS and SOLGEO, two Italian companies active in the fields of remote sensing and geophysical services. This technology has been patented and registered by Eni S.p.A (see patent references [2], [3], [4], [5]).

The e-vpms® system ([6], [7], [8], [9] and [10]) works with a multipoint network of vibroacoustic sensors, installed on the pipeline, at relative distances of tens of kilometers. The acoustic and elastic waves produced by third party interference and by flow variations (TPI, leaks, spillages, valve regulations, pig operations, etc.), propagate along the pipeline and they are recorded at the monitoring stations.

A multichannel signal processing of the collected signals enables the detection, localization and classification of the triggering event.

The e-vpms® technology has been specifically developed and used primarily for Leak Detection (LD) purposes, proving a real-time detection and localization of leak events, although it also demonstrated to be able to detect precursor events (e.g. tap placement or bunkering activities), for a detailed review of such capabilities see [14]. The proprietary integrity monitoring system is operative on downstream and upstream pipelines in different scenario, around 1400 km in Italy, Nigeria and Argentina ([10], [13], and [14]).

As summarized in the key performance indicators (KPIs) of figure 1, the e-vpms® shows high level of maturity and peak performances.



MAIN FEATURES	
Pipeline diameter	2" onwards
Pressure range	1- 300 BAR
Transported product	Any fluid or gas in single phase
Distance between sensors	Up to 50 km - Depending on the required performance level and pipeline specs
Multiproduct / batches support	Yes
SCADA / DCS interface	Yes Many protocols supported
Monitoring conditions	Both pumping and still states
Minimum detected leak quantity	**No limitation** The system is able to detect also some non-leak events
Typical false alarm rate	**Negligible**
Localization Accuracy	± 25 m
Response	**real-time**

Figure 1: e-vpms® system KPIs.

Leading-edge and robust processing algorithms permit e-vpms® to reach a detection performance at the top level among the current available market products. The qualifying numbers are:

- Sensitivity to leaking hole diameter greater than 0.2 inches (depending on pressure and acoustic noise level),
- Alarm triggering within 6 minutes,
- Leak localization accuracy up to 20-30m.

The scope of the present work is to show the capabilities of detection and classification, both human-assisted and automated, of a wide variety of phenomena besides pure leaks. In fact, the e-vpms® may be used as a smart system to ensure the asset integrity in a broader sense. By processing the data, it is also possible to monitor, detect and analyze an amount of collateral and acoustic features, such as:

- Formations of degassing bubbles
- Valve handlings
- The presence of open pre-existing branches by listening to the jet-noise
- Impacts

Moreover, the e-vpms® is able to provide thorough the analyses of the interaction between generic sources of noise (such as pumping operations) and acoustic reflectors, ascribable to the following dangerous scenarios:

- Paraffin corks
- The presence of solid objects
- Closed pre-existing branches for illegal spillage
- Deformation dents

We also briefly discuss about the acoustic features of travelling PIGs and the possibility to perform tracking and real time localization of such objects. In the last section, a real example which deals with the analysis of jet noise is discussed; the proprietary technique, developed in the framework of e-vpms® and called FD (Failure Detection), is able to reveal and localize a leakage in place listening to the noise produced by the flow through a pre-existing leaking holes.

2. THE E-VPMS® SYSTEM

The e-vpms® system belongs mainly to the category of leak detection systems called ANPW (Negative Pressure Acoustic Waves) including digital and statistical analysis (figure 2), with the addition of other information coming from different sensing technologies [12].

The system is designed and developed to process the vibroacoustic signals generated by leaks even though any kind of interaction with the flow (pipe rupture, holes, valve movements, PIGs) and/or with the pipe shell (impacts, third party interferences) can be potentially detected. A product withdrawal at a certain point of the conduit produces an acoustic wave that propagates at the speed of sound in the medium (e.g. about 1200 m/s in liquid fluids) in two directions within the duct itself.

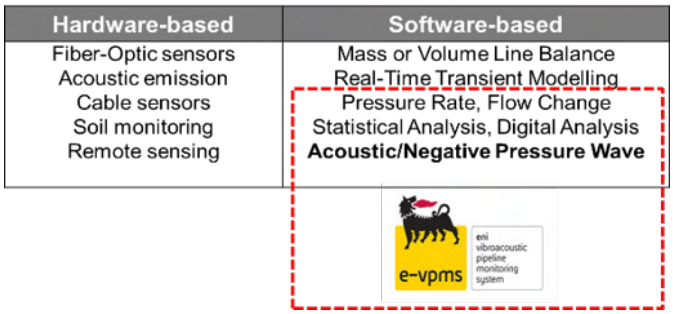


Figure 2: e-vpms® leak detection technologies.

The front of acoustic depression is detectable up to several kilometers of distance thanks to the high acoustic impedance of the liquid and the geometry of the transmission channel in which the sound propagates, that acts as the waveguide. These acoustic transients reach the acquisition stations on which are installed the proprietary highly sensitive pressure sensors, which measure the pressure changes over time.

The e-vpms® stations use several communication systems to continuously transfer the recorded data to the computing unit used for analyzing of tracks gathered from all measuring stations. The distance between consecutive stations is 10-30 km, depending on the fluid, pipeline diameter and the location of sectioning valves. The integrity monitoring application is guaranteed for any service condition (i.e. flow, steady). The e-vpms® system layout for LD and TPI applications is shown in figure 3.

Each monitoring station is composed of an ATEX-certified sensors group (figure 4), in direct contact with the pipe shell and/or with the fluid, by using a digital recorder of a processing module, a GPS antenna for data synchronization and auxiliary communication system, power and safety units. Taking advantage of numerical processing methods of signals, the system can recognize and locate the events with accuracies of about 25 m on routes of tens of kilometers.

Furthermore, compared to other commercial systems, e-vpms® has very high sensitivity; this performance excellence is achieved thanks to the ad-hoc designed sensors and to the following processing sequence.
In order to optimize algorithm performances during software operation, the system is calibrated by means of

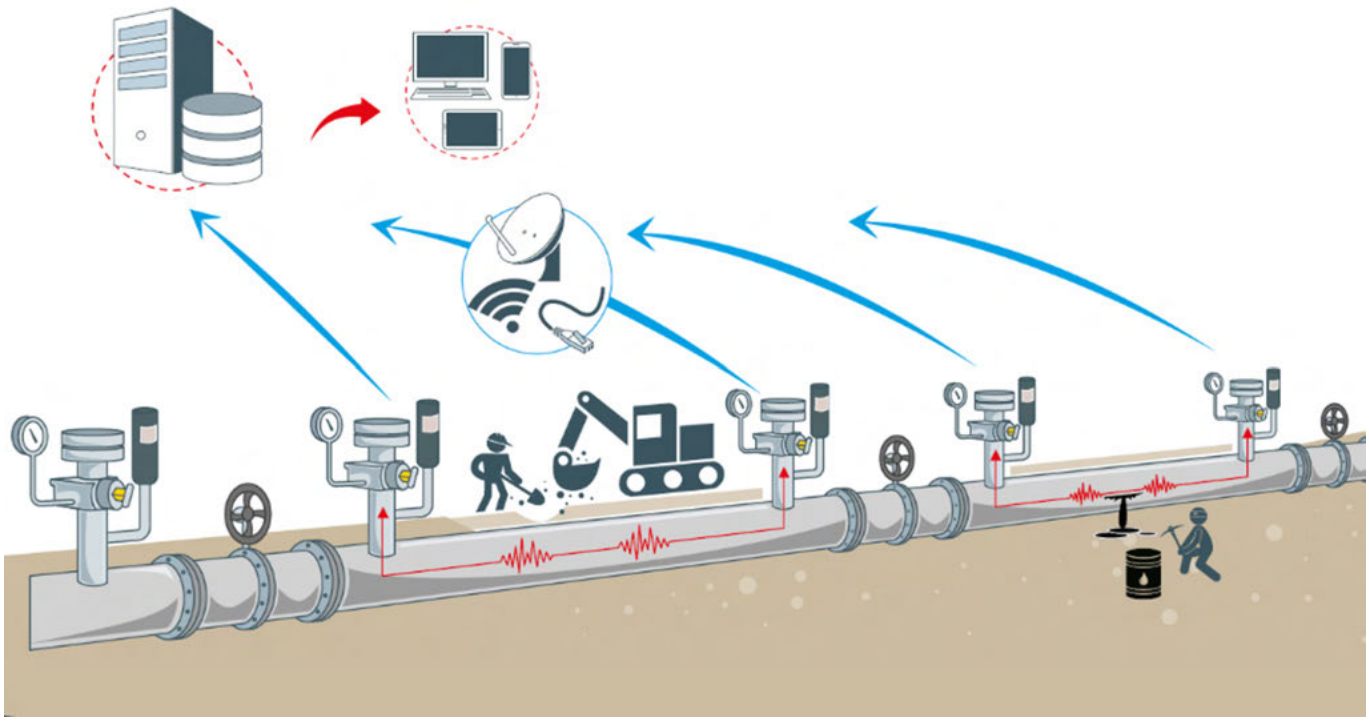


Figure 3: e-vpms® monitoring system layout.

controlled real spillages (see figure 5).

The e-vpms® software suite includes also a WEB-based pipeline management system (PMS), namely iPERTUBE, suitable for control room operators providing:

- Full control and monitoring of the system
- Reporting tool for long-term analysis of events
- Geographical maps and pipeline synoptic view
- Guided workflow to manage the life-cycle of ALARMS.

Exploiting joint information coming from vibroacoustic sensors, the e-vpms® system can detect distinguish alarm events both in presence of fluid spillage and in absence. In addition to spill detection capabilities, the e-vpms® can be used as a smart system to ensure the asset integrity in a broader sense. In fact, it is also able to monitor, detect and analyze an amount of collateral and anomalous acoustic features.

From a theoretical and operational point of view, each event or anomaly able to generate a perturbation of the vibro-acoustic wave-field into the pipeline can be measured and analyzed. According to our classification, the anomalous acoustic perturbations are divided into three main categories (see Fig.6):

- Primary
- Secondary
- Mixed

Figure 4: ATEX-certified e-vpms® recording sensor group.

Figure 5: Calibration spill performed by specialized personnel.

PRIMARY SOURCES

As primary sources we mean all the sources of acoustic noise produced by a direct or indirect interaction with the fluid.

As **direct** interaction we mean all the acoustic perturbations obtained directly exciting the fluid: spills, the formation of degassing bubbles, valve handling/regulations and the jet noise generated by pre-existing breaches belongs to this subcategory.

Events of spill generates a negative pressure transient, namely an acoustic signal, able to travel for tenths of kilometers inside the pipeline waveguide. This kind of acoustic signal is characterized by a very low frequency bandwidth (e.g. < 20Hz). Degassing bubbles generally occurs when the duct is in steady state and the night temperature drops; in these conditions, if the internal pressure goes below the piezometric quote the fluid starts degassing. This phenomenon is so quick that produces a disruptive positive pressure transient; just as a spill signal, the low frequencies travel for tenth of kilometers inside the fluid product.

Any valve handling (manual, motorized, non-return) produces an acoustic transient whose intensity depends on the speed of movement. Just as spills and degassing bubbles the signal generated by valve handlings are similar and the spectral content comparable, except for their peculiar pattern. Instead, the jet noise has very different characteristics from the previous ones; it is generated by the fluid flow through pre-existing breaches.

It is generally stationary and not impulsive; in the most intuitive sense, stationarity means that the statistical properties of a process generating a time series do not change over time.

Generally, the spectral coverage is in the very high frequency range (from tenths of Hz up to kHz). Due to frequency features, this is subjected to a strong attenuation and can be revealed by up to tenths of meters.

In section 6 we will talk about a real example which deals with the application of e-vpms® FD (Failure Detection); a proprietary technique able to reveal and localize a leakage in place by means of processing of the jet-noise. Finally, also the pump noise falls into the category or direct primary sources, but it not noteworthy because it is a regular noise produced by controlled operations.

As **indirect** interaction, we mean the acoustic transients produced by all sources of vibration outside the pipeline; impacts are mainly responsible for the transmission of elastic energy to the metallic shell. The elastic wave-field travelling into the solid is transmitted to the internal fluid undergoing an acoustic conversion.

Due to the nature of the impact itself, this kind of noise is impulsive and high-pass broadband with a spectral coverage of about 1000 Hz. The well-distinguished features, in terms of signal polarity, stationarity vs impulsivity and frequency bandwidth, lead to filling out a basic and robust system of classification suitable for AI (Artificial Intelligence) applications.

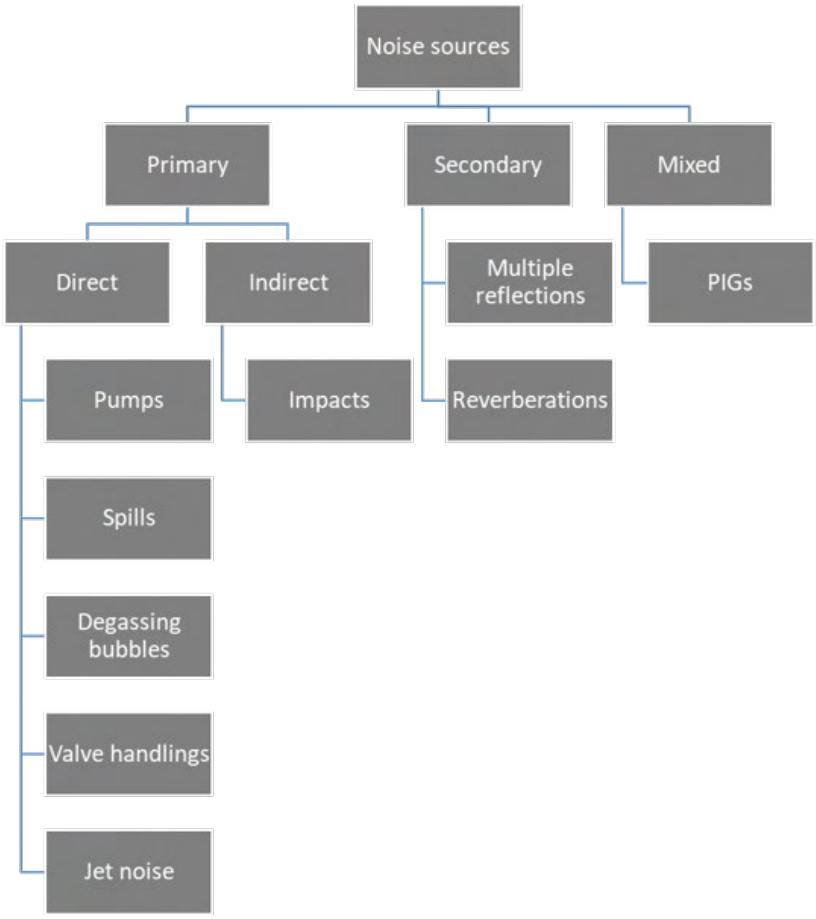


Figure 6: Classification of anomalous noise sources interacting with the fluid.

SECONDARY SOURCES

As secondary sources we mean all the signals produced by the interaction of a primary source or the pump noise itself with all the geometrical (or mechanical) anomalies of the duct.

Full obstructions, decreases/increases of the pipeline area, dents, bifurcations, illegal branches and narrow bends falls in the category of geometrical "anomalies".

From the acoustic point of view, each of these structural features acts like a full or partial reflector.

If excited by a primary source, each reflector becomes a new source of noise. This is what in optics is defined a ghost, namely the secondary replication of the primary source travelling in the opposite direction.

The ghost reflection interferes with the primary signals, and, if confined in the middle of two geometrical anomalies, bounces off the reflectors generating periodic interference patterns.

The magnitude and polarity of the reflections mainly depends on the area ratio and the involved material (i.e. the acoustic impedance contrasts). The acoustic impedance Z is defined as follows:

$$Z=\rho v$$

Where ρ is the density of the medium crossed by the acoustic wave, whereas v the speed of sound in the medium itself.

For the sake of simplicity, we introduce a simplified definition of the reflection coefficient R for normal incidence, not taking into account the thickness of involved materials:

$$R=(Z_2-Z_1)/(Z_2+Z_1)$$

Where Z_1 is the impedance of the medium in which the wave travels and Z_2 the impedance of the medium on which the wave incides.

According to the simple definition of R, it is clear that its magnitude and polarity depends on the absolute values and spatial sequence of impedances. This model is valid

for a change of material affecting the whole area of the pipeline, while in all intermediate cases the intensity of R is modulated by the ratio between areas.The ratio between areas r is trivially defined as follows:

r=(Area of reflector)/(Area of pipeline)

In order to clarify these concepts two classificators based on this principle are reported; the first (Table 1) describes the reflectors by design, the second (Table 2) the anomalous reflectors, that undermine the asset integrity. We assume that Z_1 is the impedance of the liquid inside the pipeline and the primary source originates in the liquid itself.
Table 2 is particularly worthy of interest because it involves anomalies which can undermine the pipeline integrity; corks reduce the flow rate and can produce dangerous

Type	Reflection	Area ratio	Impedance	Sign of *R*
Close valve	Full	$r = 0$	$Z_2 > Z_1$	+
Partially open valve	Partial	$0 > r > 1$	$Z_2 > Z_1$	+
Diameter decrease	Partial	$0 > r > 1$	$Z_2 > Z_1$	+
Diameter increase	Partial	$r > 1$	$Z_2 < Z_1$	-
Ideal bifurcation (from one way to two ways)	Partial	$r = 2$	$Z_2 < Z_1$	-
Narrow bend	Partial	$r = 1$	$Z_2 < Z_1$	+

Table 1: Classification of reflectors by design

Type	Reflection	Area ratio	Impedance	Sign of *R*
Paraffin or impurity corks, solid objects	Full/partial	$0 \geq r > 1$	$Z_2 > Z_1$	+
Already formed gas bubble	Full	$r = 0$	$Z_2 < Z_1$	-
Dent	Partial	$0 \geq r > 1$	$Z_2 > Z_1$	+
Existing branch for illegal spills	Partial	$0 > r > 1$	$Z_2 > Z_1$	+

Table 2: Classification of reflectors undermining the asset integrity

overpressures, the presence of gas bubbles accelerates the corrosion process, dents are possible source of corrosion or ruptures and existing branches for illegal spillage are not safe installations. The processing and interpretation of these secondary signals is quite complex because of the use of special processing techniques. Each new detected reflector should be considered as a very probable source of catastrophic event and managed as such.

MIXED SOURCES

For mixed sources we mean all the noise sources combining the joint effects of primary and secondary sources, such as a PIG (Pipeline Inspection Gauge) travelling into pipeline. In these cases, an analysis of simple pressure data is not enough to provide a correct interpretation of the recordings involved, but efficient and real-time algorithms are required because of the transience of the phenomenon [3], [4].

From the acoustic point of view, the PIG is a full obstruction, like a closed valve; it reflects the whole wave-field produced by the pumping process, but it moves generating characteristic sounds when impacts on the welds, or internal walls of the pipeline or on foreign objects. Moreover, it compresses the fluid forward generating positive pressure wave-field, while produces a negative field backward.

The PIG may appear as a complex acoustic phenomenon, but by means of suitable processing algorithms based on cross-correlation analysis, it can be remotely tracked and localized in real-time. In addition, a thorough investigation of all the sounds produced by internal impacts can highlight the presence of foreign objects, dents or too narrow bends [8], [11].

CASE HISTORY: JET ACOUSTIC NOISE (FAILURE DETECTION)

We describe in this section a case history of a smart application of the e-vpms®: the detection and localization of a pre-existing leaking hole in onshore pipeline due to corrosion phenomena (i.e. FD, Failure Detection). The application exploits the acoustic noise produced by the fluid jet noise when exiting out of the pipe by measuring and processing the acoustic pressure (see Fig.6). The failure interested a segment of a liquid-transporting pipeline was in upstream asset, North of Italy. The critical segment was delimited by two valves 220 m apart.

The Failure Detection campaign has been performed on the last quarter of 2019. The procedure was as follows:

- Two e-vpms measurement stations were installed at the two extremes of the pipe segment (Fig.7).
- The pipe segment was pressurized with nitrogen up to 10 bar.
- The valves were closed, and the pipe was left to spontaneously depressurize because of the leaking hole.
- The jet noise was measured by the e-vpms® sensors and used for localizing the leak.

The source of the jet noise, associated to the leakage, was localized by the e-vpms® system at about 70 m from the left end (figure 8). The pipeline asset manager therefore

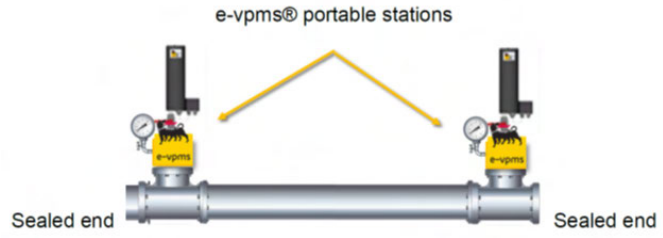


Figure 7: Layout of the Failure Detection e-vpms® installation on pipeline section.

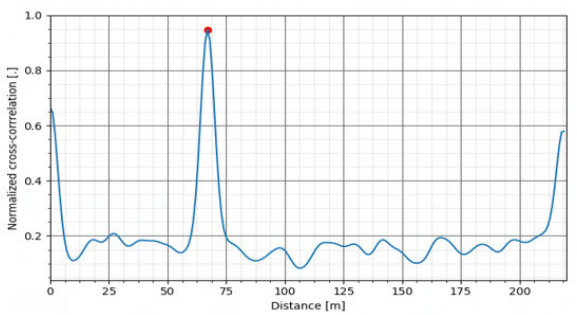


Figure 8: Cross-correlation of sensors data. The maximum at about 70m (red circle) identifies the position of the leak.

performed the excavation in the position pointed and the leaking hole was found during the excavation with very high precision (meters).

DISCUSSION AND CONCLUSIONS

In this work we have shown the e-vpms® capabilities of detection and classification, both human-assisted and automated, of a wide variety of phenomena besides pure leak. In particular, we have provided a simple system of anomalous event classification, based on robust features gathered from acoustic signals.

Our classificator divides the anomalous sources of noise into three main categories: primary, secondary and mixed. As primary sources we mean all the sources of acoustic noise produced by a direct or indirect interaction with the fluid. As secondary sources we intend the signals produced by the interaction of a primary source or the pump noise itself with all the geometrical (or mechanical) anomalies of the duct. As mixed we mean all the noise sources combining the joint effects of primary and secondary sources, such as a PIG (Pipeline Inspection Gauge) travelling into pipeline. Special attention is paid for all the anomalous source of noise which may be ascribable to dangerous scenarios or, however, situations undermining the asset integrity.

A successful case history is also described in order to present one of the possible smart application of the e-vpms® system: the detection and localization of a pre-existing leaking hole in pipeline (i.e.Failure Detection). The application exploits the acoustic noise produced by the fluid jet when exiting out of the pipe and is capable of providing a high accuracy localization of the leaking hole.

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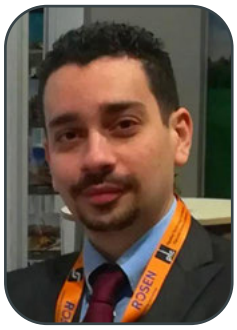

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References

1. Performance of European cross-country oil pipelines. Statistical summary of reported spillages in 2015 and since 1971 (2017), CONCAWE Report, Brussel, June 2017.
2. Dalmazzone, G. M., De Lorenzo, G., Giunta G., 2016, System and method for the continuous detection of impacts on pipelines for the transportation of fluids, particularly suitable for underwater pipelines, ENI S.p.A, Patent US9267648B2 (2016), EP2483656B1 (2017).
3. Giunta, G., Bernasconi, G., 2017a, Method and system for continuous remote monitoring of the integrity of pressurized pipelines and properties of the fluids transported, Patent EP2936106B1 (2017), US10401254B2 (2019).
4. Giunta, G., Bernasconi, G., 2017b, Method and system for the remote detection of the position of a pig device inside a pressurized pipeline, EP2935969B1 (2017), US9897243B2 (2018).
5. Giunta, G., Bernasconi, G., Del Giudice, S. 2017c, Method and system for the continuous remote tracking of a pig device and detection of anomalies inside a pressurized pipeline, EP2944857008B1 (2017), US10132823B2 (2018).
6. Giunta, G., Dionigi, F, Bassan, A., Veneziani, M., Bernasconi, G., Del Giudice, S., Rovetta, D., Schiavon, R., Zanon, F., (2011), Third party interference and leak detection on buried pipelines for reliable transportation of fluids, 10th OMC Conference and Exhibition, Ravenna, Italy.
7. Bernasconi, G., Del Giudice, S., Giunta, G., 2012, Pipeline Acoustic Monitoring, Pipeline Technology Conference 2012, Hannover, Germany.
8. Giunta, G., Bernasconi, G., Del Giudice, S., 2015, Pipeline Monitoring with Vibroacoustic Sensing, Materials Evaluation, Vol.73 (7), pp. 979-986.
9. Bernasconi, G., Del Giudice, S., Giunta G., Dionigi F. 2013, Advanced pipeline vibroacoustic monitoring. Pressure Vessels and Piping Division, ASME 2013, Paris; PVP2013-97281.
10. Giunta, G., Timossi P., Borghi G.P., Schiavon R., Bernasconi G., Chiappa F., 2015, Field development of Eni Vibroacoustic Pipeline Monitoring System (e-vpms™): Long term performance analysis, 13th OMC 2015 Conference and Exhibition, Ravenna, Italy.
11. Bernasconi, G., Giunta G., Chiappa F., 2015, Gas filled pipelines monitoring using multipoint vibroacoustic sensing, Proceedings of the ASME 2015 Ocean, Offshore and Arctic Engineering, St. John's, OMAE2015-41265.
12. Giunta, G., Morrea, S., Gabbassov, R., Bernasconi, G., S. Del Giudice, S., 2016, Performance of vibroacoustic technology for pipeline leak detection, Proc. ASME. 49965; Volume 5: Pipelines, Risers, and Subsea Systems, V005T04A029, OMAE2016-54181, doi: 10.1115/OMAE2016-54181
13. Giunta G. 2018, Vibroacoustic Technology for Pipeline Integrity Monitoring: Leak detection performances in relation to theft events, Copex 2018, CONCAWE, Antwerp, Belgium.
14. Marino M., Chiappa F., Giunta G. (2019) Anticipating bunkering events: notable cases evidence using Vibroacoustic Leak Detection Technology to detect precursors, 14th Pipeline Technology Conference, Berlin, Germany

EUROPEAN/AFRICAN INTERNATIONAL TRANSFER CENTRE FOR INFRASTRUCTURE DEVELOPMENT IN AFRICA (ITIDA) FOUNDED

THE CENTER AIMS TO TRANSFER TECHNOLOGY AND KNOW-HOW FROM EUROPEAN INSTITUTIONS TO AFRICA

The European governments are currently pushing their companies and institutions to increase their involvement in Africa. From the Governments point of view, Africa offers many business opportunities.

ITIDA is a major initiative that supports this development by enabling the systematic transfer of technology and know-how between Europe / the industrialized countries and Africa. It provides a framework that enables companies to apply their expertise, which is already renowned in most parts of the world, in Africa as well.

At the same time, it offers African authorities, state-owned enterprises and private companies access to important know-how and technologies from all over the world. In this way, the initiative should contribute to the improvement of the economic circumstances and thus to the overall situation.

The International Transfer Centre for Infrastructure Development in Africa (ITIDA) is operated by several institutions with a similar interest: to improve the infrastructure in Africa with the expertise of European companies. Originally, the initiative was created by two cooperating institutions:

The three institutions of ITIDA: The EITEP Institute, TEAM Academy & Hamburg Port Consulting (HPC)

The Euro Institute for Information and Technology Transfer in Environmental Protection, EITEP Institute is Europe's largest networker in terms of oil, gas and water pipelines. TEAM Academy (Training and Education in Africa and Middle East) is a group of German companies dealing with the construction, operation, maintenance and repair of water supply and sanitation infrastructure. Together they have already won another important partner for the initiative: Hamburg Port Consulting (HPC), which brings enormous expertise regarding worldwide port, logistics and transportation routes.

Together, these three institutions are currently preparing their first major project in Africa. It is an international conference& exhibition named Infrastructure Development in Africa (IDA). The event will take place in November 2020 in Tunis, Tunisia. It marks one of the highlights ITIDA has planned for 2020. Fixed topics during the event:

- Supply / Disposal Solutions for Water, Waste Water & Gas
- Production / Treatment Solutions for Water & Waste Water
- Transport and Logistic Solutions for Ports
- Pipeline Solutions for Oil, Gas, Petrochemicals and other Products

Furthermore, the organizers are eager to increase the scope of the first IDA. Partners are welcome for following areas: power supply regional and international; urban traffic development, cross-region road, rail and air transport; telecommunications.

ITIDA's administration and seminar building in Tunis

One of the topics of IDA: supply, disposal and treatment solutions for water and waste water (including training measures)

Logistics and transport services of ports are further focus of IDA

One of the topics is oil, gas and water pipelines

Although the Infrastructure Development in Africa (IDA) is without doubt an integral part of the ITIDA agenda, it is by far not the only attractive activity. The following additional steps are currently in planning, showing the full scope of this ambitious and promising project:

- Advisory services for cities and federal states, drawing on the expertise of German institutions
- Creation of international electronic journals and newsletters covering all aforementioned topics
- Establishing a job and trainee platform for access to the European and African job markets
- Train-the-Trainer-Activities
- Establishment of drinking- and waste water treatment plant neighborhoods
- Etc.

All ITIDA players have many years of experience in international economic cooperation. Success in this work also requires cooperation with other initiatives.

> *We seek coordination with the goals set by African institutions and initiatives*
> ***Dr. Klaus Ritter, President of EITEP***

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Advancements In Leak And Theft Detection Technologies

Harry Smith > Atmos International

Abstract

API 1175 discusses the requirements for continuous improvement in pipeline leak detection and the culture required for an effective leak detection program.

The most commonly used internal based methods for leak detection are flow balance, negative pressure wave and Real Time Transient Model (RTTM). Several papers have been written on each type of method with their advantages and disadvantages being heavily discussed. However, improvements made to improve sensitivity, leak location, response time and reliability to these methods have previously not been significant.

This paper will discuss the improvements that Atmos International (Atmos) has made in the last few years to tackle some of the challenges often associated with the negative pressure wave and flow balance methods. The paper will discuss the introduction of fast scanning to flow balance technology allowing for dramatic improvements to leak location and new filters to improve detection time. It will also highlight the introduction of inexpensive non-intrusive hardware to provide additional instrumentation on a pipeline to improve sensitivity and reliability on the negative pressure wave method. In addition, the paper will cover Rupture and Nano-wave modules to help detect all scenarios such as leaks, thefts and ruptures. Finally, it will summarise how information is presented within new graphical user interfaces (GUIs) including web GUI interfaces and mobile applications.

FLOW BALANCE TECHNOLOGY

Utilizing the flow readings on a pipeline is the most common method of pipeline leak detection being used for flow/mass balance, statistical leak detection (Atmos Pipe) and RTTM systems. These systems have several advantages from being able to detect leak sizes of 0.5-1% of the nominal flow, detecting both spontaneous and creeping leaks while maintaining a low false alarm rate. However, one of its biggest disadvantages has been poor leak location when detecting a leak. As most systems utilize the flow signal data from the SCADA systems, they are limited by the refresh rate of the data, subject to the best-case refresh of one second but it can be lower such as 2,5,10 seconds and in some cases even one minute.

This means that the best possible leak location accuracy of flow balance systems would have been +/-1km (based on a 1000m/s speed of sound). Atmos has seen this as an area of the technology that needed improvement, thus has developed an upgrade for its flow balance systems (Atmos Pipe and Atmos Wave Flow). The upgrade is known as "Fast Scanning". This upgrade utilizes modern hardware such as an AWAS unit (small compact RTU) that allows flow and pressure data to be acquired at 60Hz (60 samples a second). This data is then stored in a database. When a leak is detected by the system, that section of data is replayed at the higher acquisition rate, and an improved leak location is provided in real-time. The "Fast Scanning" upgrade has allowed Atmos to improve leak location accuracy from +/-1km to +/-150m.

As well as utilizing Atmos hardware Atmos can use OPC UA protocol to improve the acquisition of the data from the SCADA RTUs as well (this only currently works with certain models of RTUs).

RUPTURE MODULE

API 1175 discusses the requirement to continually review leak detection systems and identify gaps where improvements can be made. One improvement identified is understanding how leaks, ruptures and thefts often require different techniques and how to improve LDS systems to handle all these unique events. Atmos has implemented a rupture module into its flow balance systems.

The objective of this module is to reliably detect ruptures within the shortest time possible regardless of the pipeline conditions at the time of the event. When a rupture alarm occurs, the operator will have the confidence to shut the pipeline down immediately unlike a leak or theft where some initial investigation might take place first.

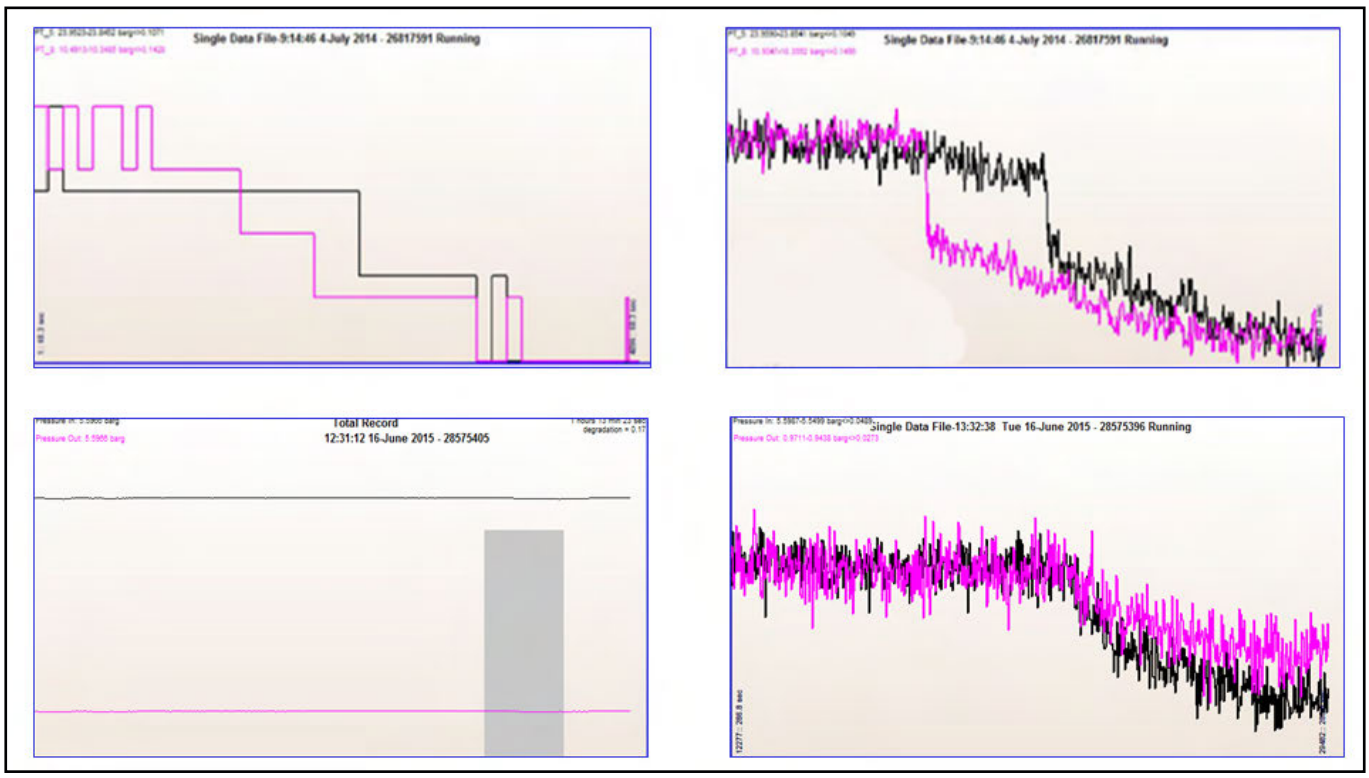

Figure 1: shows the advantage of higher acquisition data (60 Hz) compared to SCADA data (1 Hz)

The minimum rupture size detectable depends on the individual pipeline and operational factors such as:

- Fluid type eg highly volatile liquids operating at vapor pressure
- High pressure or gravity flow lines
- Steady or highly variable operations e.g. multiple transients because of rate or flow changes
- Single pipeline or complex distribution networks with multiple and variable flow configurations
- Liquid filled or slack conditions

This module combines four different detection methods to detect ruptures in all operational conditions.

- Low KL: Detects near pump stations where the product is easier to pump
- Inventory: Detects on pipelines that can go slack
- Dynamic Model Analysis (DMA): pattern recognition that can detect ruptures in all areas of a pipeline. Every data sample (flow, pressure, pump speed) is analyzed for the unique signature of a rupture.
- Pressure Difference Analysis (PDA): detects ruptures on all areas of the pipeline

NEGATIVE PRESSURE WAVE

Negative pressure wave has several advantages for leak detection including fast response time and accurate leak location. However, it has previously provided some challenges such as higher false alarm rates compared to flow balance systems and in some cases, can miss creeping or spontaneous leaks if the pressure drop isn't large enough, slack is present, or the pressure wave must travel a significant distance to be seen by a pressure sensor.

The solution to improving a negative pressure wave system has therefore been to focus on the ability to install additional pressure sensors along the pipeline, reducing the distance the negative pressure wave is required to travel. This has not always been possible due to the lack of available existing tapping locations and pipeline operators not wanting to modify the pipeline with additional tapping points.

To counter this, Atmos International has developed a non-intrusive technology called "Atmos Eclipse". Atmos Eclipse is a self-contained, non-intrusive instrument unit that acquires non-intrusive pressure, flow and temperature

Scenario	DMA	PDA	Inventory	Low KL
Rupture at the inlet, no trip, horizontal, well packed	✓	✓	✓	✓
Rupture at the inlet, trip, horizontal, well packed	✓	✓	×	✓
Rupture at the middle, no trip, horizontal, well packed	✓	✓	✓	×
Rupture at the outlet, no trip, horizontal, well packed	✓	✓	✓	×
Rupture at inlet, no trip, large elevation profile, well packed	✓	✓	✓	✓
Rupture at inlet, trip, large elevation profile, well packed	✓	✓	×	✓
Rupture at middle, no trip, large elevation profile, well packed	✓	✓	✓	×
Rupture at end, no trip, large elevation profile, well packed	✓	✓	✓	×
Rupture at inlet, no trip, large elevation profile, slack	×	×	✓	✓
Rupture at inlet, trip, large elevation profile, slack	×	×	×	✓
Rupture at middle, no trip, large elevation profile, slack	×	×	✓	×
Rupture at the end, no trip, large elevation profile, slack	×	×	✓	×
Horizontal, slack	×	×	✓	✓
Multiple slack start	×	×	✓	✓

Table I: shows the methods used to detect ruptures in different scenarios

data. All communication and data collection are completed within the unit meaning no cabinet space is required. The device is ATEX certified and can detect pressure changes down to 10-15mBar. The device can also be buried to a depth of 2 meters if required.

This unit allows instrumentation to be installed in locations that might have not been possible before which means pipeline distances between sensors can be reduced resulting in improved reliability, sensitivity, leak location and response time that a negative pressure wave system can provide.

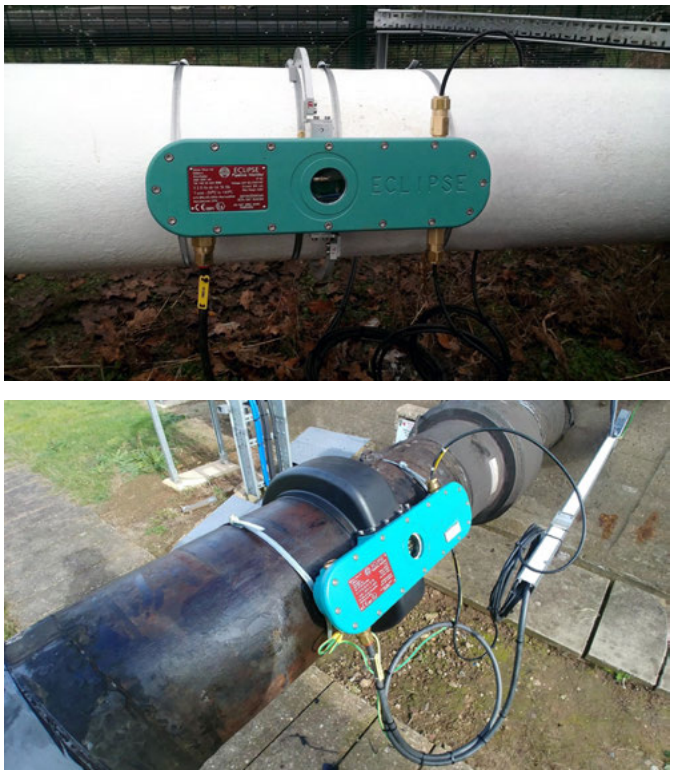

Figure 2: shows eclipse units installed on pipelines

As well as new hardware available to the negative pressure wave method, additional software modules have been developed to improve sensitivity during dynamic or steady-state conditions in the pipeline to help detect smaller leaks and slow opening theft events. This module is known as "Nanowave". The software module requires sensors to be distributed evenly along the pipeline; for example, for a 100km section they would be spaced every 20-30km, but the software module can be used on shorter sections of pipelines if there are four distributed sensors placed such as along a pipeline crossing rivers. The module and configuration can also be used to provide leak detection for multiphase pipelines. The Nanowave module has been designed to detect leaks that are less than 0.3% of the nominal flow.

The module utilizes cross checking of sensors with long filters to look for small changes of pressure associated with the presence of a leak or theft.

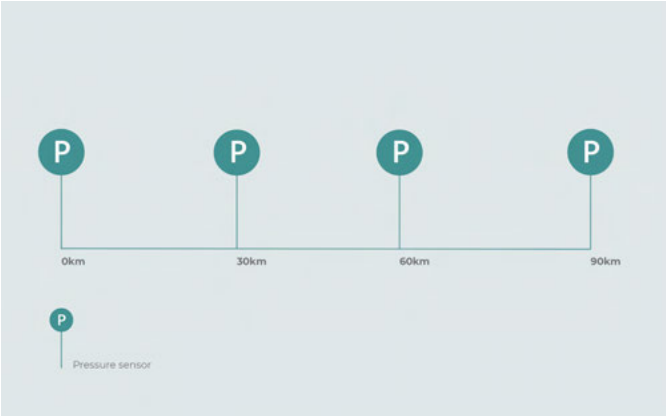

Figure 3: shows an example of the Nanowave configuration

Figure 4: shows a leak detected by the Nanowave configuration

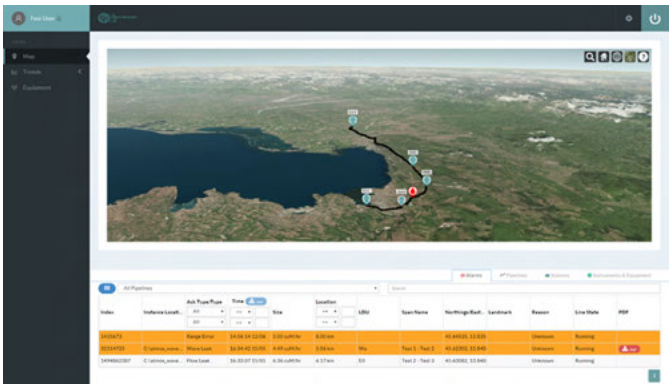

Figure 5: shows the Atmos Web GUI interface

GRAPHICAL USER INTERFACES

As well as improving the performance and reliability of leak detection systems it is important to improve how pipeline operators interact with the leak detection system. New improvements allow leak detection systems to be presented through the internet and provide multiple users with secure logins using VPN connections to increase cybersecurity standards and reduce the risk of cyber-attacks.

The use of web GUIs means that you can provide access to the leak detection system to more people than just the control room operators of the pipeline resulting in a lower chance of leak alarms being missed or ignored in some cases. Other improvements include email and SMS leak alarms.

CONCLUSIONS

As raised in API 1175, there needs to be a clear strategy in place from leak detection vendors (such as Atmos International) to continuously evaluate their technology to identify improvements in all aspects. This paper shows that Atmos has identified several key areas that required improvement and has provided clear solutions to these areas.

The ultimate goal of the pipeline industry is zero release of product, with the ability to continually identify gaps in the technology, process and procedure. This is an aim we can all work towards.

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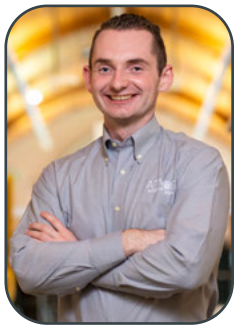

References

1. http://business.financialpost.com/news/energy/these-are-the-5-countries-most-plagued-by-oil-theft?__lsa=906f-a9b4
2. Peter Han and Mark Kim 2014: "Synergy in Leak Detection: Combining Leak Detection Technologies that use different Physical Principles", 10th International Pipeline Conference. Calgary, Alberta, Canada, 29th September to 3rd October 2014. Canada: IPC2014
3. Jun Zhang, Andy Hoffman, Adrian Kane, John Lewis 2014: "Development of Pipeline Leak Detection Technologies", 10th International Pipeline Conference. Calgary, Alberta, Canada, 29th September to 3rd October 2014. Canada: IPC2014
4. Jun Zhang, Andy Hoffman, Harry Smith 2019, "Improving Leak Detection System Performance with Non-Intrusive Sensors", 50th Pipeline Simulation Interest Group (PSIG), London, United Kingdom, 15-17th May 2019. UK PSIG2019
5. https://asgmt.com/wp-content/uploads/2016/02/004.pdf
6. Summary: API recommended practice 1175

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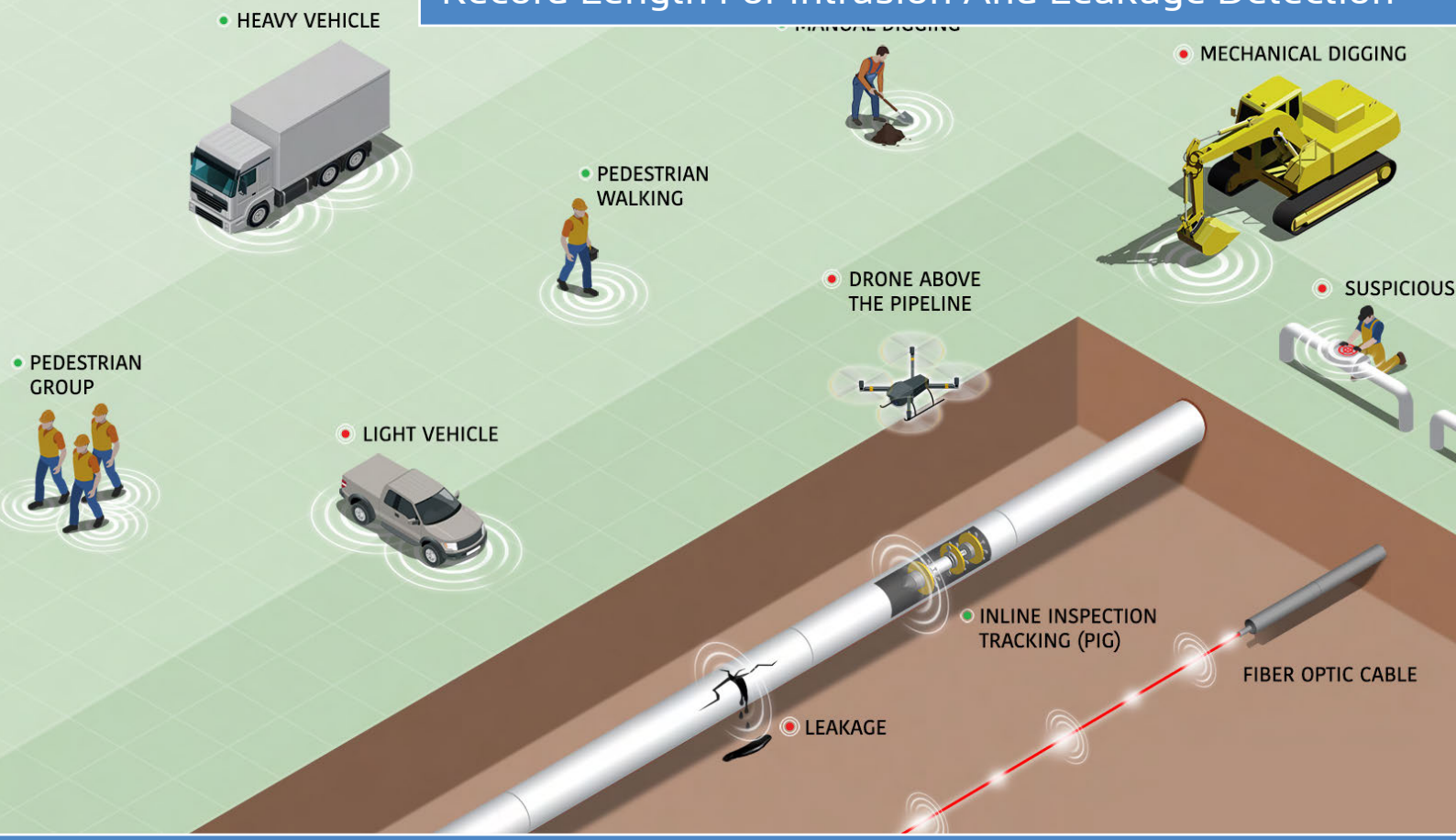
100km Pipeline Monitoring: Record Length For Intrusion And Leakage Detection



Dr. Eran Inbar, Dr. Eitan Rowen, Dr. Avi Motil > Prisma Photonics Ltd.

Abstract

We demonstrate a record length of distributed acoustic fiber sensing (DAS) for pipeline monitoring. Both intrusion (third party interference) and leakage can be detected. An ultra-sensitive architecture enables record length (100km for a single ended fiber sensing system or 200km for sensing from both ends) detection while advanced classification capabilities minimize both false and nuisance alarms. Targets are localized (high resolution of few meters) and classified.

While conventional DAS fiber sensing is limited to 20-50km, increasing the effective range to 100km can significantly decrease the number of systems and number of stations needed for long range pipeline monitoring.

INTRODUCTION

Fiber Sensing is an ideal solution for long infrastructure monitoring due to the following inherent advantage: "the fiber is the sensor", i.e. passive, highly reliable, very long lifetime, "zero maintenance" and very attractive cost structure (in $/km). A single Optical Interrogator (OI) unit can be used to monitor tens of kilometers of standard single mode fiber optic cable.

One of the prominent applications is oil & gas pipeline monitoring, and the two main use-cases are intrusion (third party interference) and leakage detection. The effective detection range in this application is 20-50km per OI unit. In this paper we will present our recent results, demonstrating effective and reliable detection at range of 100km. There are strong drivers and motivation to increase the OI detection range, for example:

- Reduced complexity for installation and maintenance: reducing the number of OI systems along a pipeline by a factor of 2-5 can significantly simplified both installation complexity, cost and maintenance.
- Improving cost structure: the user's cost calculation is based on $/km structure and not on the actual cost of the OI unit. Therefore, increasing detection range will decrease the number of OI systems and therefore it is one of the most effective approaches for an overall project cost reduction.
- Reducing False Alarm Rate (FAR): performance of existing DAS fiber-sensing technology at maximum range (the 20-50km range) is characterized by relatively high FAR. An architecture that can enable high-probability detection at very long range (100km vs 20-50km) can achieve a significantly higher signal to noise ratio (SNR) at the 20-50km range and therefore has the ability to achieve a substantially improved FAR.
- Reducing Nuisance Alarm Rate (NAR): in "real-life" application, one can find that the limiting factor in many cases, is not FAR but rather NAR (the limited ability to classify and differentiate between relevant target and irrelevant/unimportant target). A richer data (as described below in Section 2) is the basis for advanced classification, the foundation for NAR reduction.

In the following sections we will present our recent results of high-quality (high SNR) detection at record length of 100km.

PRISMA PHOTONICS EDGE

One of the limiting factors in DAS is a typically low SNR. The total number of photons transmitted into the fiber is determined by the product of the pulse duration by the pulse power. The pulse power is limited by non-linear phenomena that can distort the signal as it propagates along the fiber [1]. Increasing the pulse width lowers the system resolution, and typically chosen to be around 10m, corresponding to a pulse width of 100ns. The maximal pulse energy is then in the range of 80nJ. Together with the low Rayleigh backscatter coefficient of -60dB for pulse width of 100ns [2], and round trip fiber attenuation of at least 0.4 dB/km along tens of km, the Rayleigh back-scattered signal is typically so small, that it limits the ability to observe acoustic signals at a large distance (higher than 50km).

Prisma Photonics novel Hyper-Scan technology enables transmitting more light into the fiber, thus increasing the signal. We combine this with a novel amplification scheme, that amplifies both the transmitted pulse and the back-scattered signal along over 50km [3]. This amplification process takes place within the standard single-mode (SM) sensing fiber, without the need to install any amplifier, repeater to specialty fiber along the fiber itself. The only access to the fiber is at the fiber end where the system is coupled to the fiber. The amplification enables sensing range to be increased to 100km.

Moreover, our technology supplies the real-time analysis system a much larger and richer data set, enabling full reconstruction of the entire vibrational signal at every point along the detection fiber. This information is used not only to enable the detection of very weak vibrational signals, but also to classify them accurately, and reduce false alarms dramatically.

SENSING USING PRE-EXISTING OPTICAL CABLES

Many infrastructures have optical cables deployed alongside the infra-structure. It would be very beneficial to use these cables for fiber sensing. In such a case, turning the infrastructure into a monitored smart infrastructure could be done by installing fiber interrogators at the fiber ends without need for any additional sensor installation along the infrastructure.

However, there are a few challenges in this approach. The cables themselves may have been deployed with the intention of communication rather than fiber sensing and hence are not optimal for coupling to the vibrations. In addition, the cables are usually deployed in a conduit, which further suppresses the coupling. Attenuation of up to 20 dB have been measured when comparing communications cable deployed in a conduit to a designated fiber sensing cable [4]. In addition, the fiber-optic cable will not typically be buried in the best location for fiber sensing. It may be located up to a few meters away from the monitored infra-structure, reducing the signal even more.

Using both the Hyper-Scan technology and our Smart Amplification scheme, we overcome these challenges. The combination of the very high SNR, rich data, and novel classification algorithms enable us to detect and classify different events at distances of up to 100km, using a pre-existing optical cable in a conduit deployed along a pipeline.

MEDIUM RANGE SENSING DATA

In this section we will present real-life generated data gathered and processed in real-time along a pipeline infrastructure. The pipeline is buried at a depth of 1.5-2m, varying according to ground conditions. The sensing fiber is a standard SM fiber, originally deployed for the purpose of optical communication, buried in a plastic conduit at a distance of 1-2m from the pipeline. The data below shows a 9km section, out of the hundreds of kilometers of pipeline infrastructure.

The pipeline passes near roads, railways and settlements. The environment is thus noisy and includes many sources of different acoustic signals. Many of them are harmless events that do not require special attention, such as cars passing, humans walking, farm animals grazing and such. The high quality of the gathered data enables our advanced algorithms to detect and classify correctly all the targets in the vicinity of the pipeline, both the harmless background sources and sources that are threats to the pipeline, such as machine digging and even human digging with a hoe. Once all the targets are classified correctly, the system clears the nuisance alarm (harmless targets) and alerts the user only when a pre-defined target is detected. In our case, the pipeline crosses agricultural and rural areas. It is buried under and parallel to highways and train tracks. These busy areas are fruitful grounds to numerous different strong and weak background signals. If the classifying algorithm would not disregard them, the high nuisance alarm rate of the system would deem it useless.

The following figures show data examples recorded in real time by the system. In these graphs, the x-axis presents the location along the interrogated fiber and the y-axis presents the time. Figure 1 shows the trace of a car driving back and forth at a varying distance of 10-50m from the pipeline, around the 7th km of the fiber. One can also clearly see the acoustic noise (at 5.5km) generated by cars passing on a road that crosses the pipeline route.

Figure 2 below shows human digging activity, comprised of 20 hits to the ground with ah hoe at a distance of 10 m from the pipeline. In Figure 3 machine digging activity at the same location is presented, over a much longer time.

Figure 4 is a snapshot of the PrismaSense graphical user interface. The presented snapshot is of the machine digging of Figure 3. The detected and classified events are presented both on a map, and in a table, providing the user with additional detailed information about the event. According to user supplied rules, part of the events are classified as threats and appear in a table of alerts. An additional, optional table presents all the events, including both alerts and harmless events. Here, the system detected and classified two irrigation water pumps which are presented only in this table, as they pose no threat to the monitored pipeline, and only the digging is presented as a threat.

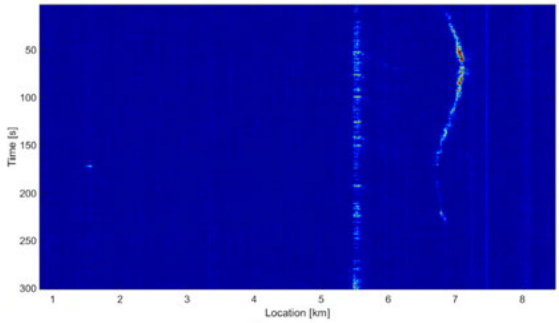


Figure 1: Vehicle trace at 7km

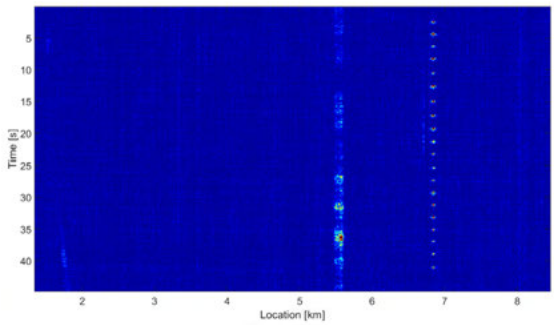


Figure 2: Human digging activity at 7km

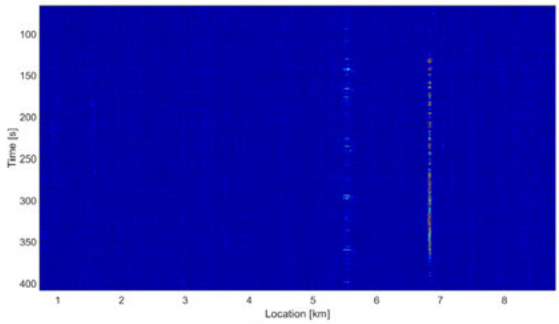


Figure 3: Machine digging activity at 7km

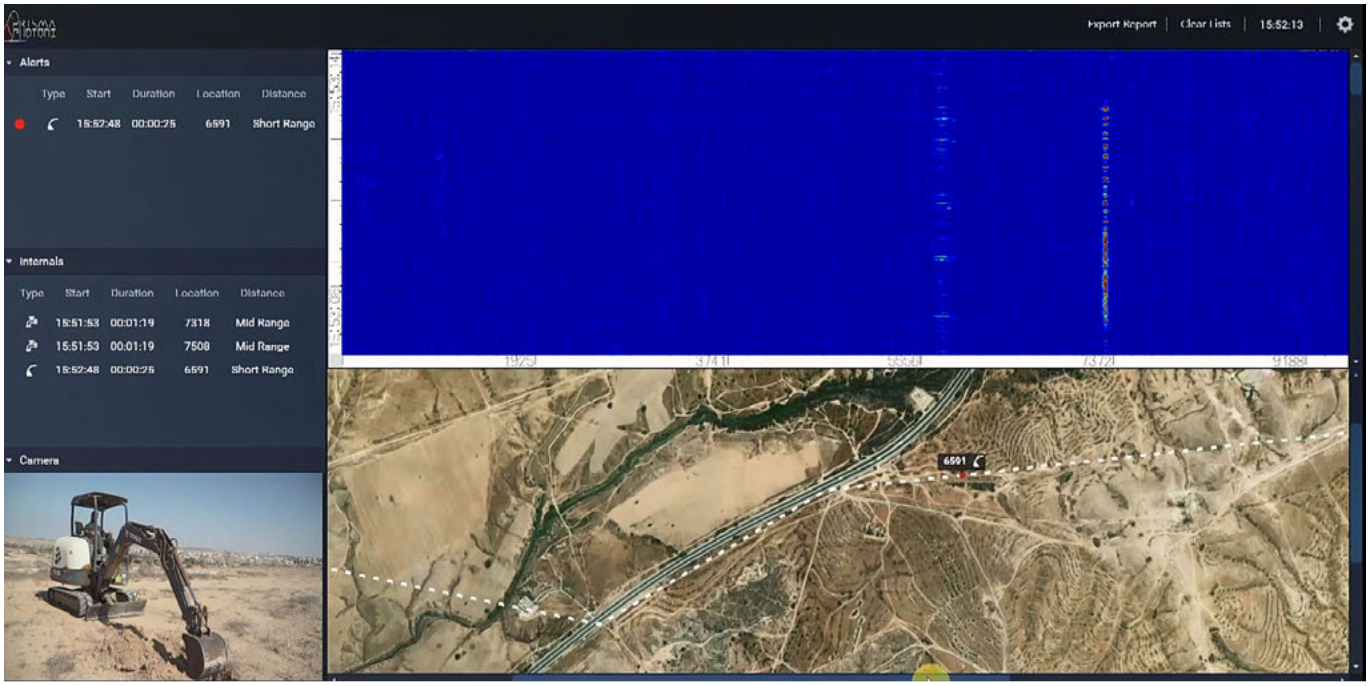


Figure 4: System user interface

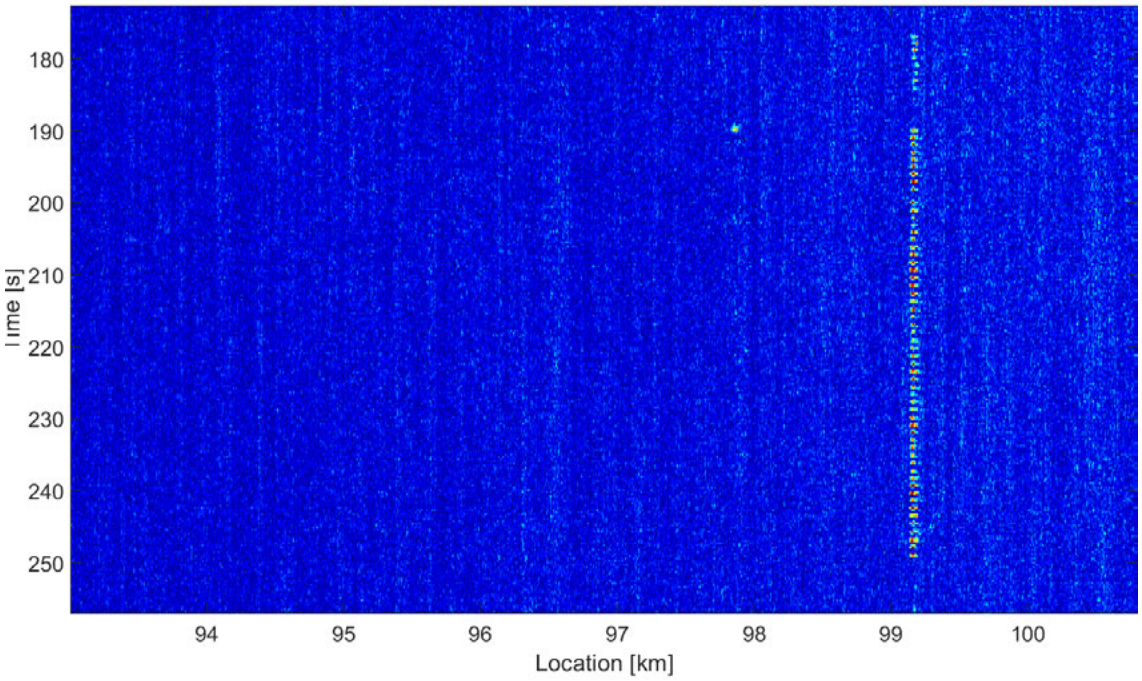


Figure 5: Human digging activity at 99km

EXTENDING THE SNSING RANGE TO 100KM

This section demonstrates the unique PrismaSense system capability of monitoring a record length of 100km, in a distributed manner, with a single interrogator. Figure 5 and Figure 6 show a closeup of a fiber section starting 93-94km away from the interrogator. As briefly described in Section 2, the combination of the unique Hyper-Scan technology and tailored Smart Amplification, improve SNR significantly, enabling us to extend the sensing range to 100km. The expected SNR degradation is apparent in the 100km data, remains sufficient for detection and classification of the events of interest, in this case, human and machine digging.

SUMMARY

We presented fiber-sensing DAS detection capabilities at record length of 100km. A high-quality (high SNR) data was achieved even for relatively weak targets (for example: human digging 10m away from the fiber). The testing scenario was even more challenging since all those measurements were taken using "pre-existing" optical communication fibers (fiber optic cables in conduit, which, based on [4], reflects additional 20dB of signal attenuation).

The high signal to noise ratio (SNR) and very rich data is the foundation for FAR (false alarm rate) and NAR (nuisance alarm rate) reduction and performance optimization.

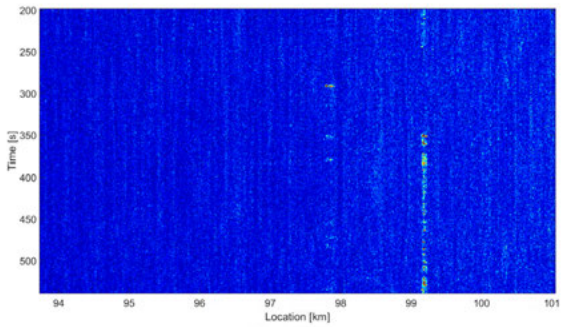


Figure 6: Machine digging activity at 99km

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References

1. G. P. Agrawal, Nonlinear Fiber Optics, Oxford: Academic Press, 2013 (fifth edition).
2. „Corning SMF-28 Ultra Optical Fiber Product Information," Nov 2014. [Online]. Available: https://www.corning.com/media/worldwide/coc/documents/Fiber/SMF-28%20Ultra.pdf. [Accessed 2020].
3. Rowen et al., „TAILOR DISTRIBUTED AMPLIFICATION FOR FIBER SENSING". Patent US 10451448 B2, 22 Oct 2019.
4. Riley S. Freeland et al., „Relative acoustic sensitivity of standard telecom and specialty optical fiber cables for distributed sensing," Fiber Optic Sensors and Applications XIV, vol. 10208, pp. 139-148, 2017

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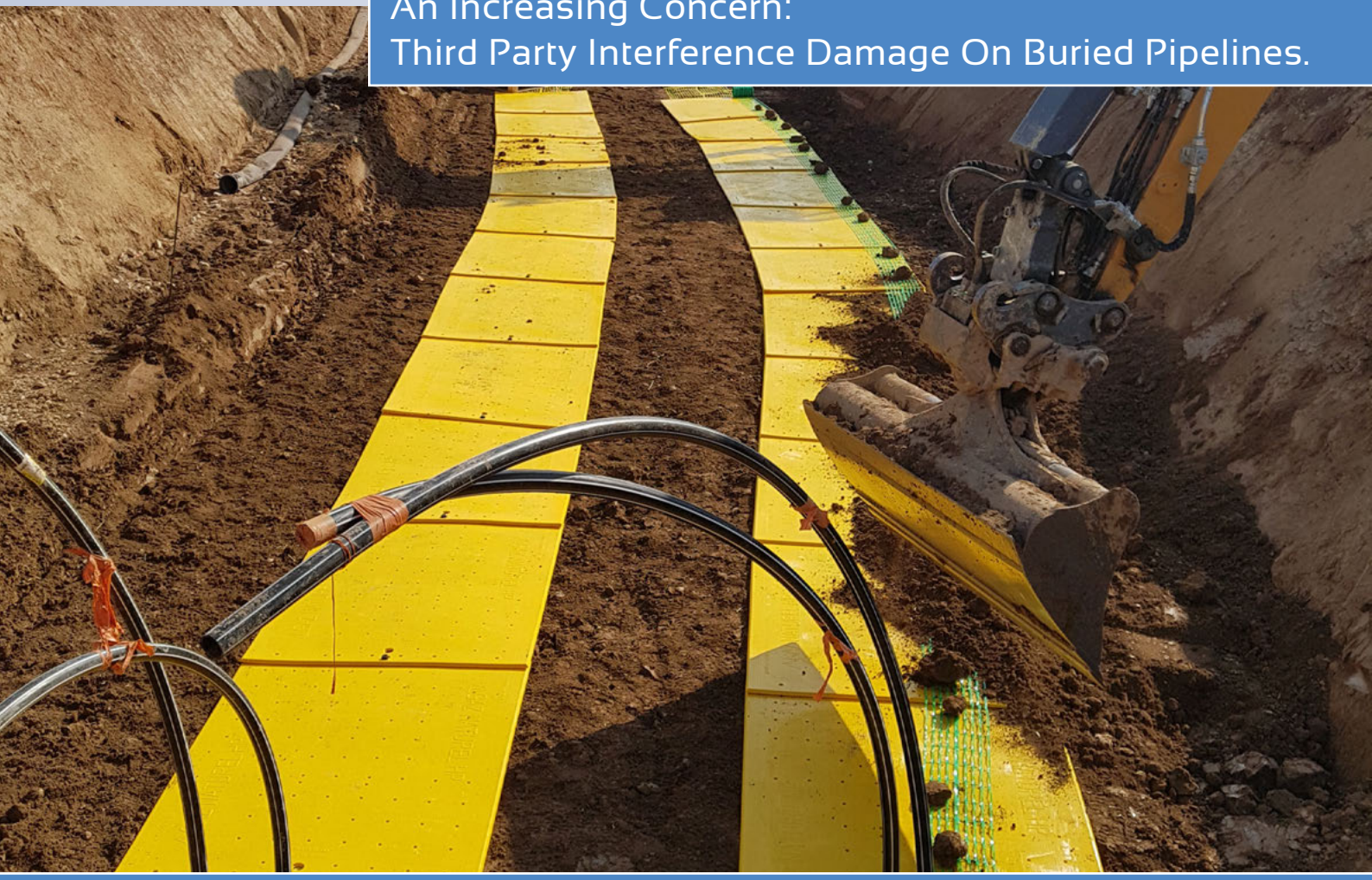
An Increasing Concern: Third Party Interference Damage On Buried Pipelines.



Yannick Joubeaux> OVERPIPE

Abstract

Encroachments on buried HP Gas pipelines represent 50% of accidents on pipelines world-wide.
The consequences for pipeline owners can be critical, resulting in fatalities and injuries, but also economic cost: shutdown of refineries, damage to the environment, increased compliance etc.
This is a huge issue for both types of pipelines:

- Older existing pipelines because of a change in class location and therefore need of compensatory measures.
- New projects, as it is not always possible to install them far from built up areas.

1. THE POSSIBLE SOLUTIONS

Solutions differ depending on the type of pipe:

- To protect existing lines, the only reliable solution for years was reinforced concrete slabs installed above the existing pipelines.
- For new projects, extra depth, thicker walls, detours of the pipeline, visible warning, may be used and even combined following the QRA results. Cost and maintenance needs will be key factors.

2. A CASE STUDY OF A CATASTROPHIC ACCIDENT IN EUROPE & THE CONSEQUENCES

- In 2009 the French Government, in response to an earlier 3rd party strike accident, required pipeline owners to conduct QRA on all their existing lines and to retro fit protection of several hundred kilometers of hazardous sections
- How the idea to use HDPE plates was formulated and validated
- HDPE versus concrete
- Issues with HDPE plates: slippery surface, continuity of the protection, consequences for CP testing
- Applications: when on existing lines and when on new projects?
- The risk reduction factor: the French example.
- Brief summary and reflection on HDPE plate use.

AN INCREASING AND WORLDWIDE CONCERN

For sure, 30 or 40 years ago, when this HP gas pipe was installed, it was in an empty land, with no specific safety issue. But today, close to various sections of this pipe, there are residential buildings, schools, shopping areas and factories.

Moreover, there is a plan to build a new mall at less than 1000 m from the gas line and it is just impossible to shut off the gas during the works. This is exactly the kind of concern that every gas company (or oil, chemicals, etc...) meets in any country. It is a worldwide issue.

Considerable progress has been made in recent years, especially regarding pipeline location accuracy (warning & GIS systems) and prior notification before starting any works (one Call, Dial Before You Dig).

However, third party interference – mainly excavation damage – is still the first cause of accidents on gas pipes. Data reinforces this is the case globally. Some examples:

- US Department of Transportation 2014 report establishes that during 1993-2012 there were 1630 incidents caused by third party damage on gas lines in the USA, with 141 deaths and 440 injuries.

Pipeline Type	Third-party Damage Incidents	Fatalities	Injuries	Property Damage
Gas Distribution	924	118	376	20
Gas Transmission	290	14	38	20
Gas Gathering	14	0	0	40
Hazardous Liquid	402	9	26	80
Total	1630	141	440	160

Table 1: Comparison of consequences of third-party excavation damage incidents over 20 years

- European Gas Pipeline Incident Data Group (EGIG) reports in 2015, 1309 incidents for the period 1970-2013 on 143 000 km of transportation lines, with 35% due to external interference

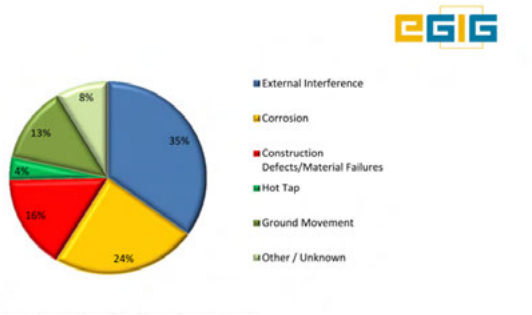


Figure 1: Distribution of incidents (2004-2013)

- In Japan, Keijo Gas Co 2009 reports 37.7% of incidents (2003-2007) due to third party construction.

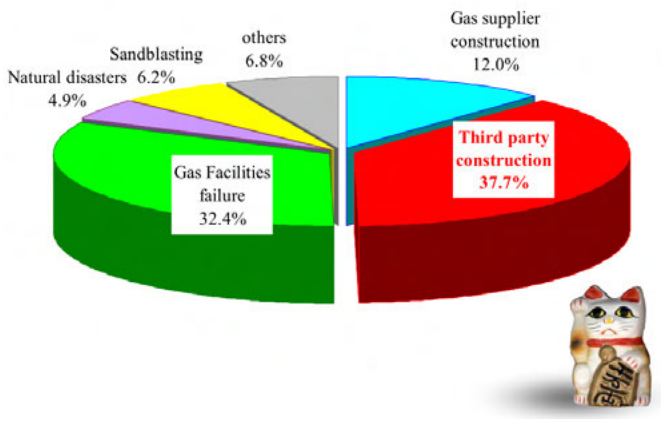


Figure 2: The status of occurence of accidents that the supply/distribution phase

Today, most end-users are conducting QRA studies to determine the sections of their pipelines impacted by this risk and to identify the appropriate solutions, for both new projects and existing lines.

POSSIBLE SOLUTIONS

Solutions exist to protect buried pipelines from third party interference.
These vary between new projects or existing pipelines.

- For new projects, this concern will be included in the design process and a wide range of solutions are available:
  - » Optimizing the pipeline route to avoid populated areas. However, it could be economically or technically impossible to make large detours.
  - » Warning devices, for example surface signage or sub surface warning tapes & meshes
  - » Increased pipe wall thickness to resist penetration or increasing the depth at which the pipeline is buried (both of which can have large cost implications)
  - » Installation of mechanical protection on some sections.

Figure 3: The Ghislenghien accident

- A different issue arises with the protection of existing pipelines. A change in class location or protection needs due to a new building project for example, limits the solutions for the pipeline owner. In these cases, installation of mechanical protection above the existing pipeline is the primary solution. This requires the re-opening of trenches, careful excavation above the pipe, installing the protection and backfilling. The main mechanical protection device until recently was to use reinforced concrete slabs, which are costly to install, inefficient as a warning device and cumbersome to deal with for future inspection or repair of the pipeline.

A CASE HISTORY: THE GHISLENGHIEN ACCIDENT AND ITS CONSEQUENCES IN FRANCE

2004, July 30th, 8.56 AM. (adapted from Wikipedia)
A few weeks before the date of the explosion, during the construction of a factory in the industrial park of Ghislenghien, (Belgium) an excavator hit a HP pipe of natural gas (maximal pressure 80 bars) belonging to the company Fluxys. It was neither noticed or reported.

On July 30th, following a normal increase of gas pressure in the pipe, the gas main ruptured and began to leak. As fire brigades arrived, responding to the leak, the main exploded. A column of flames, almost 100 meters high, rose into the sky. It was seen from more than 15 kilometers away. A section of the gas main, 11 meters long and weighing several tons, is thrown 200 meters.

Electric circuits in buildings located several hundred meters from the explosion, melted due to the intensity of the heat. This heat was felt within two kilometers of the site. Pieces of building were thrown up to six kilometers away. The noise of the explosion was heard by numerous witnesses up to the southeast of Brussels (50 km). The disaster caused 23 deaths and 132 injured. Some bodies were found up to 100 m from the explosion.

The shock at the magnitude of the disaster was felt not only in Belgium, but across Europe and in France in particular.

THE FRENCH REACTION TO GHISLENGHIEN

There are on the French territory 50,200 km of pipelines carrying hazardous products (36,500 km of which for HP gas transmission) with an average age of 26 years (2009).

After the Ghislenghien accident, the risks posed by the age of the network, growing urbanization encroaching on pipeline reserves and the lack of recent, reliable Quantitative Risk Assessment (QRA) were deemed as no longer acceptable.

The French government made an "order" (which does not require a parliamentary vote) published on 2006 August 4th. It is called "arrêté multifluides".

This order stated new rules for the design, construction and operation of transmission pipes. New values for danger thresholds and calculation of lethal effects were adopted, leading to important changes in class locations and protection measures. Regulations for prior notifications, declarations and authorizations were substantially reinforced. Generally speaking, all actions to be taken were aimed to enhance security of buried lines.

Regarding specifically the risk of third-party interference, this "order" led to several legally binding guides, established by a committee composed of all companies involved in transport of hazardous products by buried pipelines (called "GESIP). One of those guides sets the rules for QRA as follows:

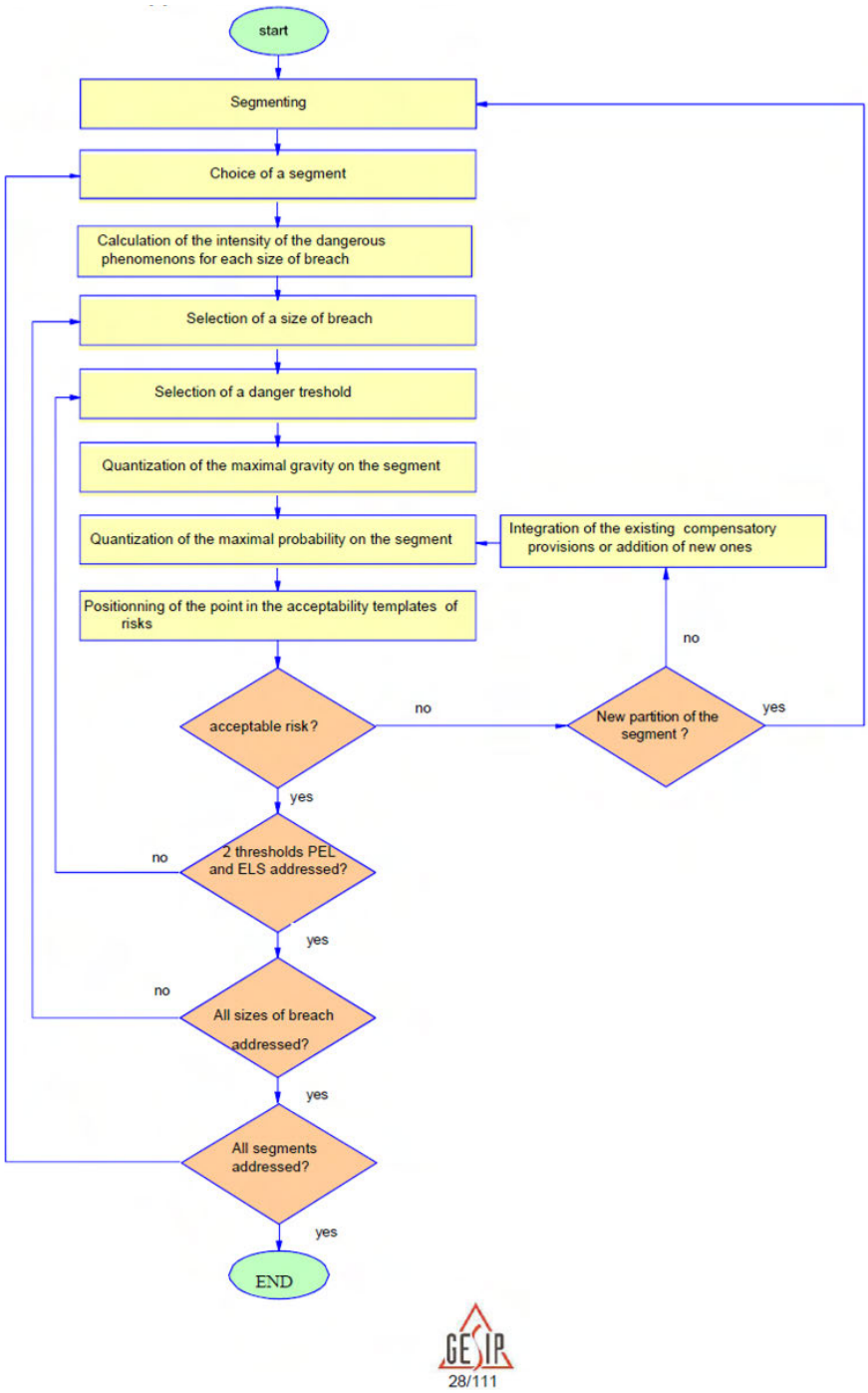


Figure 4: Quantitative risks assessments

These new obligations required the operators to dramatically change their practices to manage third-party damage prevention. Due to the level of measures to be implemented in such a short time frame, operators had to be innovative. Examples of this innovation were early use of drone surveying and the use of optical fibers for pipeline monitoring.

The" SIG" (geographic information system) was also strengthened, a system of ONE CALL was established (eg Dial Before You Dig) and training was made mandatory for excavator operators.

But the most substantial changes may have been the ones brought to mechanical protection, due to the challenging nature of the issue.

MECHANICAL PROTECTIONS: A PRESSING NEED FOR INNOVATION

When the studies were conducted, several hundred kilometers of existing transmission pipelines were revealed to need a mechanical protection to comply with the new security regulations. All to be completed by the end of 2012.

At the time the only possibility was to install reinforced concrete slabs above the pipelines. Although theoretically possible, this was practically inconceivable. Such works would need to manufacture and transport hundreds of km of concrete slabs and considerable resources (both personnel and equipment). As an example one full truck will transport about only 100 m of concrete protection slabs.

Pipeline owners, primarily Gaz de France (now named ENGIE), were also concerned with the practicality of removing concrete slabs in cases of inspection or repair.

The R&D Department of Gaz de France took the initiative to create a working group with the goal to suggest innovative solutions. As a regular contractor for GdF, Yannick Joubeaux was invited to join this group in 2005.

THE IDEA: REPLACE CONCRETE WITH PLASTIC!

The terms of reference for mechanical protection were to find an easier, lighter and cheaper solution to concrete. Yannick suggested designing a plastic plate to protect the pipes. Proposing to replace 150 mm of reinforced concrete by 15 mm of plastic was not at first regarded as the magic bullet.
However, after an extensive program of testing various raw materials and processes (with GdF its own tests in their laboratory), HDPE plates were recognised as a reliable solution. GdF R&D department reported the following at the IGRC conference in 2008:

Figure 5: Logo of the IGRC 2008

6. PE SLABS : A VERY EFFICIENT WAY TO PROTECT PIPELINES, WITH GREAT ADVANTAGES.

Polyethylene (PE) slabs have been felt as a good alternative to protect buried pipelines against earthmoving equipment. Compared to concrete slabs, PE slabs would offer some great advantages :

- A light solution : handling is much easier; there is no need for lift apparatus and installation is much faster,
- A thin solution : less cluttering in the ground,
- A warning solution : PE is more unusual in the ground than concrete, and it may be tinted yellow and printed ("high pressure gas" for example).

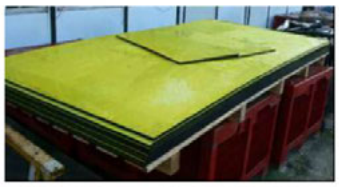


Figure 6 : Some of the tested PE slabs

Furthermore, operation of networks would become easier : this solution is easy to cut if we need an access to the pipeline.
PE slabs (from 10 mm to 20 mm thick) have been tested under controlled conditions : a 1 m high vertical bucket impact given by a 32 t mechanical excavator. Results show that PE slabs are at least as efficient as concrete slabs :

- depending of the sharpness of the teeth, from 1 to 10 knocks of bucket are necessary to go through the slab,
- the slab is not broken by the impacts : the teeth punch it... and are then blocked. When trying to remove its bucket, the operator generally also removes the slab (if not, the slab is still in place and keeps its mechanical barrier role).

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Figure 6: Extract IGRC report 2008

PE PLATES: YES BUT. . .

Of course, to deserve this recognition, the HDPE plates have to meet many specifications. Some of those were adopted into a GESIP report dedicated to safety compensatory measures on transmission lines , other added in the end-users standards. Hereunder the main requirements:

MECHANICAL RESISTANCE

Obviously the first target!
Despite shortcomings, concrete slabs do offer very high mechanical resistance to external impacts. They therefore set the standard for mechanical resistance. So any new solution would need to resist the assault by a shovel of a 32 tons excavator using its full power at 1M height.

Why excavators? Because they are used in 70% of the construction sites in urban zones and 80% in rural zones (IGRC report 2008).

Why 32 tons? Because more than 80% of the excavators used in urban sites have a mass lower than 32 tons...and 100% in urban zones. (IGRC report 2008)

What does "resist" mean in this context?

The goal is: the pipe protected by the plate MUST NOT BE HIT by the teeth of an excavator shovel, whatever its direction and power (up to 32 tons, which covers nearly all the uses). In order to guarantee this, it was specified that the plate should preserve its "integrity" after an assault. In this case, "integrity" means that the teeth of the bucket must not destroy the plate and moreover that there must not be any crack growth between the points of impact although the plate may be punctured by the teeth (depending on the kind of soil).

COLOUR IDENTIFICATION

Resisting an excavator assault is the main purpose of pipe protection. But the security will be much higher if any assault can be avoided. This goal requires an efficient warning that will stop the driver in his digging work.

One of the disadvantages of concrete slabs is that they have the colour of.... concrete. When installed in inhabited areas they can be easily mistaken for old buildings foundations. Trials conducted by Gaz de France with excavator's drivers showed that a majority did not understand that a pipe was under the slab when they hit it! They just wanted to remove it to go on with the digging and sometimes deployed their hydraulic hammer to break up the slab.

This is why a yellow full body coloured plate was proposed. When an operator sees not only one yellow plate but realizes that the plate encountered is connected with others to form a continuous yellow line – as the plates protect a significant part of the pipe – there is a very little chance that he doesn't imagine that all this has a meaning. Of course he will stop digging.

WARNING MESSAGE

In addition to the colour warning, a warning message was added – fully customizable – on the plate, such as "DANGER GAS PIPELINE BELOW".

The warning message is embossed during the production molding process. Printed messages will never have multiple decades life needed.

SECURITY OF WORKERS

Plastic plates are obviously slippery and therefore represent a danger for workers during installation. This is why end users such as ENGIE require a non-slip surface that can be achieved by pins pattern embossed during the molding process.

DURABILITY

HDPE which will last decades underground without significant degradation. A SABIC report (2008) on reliability of HDPE pipes in water distribution: 40-year-old pipes were tested and continued to perform well. Concrete slabs cannot offer any comparable guarantee as the concrete but also the reinforcing steel will be dramatically affected by the soil components.

CHEMICAL RESISTANCE

HDPE offers a very high and wide resistance to chemicals as stated in SABIC's report on chemical resistance of PE.

CP READINGS

Concrete slabs are indeed a very efficient screen above the pipe they protect which has a potentially harmful side-effect.The protection installed must allow water to go through. This is very important to avoid discrepancies in measurements of cathodic protection by maintaining a same resistivity above and under the plate.

This is why HDPE plates have drainage holes.

So, as not to compromise the structural integrity of the sheet, their number and surface must be limited: a ratio of 0.6% of the total surface has been decided by GRT Gaz, ENGIE's subsidiary for gas transmission. Holes drilled post production can weaken the sheet, therefore it is important to have them integrated in an injection molding process.

TRANSPORT/INSTALLATION

Use of plastic protection plates will eliminate the requirement for lifting gear and dramatically reduce transport costs. No more cranes and 30 sheets to a double pallet for transport. A full truck will allow to transport more than 800 m protection. The light weight also means the heaviest plastic plates are still only a two-man lift.

CONTINUOUS CONNECTION

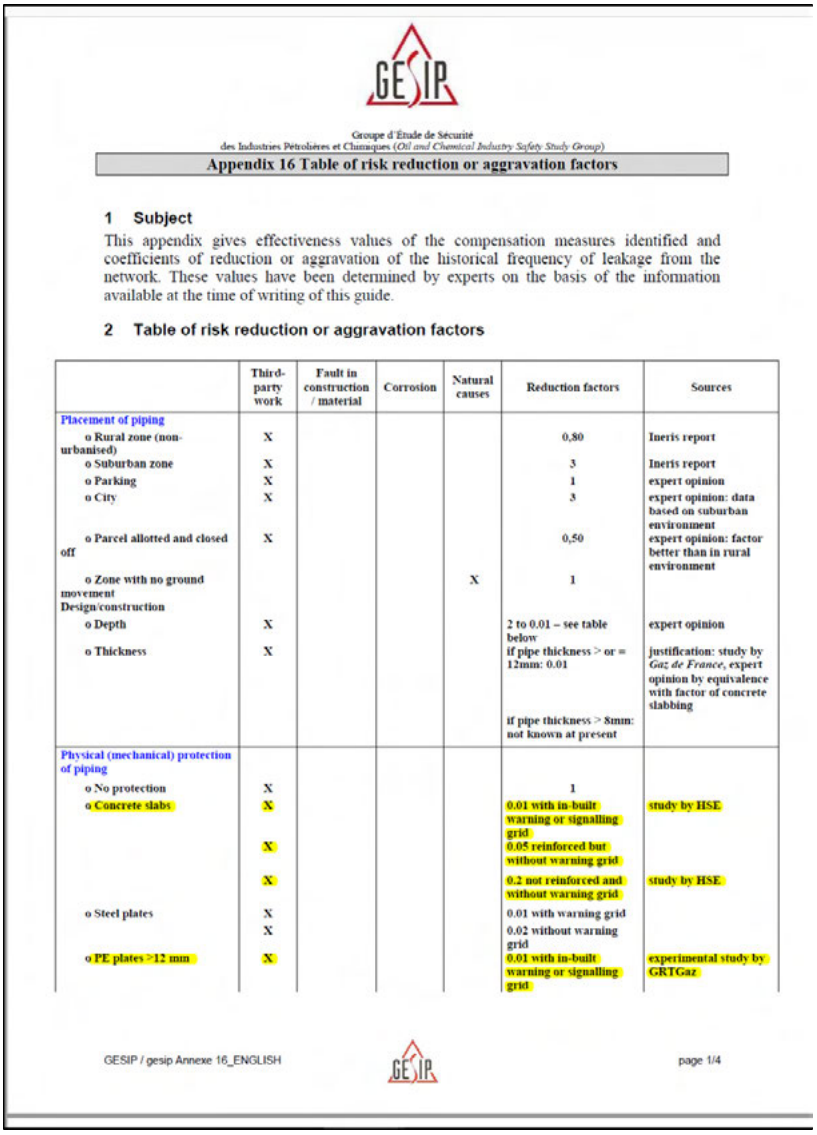
It was specified that the plates have a connection system. A removable clip was proposed, as easy to install as to remove for further inspection or repair. Other systems can be implemented to ensure an overlap between the plates or an end to end installation.

PRICING

At the draft stage it was pointed out that the economic record of the new products must be clearly competitive compared to concrete slabs. Considering costs of transport, machinery (as cranes) and manpower, this was probably the easiest goal to reach.

RISK REDUCTION FACTOR

Considering the order of 2006, it was decisive that the plates were granted with the same risk reduction coefficient as the concrete slabs. Based on the numerous tests made by GdF, the GESIP group adopted the following matrix: HDPE plates have the same reduction factor as concrete slabs, i.e.0.01. That means that the plate divides the risk of accident by 100.



GESIP

Groupe d'Étude de Sécurité
des Industries Pétrolières et Chimiques (*Oil and Chemical Industry Safety Study Group*)

Appendix 16 Table of risk reduction or aggravation factors

1 Subject

This appendix gives effectiveness values of the compensation measures identified and coefficients of reduction or aggravation of the historical frequency of leakage from the network. These values have been determined by experts on the basis of the information available at the time of writing of this guide.

2 Table of risk reduction or aggravation factors

	Third-party work	Fault in construction / material	Corrosion	Natural causes	Reduction factors	Sources
Placement of piping						
o Rural zone (non-urbanised)	X				0,80	Ineris report
o Suburban zone	X				3	Ineris report
o Parking	X				1	expert opinion
o City	X				3	expert opinion: data based on suburban environment
o Parcel allotted and closed off	X				0,50	expert opinion: factor better than in rural environment
o Zone with no ground movement				X	1	
Design/construction						
o Depth	X				2 to 0.01 – see table below	expert opinion
o Thickness	X				if pipe thickness > or = 12mm: 0.01 if pipe thickness > 8mm: not known at present	justification: study by *Gaz de France*, expert opinion by equivalence with factor of concrete slabbing
Physical (mechanical) protection of piping						
o No protection	X				1	
o Concrete slabs	X				0.01 with in-built warning or signalling grid	study by HSE
	X				0.05 reinforced but without warning grid	
	X				0.2 not reinforced and without warning grid	study by HSE
o Steel plates	X				0.01 with warning grid	
	X				0.02 without warning grid	
o PE plates >12 mm	X				0.01 with in-built warning or signalling grid	experimental study by GRTGaz

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Figure 7: Table of risk reduction or aggravation factors

CONCLUSION

The accident in Ghislenghein caused an unexpected awareness in France of the importance of 3rd party strike prevention and of the danger due to the urbanization close to pipelines. The subsequent actions taken by the authorities made it necessary to imagine new solutions.

Development and use of plastic mechanical protection for buried pipelines became one of these new solutions.

The same issues in other countries are leading to the same conclusions and since they are aware of this solution, HDPE plates are recognised in countries such as Saudi Arabia, Malaysia, Australia and New Zealand.

One can be sure that this kind of solution will spread worldwide as it presents many advantages for all stakeholder.

OVERPIPE

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References

1. US Department of Transportation (PHMSA): a study on the impact of excavation damage on pipeline safety
2. IGRC 2008: two mechanical protections for natural gas transmission pipelines
3. US Department of Transportation (PHMSA): final report on mechanical damage. M. Baker Jr INC (April 2009)
4. PENSPEN IPC2012: using quantitative risk assessment to justify location class changes
5. Gaz de France : transport de gaz naturel par canalisations : études de sécurité
6. Guide Professionnel GESIP 2008/02 ; édition de 2014
7. Guide Professionnel GESIP 2008/01 ; édition de 2014
8. American Society of Mechanical Engineers: an American standard: gas transmission and distribution piping system. ASME B31.8—2003
9. Health and Safety Executive: an assessment of measures for gas pipelines to mitigate against damage caused by third party activity (2001)
10. INERIS: control of major accident hazards involving land transmission pipelines
11. EGIG: 9th report of the European Gas pipeline Incident data Group (period 1970-2013)
12. Keijo Gas Co Ltd: condition of the gas pipeline damaged by third party constructions and prevention
13. Arrêté du 04/08/2006 portant règlement de la sécurité des canalisations de transport de gaz combustible, d'hydrocarbures liquides ou liquéfiés et de produits chimiques
14. CEFRACOR : évaluation d'impact des protections mécaniques des canalisations enterrées sur la protection cathodique

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The Integrated Solution of Distributed Acoustic Sensing, Fibre Optic Technology with Unmanned Aerial Vehicles (UAVs) For A Rapid Response To Protect Pipelines.

Stuart Large> Fotech Group Ltd.

Abstract

When a pipeline comes under threat from criminal intent on stealing product by hot-tapping, a rapid and precise response is required to prevent the crime before damage can be done that results in spillage and costly clean-up.

Distributed Acoustic Sensing (DAS), uses fibre optic cables which are already in place alongside most pipelines for communications, effectively converting the fibre in to thousands of sensors which detect vibrations from people walking or vehicles moving where they shouldn't, digging, tunnelling and other activities involved in the hot-tapping process. The technology has been proven through deployments on thousands of kilometres of pipelines all over the world.

DAS technology can detect a threat and raise an alarm within seconds, but it still takes time for a security team to drive to site and intervene, especially where distances are long, or terrain is challenging.

The rapid advancement of Unmanned Aerial Vehicles (UAV) or Drone technology introduces the new possibility of automatically launching a UAV which can fly along the pipeline to specific coordinates provided by DAS of where the threat is present. With the right strategy in place, the UAV will be able to reach any location along the pipeline in the required target response time and provide clear footage from visual and thermal cameras. It will also be possible for the UAV to make its presence known to the criminals with strong LED lights for night time operations and audio, so they know they have been detected and are deterred from continuing, thereby preventing a tap attempt that goes wrong and results in a spillage and costly clean-up.

The UAV also protects the law enforcement officers by giving them situational awareness, allowing them to assess the criminal's weapons capabilities, who might threaten their personal safety, before going to site in person.
This paper and presentation will describe how the technology can be deployed as one integrated solution.

INTRODUCTION

Distributed Acoustic Sensing (DAS) systems can be used to monitor pipelines hundreds of kilometres long, automatically recognising threats, usually within a matter of seconds and pinpointing the location of concern to within a few meters. The challenge for a pipeline operator is how to respond to a threat with the rapidity required to either catch criminals in the act or warn them off before they can do damage to the pipeline.

A typical hot-tapping attempt on a buried pipeline will start with the arrival of people on foot or by vehicle. They will then excavate soil, usually by hand, but sometimes by mechanical digging to reach down to the pipeline (Figure 1). Once the pipeline is exposed, a mechanical fitting can be attached, and the pipeline cut (Figure 2). The intention is then to bleed off product through a small secondary pipe a rate low enough not to be noticeable by leak detection systems on the pipeline.

The movement of vehicles or people walking around near the pipeline, the activities of digging in the ground by hand or machine, and fitting the hot-tap all generate noise and vibration in the ground. If a fibre optic cable is buried in the ground near the pipeline, a DAS system should be able to monitor and detect those events that are of concern and raise an alarm. The algorithms should also be smart enough to ignore those activities that are of no concern, thus reducing false alarms.

RESPONSE TIME AND PERSONNEL SAFETY.

DAS technology can alert a pipeline operator of a threat within a few seconds. The challenge for security personnel is how to respond. By their nature, pipelines cover long distances, often in sparsely populated and inhospitable terrain. They might pass through forest, desert, or icy tundra which are difficult for humans to travel across, so response by road or foot may take a few hours in some cases. Response by air will often be the fastest and most direct route to location. However, helicopters or planes are expensive to operate.

An Unmanned Aerial Vehicle (UAV) or Drone provides a good way to launch a fast response, fly a direct route from base to the threat location, capture visual and potentially thermal images of activity and let the criminals know that they have been detected.

Another concern for security teams is the threat to their physical safety. Criminals caught in the act might be expected to fight back, potentially with gunfire, and hence it would be preferably to assess the threat and perhaps make initial contact remotely, given it would be preferable to lose a UAV to gunfire rather than a human life.
An assessment needs to be made to consider what response time is required for any given location along the pipeline. Once criminals know they have been detected and are being observed, they will give up and leave the site. There is no point to continue the operation to hot-tap the pipeline, as they will know the tap would be immediately removed and no product could be extracted.

If criminals only manage to dig a hole in the ground above the pipeline but are deterred before they reach the pipeline and start to cut it then this is a success. The hole can simply be filled in. The danger occurs once cutting of the pipeline commences. One European pipeline operator Fotech spoke to has experienced two incidents in recent

Figure 1: Digging detected and stopped on a pipeline in India.

Figure 2: Hot-tap connected to a fuel pipeline in India.

years where hot-tapping attempts have been aborted after cutting the pipeline, either because the criminals have been frightened off or it has simply gone wrong and hence significant amounts of petroleum product have leaked from the pipeline over the following hours or days, causing environmental impact and costing millions of Euros to clean-up.

The required response time is an estimate based upon the following factors:

- Depth of burial of the pipeline – It takes longer to dig down to a deeper pipeline.
- Soil type – Some soils or sand can be excavated quickly; others take much longer.
- Location conditions – Perhaps dictating whether the excavation will have to be made by hand or if a machine could be bought to location.

The response time determines what UAV technology will be required, how many UAVs will be required, and where they will need to be placed. Key factors to consider in this calculation are:

- Launch time.
- Flying speed.
- Flight time / Range.
- Physical constraints on launch pad locations.
- Airspace restrictions.

In a typical project the maximum allowable response time might be calculated to be 45 minutes and hence with a UAV capable of launching in 1 or 2 minutes and flying at 20m/s (72km/hr), it could cover approximately 50km in the allowable time. This would dictate that one UAV could cover 100km of pipeline and hence for a long pipeline, the UAV stations should be located at 100km intervals.

If a faster response time is required, then UAV launch sites will need to be closer together.

DISTRIBUTED ACOUSTIC SENSING, DAS.

DAS works by effectively converting a fibre optic cable running alongside a pipeline into tens of thousands of individual highly-sensitive vibrational sensors. A DAS interrogator uses a laser to send thousands of pulses of light every second into the optical fibre deployed on or near the pipeline. A small amount of the light returns to the interrogator through the process of Rayleigh backscatter. Acoustic disturbance of the fibre causes disturbances in the backscatter of light. These perturbations are continuously monitored by the interrogator, and by analysing the characteristics of the changes in the backscatter, the DAS system can identify, locate and categorise the disturbance on the pipeline.

Powerful software tools interpret these disturbances – alerting operators to whether the threat might involve heavy machinery or large groups of people. This gives security operatives in the field much better information to make a decision on how they will respond. By providing information to such an incredible degree of accuracy, DAS enables operators to make quick, well-informed decisions and prevent criminal activity at the earliest stage.

Critically, DAS provides this level of insight and visibility across the entire length of the pipeline, and in real-time - something that is not possible with other technology systems available to operators.

Figure 3: LivePIPE module.

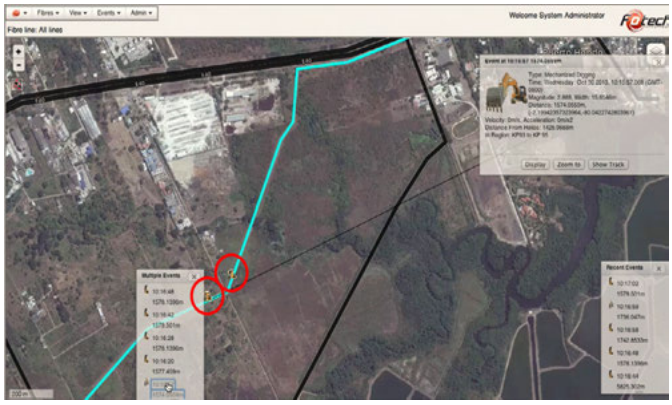

Figure 4: Two digging alarms, with locations highlighted on a map (Panoptes Alarm software, part of LivePIPE).

Fotech's Helios DAS systems are rack based, integrating a power supply, network connections, user interfaces and the Panoptes alarm server to make LivePIPE (Figure 3).

Each length of monitored fibre cable can be up to 50km long, so a two-channel system can monitor up to 100km of pipeline from one location. Multiple LivePIPE systems can be networked together to monitor the entire pipeline, which could be several hundreds of kilometres long.

REAL WORLD RESULTS FROM DAS

Fotech LivePIPE systems installed in India and South America, where hot-tapping is commonplace have shown how effective DAS can be in protecting critical pipeline infrastructure against criminal thefts. On one 72km long pipeline in India, during a six-month period, twenty-six separate hot-tapping incidents were detected.

The majority of these tapping attempts were prevented before the potential thieves could reach the pipeline, as digging in the proximity of the pipeline was detected and an alarm was raised, providing timely, actionable information for the operators to direct their security responses to maximum effect.

This particular operator employs several line-walkers and as the pipeline is relatively short a response could be made in short enough time to deny the criminals the chance to fit a tap on the pipeline.

In one particularly sophisticated attempt to steal product, a tunnel was dug from a building about 20m from a buried pipeline.

Two monitoring technologies were combined, Fotech's LivePIPE technology identifying tunnellers digging and then operating the valve of their bleed-off pipeline, and a Mass-Balance system detecting loss of product. The information from both collectively confirming criminal activity.

The LivePIPE system identified and located sporadic and often quiet activity associated with tunnelling over several nights. The Mass Balance sensing technology subsequently recognised a loss of product and located the area of loss to a region of 500m. However only by cross-refencing this with the LivePIPE data were operators able to reduce the search area to a region of 10m – The same 10m stretch in which LivePIPE had previously identified digging activity.

UNMANNED AERIAL VEHICLES (UAVS) OR DRONES

The technology in this sector is developing at a fast pace. Once the domain of the military, there is now a wide range of technology available to industry and the hobbyist, and costs have fallen to make the technology viable for many applications.

Developments have occurred and continue to occur in several sectors which have enabled the rapid rise in capability of the UAV and it is now ready for deployment along pipelines.

DEVELOPMENTS

FUEL

Mobile device technology has driven vast improvements in battery capacity. We also have small, lightweight electric motors and petrol engines, or even a hydrogen fuel cell which converts hydrogen fuel into electricity. Hybrid UAVs now exist which can combine a petrol engine for long range flight with electrical systems for vertical take-off and landing or emergency landing in case of primary engine failure. Hydrogen fuel cells can generate more electricity during flight to replenish a battery that would otherwise run out in a few minutes. Moreover, the experience gained from manned aviation allows commercial UAV manufacturers to propose systems compliant with EASA safety regulation, propelled by turbines, ensuring an easy maintenance and smooth operation, using heavy Fuel JP5 (F-44), JP8 (F-34), and also Jet A-1 fuel. These inherited improvements are also taken into consideration in the design of the fuel tank, adapted to withstand the most critical missions.

MATERIALS

Advancements in materials, 3D printing and design have enabled the creation of light airframes and components, reducing fuel consumption and allowing longer flight time. This has an impact on the after sales and maintenances procedures, where level 1 & 2 maintenance operations can be carried out by the end users, including 3D printing and mounting of spare parts, reducing the maintenance time and allowing them to operate even in remote areas.

PAYLOAD

We have increasingly powerful cameras installed in our mobile phones and see improvements in the software that stabilises the videos captured by sports action cameras. These developments mean that UAVs can carry cameras that provide high-resolution images and video from a lightweight device carried below the airframe. The advancements in machine learning, computer vision and onboard image processing enable the UAV to detect autonomously any graphic element of deviation from a given situation, like the presence of people or vehicles. This ability can be extended to a wide range of other payloads and sensors, like OGI (Optical Gaz Inspection) cameras, thermal

and infrared sensors, magnetometers, radars etc. also in scenarios where the UAV plays a proactive dissuasion & inspection role.

The response to detections provides a real time situation awareness and live video stream, triggers an email or SMS alert if justified, and allows wider reporting and analytics about a particular element of interest occurring on the infrastructure itself or at a certain distance from it.

High power LED lights, carried by the UAV, can be used to light up the location and it's even possible to carry a microphone and loudspeaker from which a security officer can communicate both ways with criminals and make it clear they have been discovered, inform them they are being filmed and warn them off or hear their response if they claim to have a good reason to be there.

COMMUNICATIONS

There are two aspects to communication with a UAV. First is the ability to maintain control of the UAV and fly it safely to its destination. Second is the provision of an additional video and data feed from the payload (thermal camera or other sensor), so that a threat can be assessed. These communications have improved dramatically in recent times to the extent that it is now possible for a UAV to fly on autopilot and be monitored by an operator in a control room on the other side of the world. Also, the autopilot will be able as standard feature to mitigate any loss of communications and respond to it with the appropriate safety procedure. Moreover, UAV manufacturers are most often flexible and familiar with a wide range of communication & data links, hardware manufacturers, to easily integrate in the ecosystem of the end user, and even combine different protocols to allow maximum redundancy when needed for critical missions (e.g. radio frequency & LTE, satellite & radiofrequency etc.)

REGULATIONS

The rapid rise of this technology has been met with varying responses from different nations. The UK for example, recently suffered high profile problems with UAVs apparently sighted close to Gatwick Airport. They are of obvious concern to air traffic controllers. However, the overall sentiment is that this technology is gaining acceptance and the regulators are working to enable the deployment of this technology. Major players such as Amazon wish to drive the market for parcel delivery and emergency responders recognise the capability of a UAV to provide an overhead view of a location, and faster response time. The key step is having the ability to fly the UAV beyond the visual line of sight, thus allowing long-range and automated flight, without compromises on the safety.

The technology in the UAVs can also help, as for example even some of the moderately priced hobbyist UAVs have sensors that allow obstacle avoidance and can fly back home by themselves if communication fails, or in the more professional systems, advanced inertial sensors for navigation of the aircraft, allow it to eventually withstand electromagnetic interferences.

INTEGRATION WITH DAS TECHNOLOGY

The LivePIPE DAS system notifies the UAV flight management system where the threat has been detected by providing GPS coordinates in a message. The flight management system automatically determines the flight path, taking into consideration the topology and obstacles to reach the target, the endurance of the battery and eventually the actual weather conditions.

The lid of the storage box in which the UAV is kept on standby automatically opens to let the UAV out. The UAV takes off by itself and flies to the designated coordinates.

The flight is monitored from an operations room either at the pipeline operator security centre, or at the UAV service provider. The flight of the UAV is monitored and the operator (pilot) notifies Air-Traffic control of the flight path. They will also be able to take over the control of the UAV when it gets to the threat location, or in the unlikely event of a failure of the flight management system.

At the end of the mission the UAV will return to its base and land. All flight hours of the UAV are automatically logged in, and update the integrated maintenance software, to always have a real time status of the UAV, in the different types of flight conditions (salty air, dust & sand, rain etc.) to plan maintenance accordingly and extend the lifetime of the system.

UAV SPECIFICATIONS FOR PIPELINES

For most pipeline projects, but also in general, the best choice of UAV will be a system that can withstand the harshest weather conditions, offer the most flexibility in flight (ability to hover on the spot), keeping a fast speed of operation and a Vertical Take-Off and Landing (VTOL) capability for ease of deployment. With this in mind a helicopter design is the best fit and can offer this type of performance, as it has already been widely adopted in other contexts for critical missions, like the maritime environment for example. Compared to a VTOL fixed wing, which is more vulnerable to wind gusts in take-off and landing phases due to its wingspan, the helicopter performs better in higher wind conditions, as it can always orient is tail accordingly, and keep its trajectory and flight steady. Also, VTOL systems are less agile in hovering flight mode, and usually operate optimally only above a certain altitude. The

Figure 5: FLYING CAM Discovery: Advanced ultra-long-range security & surveillance unmanned aircraft system.

Figure 6: FLYING CAM Discovery: Advanced ultra-long-range security & surveillance unmanned aircraft system.

higher number of engines and type of propulsion of VTOL fixed wings, make the maintenance process more complex, compared to a JET-A fuel propelled turbine, like the FLYING CAM Discovery system (Figures 5 & 6).

The FLYING CAM Discovery advanced ultra-long-range security & surveillance unmanned aircraft system integrates a wide variety of ISR payloads, like the Wescam MX-8 EO/IR dual sensor gimbal system, ideally suited for security and surveillance applications, day or night. Featuring smart object and scene tracking, thermal imaging, video recording, GPS guided gimbal control, range finder, target GPS location and more.

Smaller or larger FLYING CAM UAVs configuration with shorter or longer range and lighter or heavier payload capabilities are also available, meaning that the right UAV can be selected for any given project for a manageable budget.

The latest UAVs can provide the following autonomous flight modes:

AUTO TAKE-OFF AND LANDING

Allowing for fully autonomous VTOL take-off and landing. This mode can be activated remotely and does not require any pilot intervention. The Landing mode is supported by a laser guided system or sonar beamers, for an accurate and precise landing, even in difficult conditions.

PAYLOAD TRIGGERING

Auto trigger payload once or multiple times using Geo Reference (Coordinates), Time or Distance Intervals, so the video or sensor is active at the right time. An override for manual triggering is also available.

GUIDED MODE

Point and click autonomous mission flight mode. Aircraft will fly to and loiter (circle) at the selected location and altitude. This could be coordinates provided by the DAS system.

LOITER

Circle around the point to which the UAV has been directed by the DAS system, or manually holding altitude for efficient flight.

RETURN TO LAUNCH (RTL)

Aircraft will return to the home (take-off) position in Cruise mode until it is within the RTL radius, after which it will transition to Landing mode and land.

OBJECT TRACKING

Initially the UAV will fly to coordinates provided by the DAS system, but if upon arrival, people or vehicles are identified with the visual, or thermal camera, technology now exists so that the UAV can keep a lock on a object and alter it's flight path to continue to track the objects if it starts to move. This could allow later identification of criminals if security teams arrive on site later on.

ADAPTIVE SPEED TRACKING

The UAV will adapt its speed to the one of the tracked object, and keep a steady, dynamic and parallel trajectory, at the desired height.

AUTO-MISSION

This flight mode is indicated for autonomous pre-planned mission, and have the possibility to be 3-dimensional, also to perform inspection of complex structures.

STANDBY, LAUNCH AND SERVICE

An industrial UAV requires service after each flight. A battery will be used to allow the UAV to remain on standby for a long period of time and of course the JET-A fuel or other similar source of energy would not be depleted until consumed in flight.

To withstand the weather or the effects of UV from the sun, the UAV should be kept in a storage box, but this will be designed to open automatically from a remote command, so the UAV can take-off vertically.

UAV launch sites will be only a little larger than the dimensions of the UAV itself, so the roof of a pump station or control room will be ideal, but also a mobile vehicle with an adapted container could be used. DAS can even be used to set up a perimeter around the UAV, so that if somebody tries to approach the UAV itself, it could be commanded to take off and keep out of reach.

LEAK DETECTION

In recent years, DAS technology has also proven itself as a technology that is very sensitive and quick to detect leaks from pipelines. Where RTTM, or Mass Balance systems might require a few hours to detect a leak, DAS can reduce this to one or two minutes. This is valuable time that gives opportunity to respond quickly and reduce the size and therefore impact of the leak.

It may not be desirable to shut down a pipeline immediately, based only on an alarm from the DAS system, in case it is a false alarm, so a UAV could be dispatched to view the area and provide video of the ground conditions, looking for signs of the leak. In the future, it may also be possible for a UAV to carry out some form of spill kit, such as an absorbent, which could help contain the extent of the spill.

A UAV could also be used to support a response team after they arrive on location. For example, if the team is trying to urgently stop a flowing leak and needs a part, or tool from base, it could be rapidly dispatched, carried as a payload by the UAV.

ECONOMICS

The cost of installing a DAS and UAV monitoring and response system is a fraction of what it typically costs an operator to clean up a spillage and hence the expenditure is justified by the prevention of spills caused by failed hot-taps or allowing the earliest possible response to a leak caused by other means, such as geotechnical activity, or corrosion.

The cost to maintain a LivePIPE DAS system is low. There are costs involved in operating and maintaining the UAV system, but savings will be made elsewhere by using security assets more wisely, for example there will be fewer needless car journeys to site.

UAV flight is low-cost and so the operator may also wish to establish a program of missions, additional to those prompted by a DAS alarm, to carry out further surveillance or inspection of the pipeline route and infrastructure, or simply to act as a deterrent to prevent criminal activity in the first place.

The safety of security personnel is also an important consideration. By making fewer journeys, personnel would face less risk of road accidents and would be less likely to face criminals who might do them harm. Even if a criminal did need to be confronted, the UAV would provide evidence of how many people are present and what weaponry they might possess, so the security team could be adequately prepared and could approach with the right level of caution.

CONCLUSION

All the technology now exists to build an integrated detection and response system to prevent illegal hot-tapping of pipelines and respond quickly to leaks, thus preventing environmental disasters and saving huge amounts of money required for clean-up, or stopping reputational damage.

Distributed Acoustic Sensing technology can use a fibre optic sensing cable to recognise the vibrations and acoustic signatures generated by activities that represent a threat to the pipeline and can raise an alarm. The integrated UAV system can take the information in an alarm, program it directly into the flight management application and dispatch a UAV carrying cameras and other payloads to respond in the shortest possible time and warn-off criminals.

ACKNOWLEDGEMENTS

Thank you to Cybrid Thrust & Flying Cam, Belgium for technical insights into the integration of UAV technology for the providing information and photographs of their UAVs.

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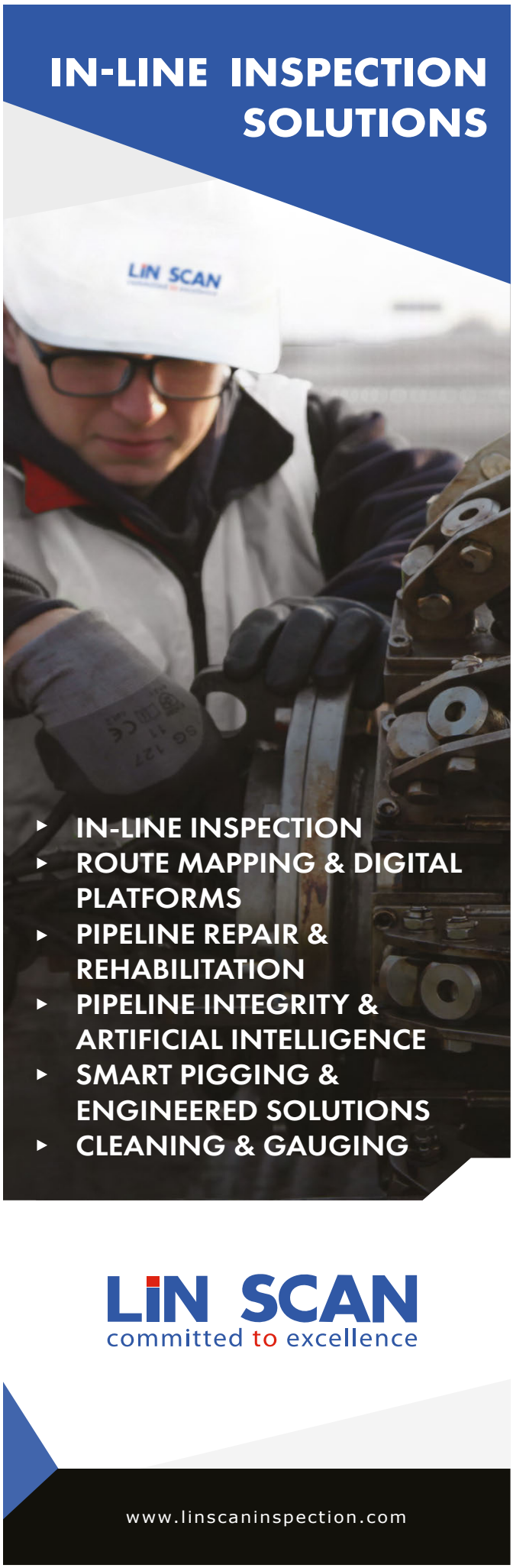

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Construction Of Pipelines In Steep Terrain With Cable Crane Systems

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Abstract

Cable crane systems provide the solution when pipelines need to be built in inaccessible terrain. Pipes, construction material and equipment can be transported easily over demanding areas and be positioned at any point of the track. With a max. length of over 3.000 m and a payload of up to 20 metric tons material ropeways (cable cranes) can be operated in any type of steep terrain.

Cable Cranes, with special adaptation, can also be used for manpower transportation to grant the personnel a safe access to the job site at the slope. In such cases, a cabin is attached to the cable crane which can be lowered and lifted at any position along the slope.

For safety purposes, cable cranes can also be used as an emergency rescue system to evacuate the manpower from the hill site or during an incident or accident along the track of the system.

With these systems, the impact on the environment can be kept as low as possible. Construction material and pipes can be transported to the designated point without any damage to natural habitats. Furthermore, the number of necessary roads can be reduced, and the route optimized, i.e. direct positioning over the pipeline trench. A cable crane system moves loads, suspended in mid-air over all kinds of terrain. The motorized crane unit can lift and lower loads at any point along the cable crane line. Furthermore, the crane unit consists of two separate lifting units, i.e. that pipes can be positioned precisely in inclined areas and be fitted easily into the welding clamp without any additional equipment. Moreover, cable crane systems are independent of climatic conditions such as snow, fog, heavy rain etc. Additionally, they can adapt perfectly to territorial challenges, for example to overcome curves on the ROW by using horizontal bend systems.

INTRODUCTION

The first cable crane system ever used for a pipeline construction in steep section was a simple build "tower and cable construction" for the Trans-Alaska-Pipeline in 1977. During one of the last project phases the team faced the 45° steep slope at Thompson Pass with a length of about 850 m. To lay the 48" and 24 m long pipes they used an easily build up cable crane system.

Cable crane systems can transport single loads of up to 25 mt over a distance of 3,000 m. A line speed of these systems of up to 6 m/s can be achieved with a lifting speed of 1.5 m/s.

CABLE CRANE SYSTEM

Cable crane systems generally consist of a hauling and a track rope, towers, anchors, crane units and winches for different demands. The machinery can be adapted to the payload, line speed and other special requirements in order to fulfill emission and safety standards.

The crane unit is winched up and down the slope by the haul rope and can lift and lower material at any point of the track. Furthermore, it is equipped with two motorized lifting devices which can be controlled simultaneously or separately by radio remote control. This allows the attached construction material to be moved into the desired position & inclination.

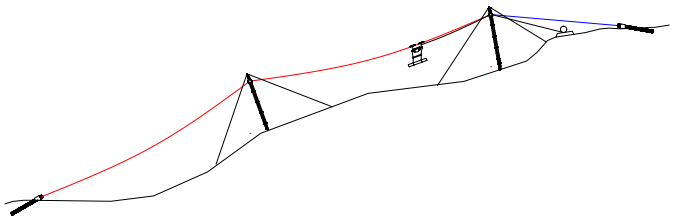

Figure 1: Sketch of a cable crane system

INSTALLATION

Temporary Cable crane systems are build up by several modules which are quickly available and can be deployed promptly after a terrain analysis and the planning. First step to assemble the system is to install the anchors and concrete foundations and the top and bottom station. At the same time the winch and winding device are positioned and horizontally, as well as vertically secured. Afterwards the towers are erected starting with the tower foundations with counter plates and finally lifted into the correct position. Depending on the terrain and length the necessary number of towers are being installed.

Next step is to spool the hauling rope onto the winch drum. The free end of the rope is pulled towards the bottom station while the rope is unspooled from the winch and everything is fixed. Subsequently, the track rope with its socket is attached to the anchors on both ends. Finally, the track rope is tensioned with a track rope tension set until the rope fits perfectly on the system, afterwards the crane unit is placed onto the track rope and connected with the haul rope.

WORKING METHOD

Construction of pipelines in steep sections with cable crane systems is a safe, efficient and environmentally friendly solution for transport in demanding areas, where traditional methods reach their limits.

Starting with the excavation of the trenches with special spider excavators, the cable crane system afterwards gets installed exactly along the centerline of the pipeline, the pipes are attached to the slings and lifted with the crane unit.

Thereafter, they are transported to the intended location. Once the load arrives at the designated unloading point it needs to be positioned accurately by the rigger in communication with the winch operator, adjusting the horizontal and vertical alignment.

Afterwards the pipe is lowered to the designated inclined position, by operating the two independent lifting units of the crane unit independently. When the pipe is in its final location, it is fixed by welding clamps and the welding work is done. From a platform above the weld sandblasting as well as coating works are carried out.

Furthermore, the cable crane system can place machinery and equipment outside of the trench by pulling sideways with chain hoists. The sideways movements depend on the relative height of the track rope vertically above the location in the trench. The maximum permitted deflection of the hoisting rope to the vertical is around 5°.

After the whole pipeline has been positioned, secured and welded, sandbags which are used as filling material and barriers can be transported with the cable crane system in a bulk or other container to the desired location and are unloaded.

Other filling material can also be moved from the loading points to the intended place where the operator unloads the goods by means of two independent lifting systems.

After the pipeline has been laid, secured and covered with filling material, the system is dismantled. The dismantling is done in reverse order to the installation procedure.

ADVANTAGES OF CABLE CRANE SYSTEMS

PRECISE POSITIONING

The cable crane system is a suitable solution, especially in critical sections, for the pipeline construction. Material with a payload of up to 20 mt can be loaded, transported and unloaded at any section of the system. This makes it possible to exactly position pipes in the intended place. Furthermore, the pipe can be held in place with the crane unit as long as necessary to position and weld it.

INDEPENDENT FROM CLIMATIC CONDITIONS

The systems are independent of climatic conditions. They can be used in the rainy season as well as during winter months, in the snow and with low temperatures. This significantly increases the time of use over the year compared to other transport solutions. The cable crane systems can be used in a temperature range from -20°C to +40°C

LOW ENVIRONMENTAL IMPACT

Another advantage of a cable crane system is the low impact on the environment as opposed to the construction of roads, as their installation requires less intervention into nature. Steep and rocky terrain, rivers and lakes do not pose a problem. Due to the direct route above the pipeline, which can be followed, the system leaves a narrow Right of Way of only around 6 to 8 meters. After the completion of the construction work it can be easily re-cultivated over time.

HIGH SAFETY STANDARD

The construction of pipelines means handling of heavy material, use of massive machinery, and consequently, a certain risk and need for safety standards. Cable crane systems significantly improve the safety standards in critical sections, as

- No heavy machinery must access steep slopes.
- Pipes, machinery, equipment are transported mid-air – directly to their final position
- Safe manpower transportation is possible with the use of a cable crane system
- Special securing winches are used for 100 % safety
- Operators on the site are not exposed to risks even though they are working in the most critical and challenging sectors.

Figure 2: Transporting of the pipes to the intended location

Figure 3: Fitting the pipes in the trench

Figure 4: Fixing and preparation for the welding

Figure 5: Transporting of a bulk for filling the trench

MANPOWER TRANSPORTATION POSSIBLE

To allow the personnel to access any point of the slope during the pipeline construction for welding or other works the cable crane system can be equipped with a gondola for limited manpower transportation. The personnel can get to any point of the track safely and comfortably, without additional constructions of access roads.

FOLLOWING CURVES

In case a pipeline needs to follow a horizontal bend or the terrain impedes the material ropeway to continue in a straight line, it is possible to install horizontal bend systems that allow the ropeway to adapt 100% to the terrain or desired track.

EFFICIENT AND COST-SAVING

Cable crane systems increase the efficiency on pipe-laying in steep sections. This method can convert complex and challenging sections into very efficient pipeline constructions, by:

- Permitting direct routes over mountains and reducing the pipeline length in general
- Reducing re-instatement costs due to fewer pipeline kilometers
- Avoiding additional road construction to gain access to steep areas

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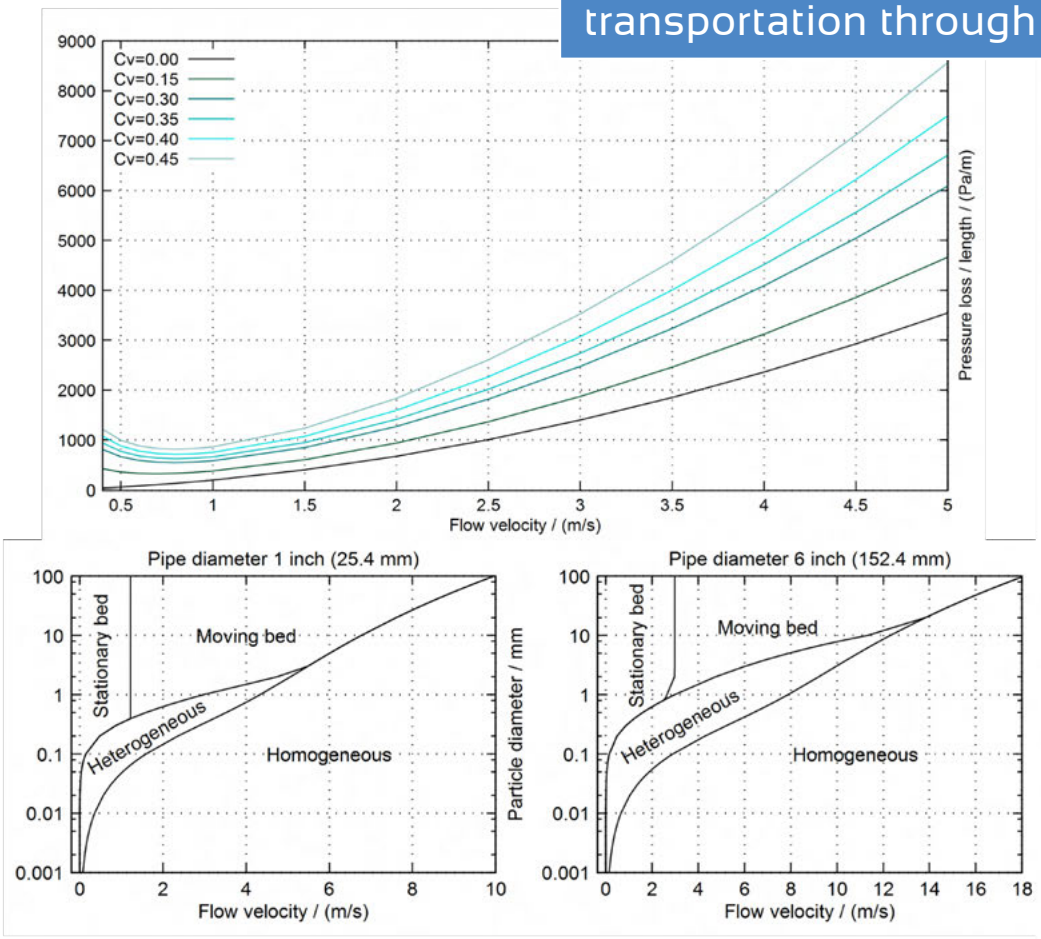
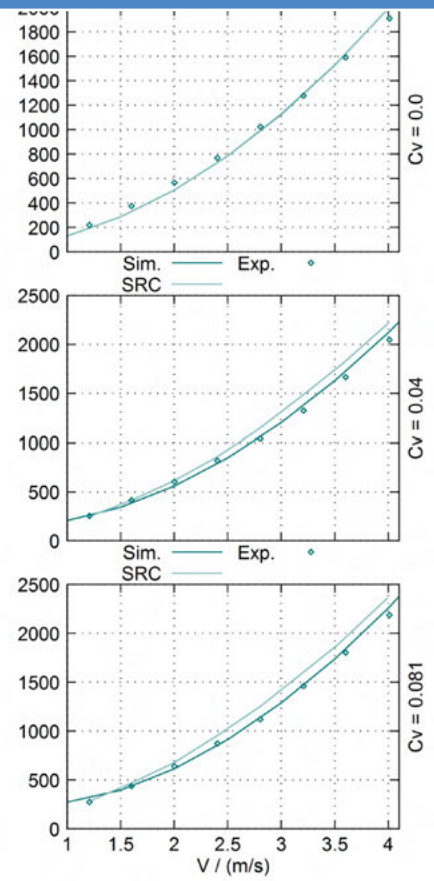
Challenges in the hydraulic simulation of slurry transportation through pipelines





Dr. Fabian Proch, Dr. Paschalis Grammenoudis > MMEC Mannesmann GmbH

Abstract

The transport of solid particles in a gaseous or liquid carrier fluid, usually referred to as slurry transport, is an important technology in various industrial fields. Examples for slurry usage are dredging and mining processes, fertilizer and cement production, desalination plants, the food and paper industry, sewage disposal and agriculture. Slurries can be transported through pipelines continuously over long distances, offering a viable alternative to conventional bulk materials transport options such as conveyor band systems, road and rail.

Compared to single-phase flows, which can be described quite well with modern simulation tools, slurry flows come along with additional physical phenomena which make precise modelling very challenging. Examples are the settling of slurry particles, which is difficult to describe and can cause unstable flow patterns, and the non-Newtonian viscous behavior of the carrier fluid if a large concentration of small slurry particles is dispersed. Therefore, a detailed understanding of the specific physical features of slurry transport is essential for a proper design of slurry transport pipelines.

The article will give a general overview of the categorization of slurry flows into different flow regimes like the (pseudo) homogeneous, heterogeneous and deposition flow regime and the dependency of the occurring flow regime on flow velocity, solid concentration, particle and pipeline diameter. In addition, modelling aspects of the different presented flow regimes are given. Understanding rheology and fluid flow is prerequisite for the development of hydraulic simulation tools and to slurry system design and operation.

Here, the authors provide an overview of the challenges and approaches in the hydraulic simulation of different slurry pipeline systems, as well as a comparison of simulation results obtained with the authors software against examples from the literature are shown.

INTRODUCTION

The transport of solids in form of (fine grained) particles in a liquid or gaseous carrier fluid is usually referred to as slurry (or suspension) transport. Slurry transport in its basic form is a very old technology that occurs frequently in nature and has been used by mankind since ancient times. Nowadays the use of slurry transports plays an important role in many industrial as well as everyday processes. Examples for slurry flows in nature are transport of debris and salt in rivers and seas as well as of sand in deserts. Industrial applications of slurry transport can for example be found during dredging, drilling, desalination and mining processes, in the fertilizer, cement, food and paper production, during sewage disposal and in agriculture [1,2].

The design of slurry transport systems requires a detailed knowledge of the pressure losses in the involved pipelines and devices. Compared to pipelines with a pure fluid or gas flow, the determination of the pressure losses for pipelines with slurry flows comes along with additional challenges. In general, the pressure loss of a slurry flow will be the pressure loss of the pure carrier fluid plus an additional pressure loss due to the presence of the solid particles, where a careful consideration of the different slurry flow regimes is essential for precise modelling.

This paper investigates a modified form of the Wasp [5,7] modelling approach for the pressure loss in horizontal slurry pipelines that covers all the occurring slurry flow regimes and also works for slurries with broad particle size distributions and non-spherical particle shapes. The modelling approach is carefully validated for different kinds of slurries by comparison against experiments [3-5] and against another common slurry flow pressure loss modelling approach [3,12].

CATEGORIZATION OF SLURRY FLOWS IN HORIZONTAL PIPELINES

Depending on the flow conditions, fluid properties, particle properties and the particle load, different slurry flow regimes can occur, which require different modelling strategies. A principal overview is given in Figure 1, which shows the pressure loss per unit length in a horizontal sand slurry pipeline depending on the flow velocity, where the different lines denote different volumetric particle concentrations Cv defined as:

$$C_v = \frac{\rho_m - \rho_l}{\rho_s - \rho_l} \Rightarrow \rho_m = C_v \rho_s + (1 - C_v)\rho_l$$

Here, ρm, ρs and ρl denote the density of the slurry, of the particle material and of the liquid, respectively.

As it can be seen in Figure 1, the pressure loss growths exponentially with the flow velocity and increases towards higher particle concentration. In contrast to a pure fluid flow (C_v=0), (heterogeneous) slurry flows show a minimum pressure loss at a velocity larger zero that is usually denoted as critical velocity. A slurry pipeline should normally be operated at a velocity close to the critical velocity to minimize the energy demand of the pump. During start-up of a slurry pipeline, a remaining pressure difference must be overcome.

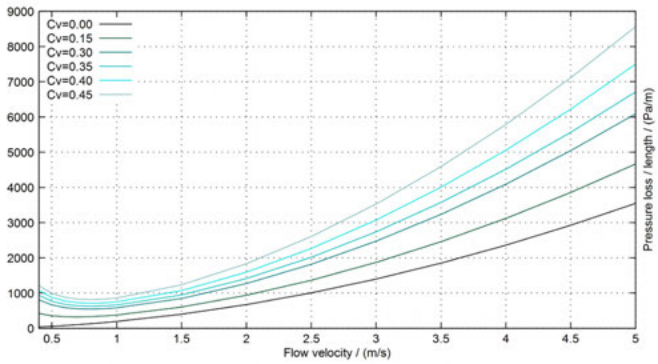


Figure 1: Pressure loss vs. velocity for sand particles in water for different particle concentrations.

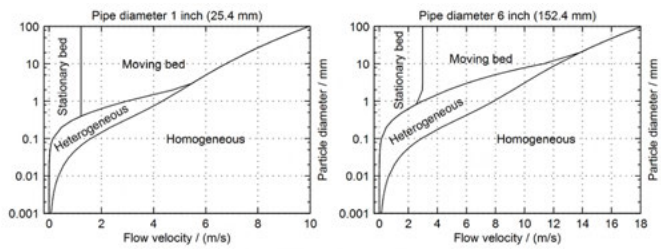


Figure 2: Slurry flow regime diagram for sand particles in water for two different pipeline diameters as introduced by Newitt et al. (C_v=0.2) [6,7,8].

Figure 2 shows that the occurring slurry flow regime depends strongly on the flow velocity and on the particle as well as the pipeline diameter, where the following regimes are distinguished [1,2,6,7] :

- Stationary bed: All particles are deposed in a non-moving bed at the pipeline bottom.
- Moving bed: All particles are deposed in a moving bed at the pipeline bottom, where the movement can occur in various steady and unsteady modes.
- Heterogeneous: Particles are suspended in the carrier fluid, where the particle concentration decreases from the pipeline bottom to the top, might also occur in combination with a moving bed.
- Homogeneous: All particles are suspended in the carrier fluid with a constant particle concentration every

- where in the pipeline.
-

Considering the case of a successive increase of the flow velocity in a pipeline of given diameter, it depends mainly on the particle diameter which flow regimes occur [6]:

- Very small particles (0.001 mm for left plot of Figure 2): Immediate transition from a stationary bed to a homogeneous slurry flow.
- Small particles (e.g. 0.1 mm for left plot of Figure 2): Transition from a stationary bed first to a heterogeneous slurry flow and then to a homogeneous slurry flow.
- Medium sized particles (e.g. 1 mm for left plot of Figure 2): Transition from a stationary bed first to a moving bed, then to a heterogenous slurry flow and finally to a homogeneous slurry flow.
- Large particles (e.g. 10 mm for left plot of Figure 2): Transition from a stationary bed first to a moving bed and then to a homogeneous slurry flow.

The influence of the pipeline diameter on the slurry flow regime borders becomes visible when comparing the left and right plot of Figure 2, an increase of the pipeline diameter shifts the borders towards higher velocities and particle diameters.

PRESSURE LOSS MODELLING FOR SLURRY FLOWS IN HORIZONTAL PIPELINES

Modelling strategies for the pressure loss in horizontal pipelines for the different slurry flow regimes presented in Section 2 are discussed in this section.

HOMOGENEOUS SLURRY

In homogeneous slurries, the particles are (nearly) equally distributed over the horizontal pipeline height. Depending on the size of the particles and interaction forces between them, the frictional behavior of the suspension can either show Newtonian or also all sorts of non-Newtonian behavior as illustrated in Figure 3, in this work we focus on the Newtonian behavior for brevity, which occurs very frequently in industrial slurry flows.

The pressure loss in a pipeline for all types of homogeneous slurries is computed with the flow velocity V, slurry density ρm, pipeline length L and pipeline diameter D as:

$$\Delta p = \frac{f \rho_m V^2 L}{2D}$$

For a Newtonian slurry, as considered here, the pressure loss can be computed from the classical formulas of Hagen-Poiseuille and Prandtl-Colebrook (implicit). To avoid

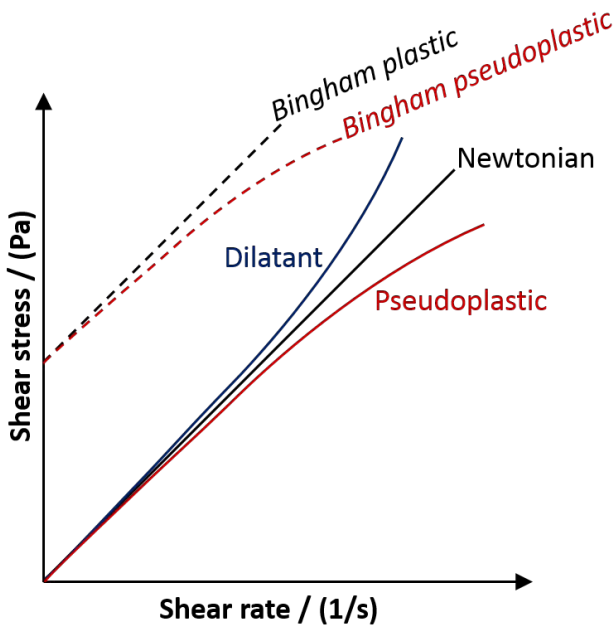


Figure 3: Shear stress vs shear rate for fluids with different rheology [1,7].

the need for an implicit solution procedure, in this work the following explicit approximation formula valid for all kind of turbulence levels is used [10], which deviates less than 3% from the classical formulas [11]:

$$f = 8\left[\left(\frac{8}{Re}\right)^{12} + \frac{1}{(\Theta_1 + \Theta_2)^{1.5}}\right]^{1/12}$$

The Reynolds number and the factors Θ1 and Θ2 are determined as:

$$Re = \frac{D\,V\,\rho_m}{\mu_m} \quad \text{and} \quad \Theta_1 = \left[-2.457 \ln\left\{\left(\frac{7}{Re}\right)^{0.9} + 0.27\frac{k}{D}\right\}\right]^{16} \quad \text{and} \quad \Theta_2 = \left(\frac{37{,}530}{Re}\right)^{16}$$

Here, the pipeline roughness is denoted by k, the slurry viscosity can be computed from the pure fluid viscosity μl and the particle load with the Thomas correlation [5,7]:

$$\mu_m = \mu_l\,[1 + 2.5\,C_v + 10.05\,C_v^2 + 0.00273\,\exp\,(16.6\,C_v)]$$

HETEROGENEOUS SLURRY

In a heterogeneous slurry, the particle concentration decreases from the bottom to the top of the horizontal pipeline. Various correlations have been developed in the past based on experiments and theoretical considerations [1,7,8,12], in this work we use the correlation as given by Durand and Condolios [1], which expressed the pressure loss in a heterogeneous slurry based on the pressure loss

in the pure carrier liquid:

$$\Delta p_m = \Delta p_l + C_v\, \Delta p_l\, K\, \Psi^m \quad \text{with} \quad K = 82 \quad \text{and} \quad m = 1.5$$

The pressure loss of the pure carrier liquid is obtained from the formulas in Section 3.1, where it is important that the slurry density and viscosity ρm and μ_m in the formulas is replaced by the pure liquid density and viscosity ρl and μl. The factor Ψ is computed from the expression given by Hayden and Stelson [1]:

$$\Psi = \frac{(s-1) g D\, V_t}{V^2 \sqrt{4/3\,(s-1)\, g\, d}} \quad \text{with} \quad s = \frac{\rho_p}{\rho_l}$$

The terminal velocity of the particles is computed from the following equation [13]:

$$V_t = \left[\frac{g\mu_l(\rho_p - \rho_l)}{\rho_l^2}\right]^{1/3} \left[\frac{18}{d_*^2} + \frac{2.3348 - 1.7439\phi}{d_*^{0.5}}\right]^{-1} \quad \text{with} \quad d_* = d\left[\frac{g\,\rho_l\,(\rho_s - \rho_l)}{\mu_l^2}\right]^{1/3}$$

Here, the influence of the particle shape on the terminal velocity is incorporated by the sphericity, which is the ratio of the surface area of a sphere with the same volume as the particle, Vp, to the particle surface area Ap:

$$\phi = \frac{\Pi^{1/3}\left(6\, V_p\right)^{2/3}}{A_p}$$

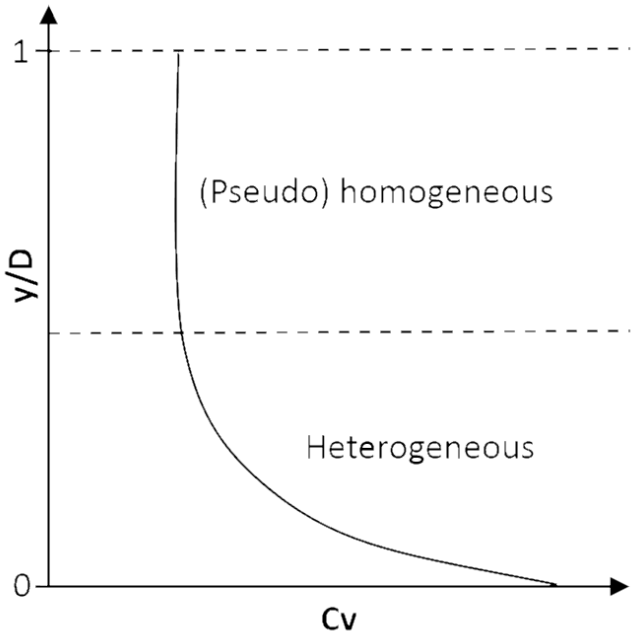


Figure 4: Distribution of the slurry in a (pseudo) homogeneous part and a heterogeneous part, as assumed in the Wasp model. Plotted is the normalized (vertical) distance from the pipeline bottom vs. the particle concentration profile.

The sphericity takes a value of one for perfectly spherical particles and values smaller one for particles with non-spherical shapes, typical sphericity values for slurry particles are between 0.4 and 0.8.

WASP MODEL

The Durand model as presented in Section 3.2 and comparable models have been used over the last decades to predict pressure losses for various types of slurries, where it often was found that the predicted slurry pressure losses deviated from the measured ones. Therefore, various improved models have been developed in the past to better predict the slurry pressure losses, well-known examples are e.g. the two-layer Saskatchewan Research Council (SRC) model, which is used extensively in the Canadian oil sand and slurry industries [3,12], or the Wasp model [5,7]. A modified version of the Wasp model is used in this work, as the Wasp model avoids the need to determine additional input parameters that are required by the SRC model.
The used Wasp model assumes that the slurry consists of a (pseudo) homogeneous (often denoted as vehicle) and a heterogeneous (often denoted as bed) part, as sketched in Figure 4.

The pressure loss of the slurry is computed from:

$$\Delta p_m = \underbrace{(\Delta p_l)_m}_{\Delta p_{hom}} + \underbrace{C_v^{het}\Delta p_l\, K\, \Psi^m}_{\Delta p_{het}} \quad \text{with} \quad K = 82 \quad \text{and} \quad m =$$

It must be stressed that the homogeneous pressure loss Δphom is computed with the formulas as given in Section 3.1 using the slurry density and viscosity ρm and μm, which are both computed using the particle concentration in the homogeneous part Cv^hom. The heterogeneous pressure loss Δphet is computed as described in Section 3.2 using the pure liquid density and viscosity ρl and μl. The particle concentrations in the homogeneous and the heterogeneous part are computed from [7]:

$$C_v^{hom} = C_v\, 10^{-(1.8\, V_t^c)/(\beta\, \kappa\, V_f)} \quad \text{and} \quad C_v^{het} = C_v - C_v^{hom}$$

In this work the von Karman constant κ is set to a value of 0.4 and the inverse turbulent Schmid number β is set to value of 1/0.7=1.43, as it is frequently used for the modelling of turbulent mixing [15]. The friction velocity of the fluid is determined as:

$$V_f = \sqrt{\frac{\tau_w}{\rho_m}} = \sqrt{\frac{f_{tot}}{8}} \quad \text{with} \quad f_{tot} = \frac{\Delta p_m 2D}{\rho_m\, V^2 L}$$

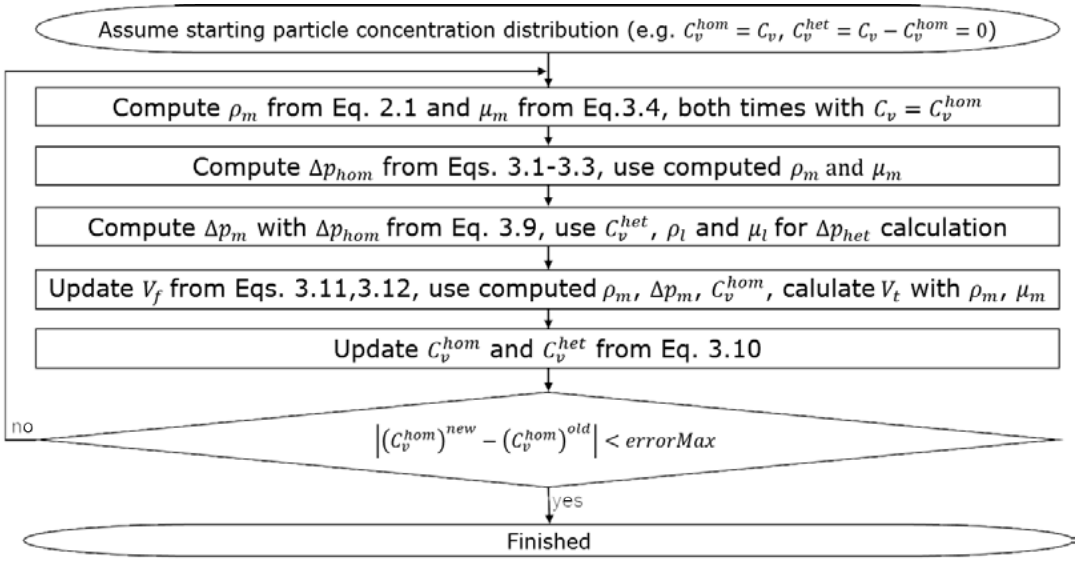


Figure 5: Iterative solution procedure for Wasp model.

The hindered particle settling velocity Vt^c is computed from the correlation given in [14]:

$$V_t^c = V_t(1 - C_v^{hom})^n \,, n = \begin{cases} 4.65 + 19.5\, d/D \,,\ Re_p < 0.2 \\ (4.35 + 17.5\, d/D) Re_p^{-0.03},\ 0.2 \le Re_p \le 1 \\ (4.45 + 18\, d/D) Re_p^{-0.1},\ 1 \le Re_p \le 200 \\ 4.45 Re_p^{-0.1},\ 200 \le Re_p \le 500 \\ 2.39,\ Re_p > 500 \end{cases} \,, Re_p = \frac{V_t\, \rho_m D}{\mu_m}$$

Please note that here the slurry density pm and viscosity µm must be used for the calculation of the terminal velocity Vt from Equation 3.7. As the knowledge of the particle concentration of the homogeneous part Cv^hom is required for the calculation of the slurry pressures loss Δpm and vice versa, the solution of the Wasp model requires an iterative solution procedure, which is given in Figure 5.

CONSIDERATION OF THE PARTICLE SIZE DISTRIBUTION

For clarity, the model descriptions in Sections 3.2 and 3.2.1 were done assuming a very narrow particle size distribution in the slurry, so that only the mean particle diameter needed to be considered. However, in the vast amount of technically relevant slurries will exist a broad particle size distribution, which needs to be considered in the modelling. One advantage of the used models is that they can easily be modified for the use of multiple particle size classes, the necessary adaptions are:

- Calculation of $[C_v^{hom}]^i$ and $[C_v^{het}]^i$ from Equation 3.10 for every particle diameter class i, as the terminal velocity V_t changes with particle diameter.
- Replacement of C_v^{hom} by the sum over all particle size classes N, $\sum_{i=1}^{N}[C_v^{hom}]^i$, for the calculation of the homogeneous part pressure loss Δp_{hom} from Equations 3.1-3.3 with the density from Equation 2.1 and the viscosity from Equation 3.4 as well as for the calculation of the hindered settling velocity from Equation 3.12.
- Calculation of $[\Delta p_{het}]^i$ with $[C_v^{het}]^i$ for every particle diameter class i, as the terminal velocity V_t changes with particle diameter.
- Replacement of Δp_{het} by the sum over all particle size classes N, $\sum_{i=1}^{N}[\Delta p_{het}]^i$, in Equation 3.9.

COMPARISON OF MODELLING RESULTS AGAINST MEASUREMENTS

In this section, a careful validation of the modified Wasp model as presented in Section 3.2.1 is carried out by comparison against experimental results, first for slurries with a narrow particle size distribution using the example of glass beads and sand. Afterwards, a zinc tailing slurry experiment is used as an example for a slurry with a broad particle size distribution.

SLURRIES WITH NARROW SIZE DISTRIBUTION

If the particle size distribution is very narrow, the pressure loss in the slurry can be modelled well by using just the mean particle diameter. The experimental results from [3] are used to assess the model performance, where pressure loss measurements have been conducted in a closed loop cooled horizontal pipeline with a diameter of 50 mm and a roughness of 0.001 mm. The fluid was water, where we found that assuming a water temperature of 35°C (ρl="994 kg/m³",µl=7.2e-4 Pa s) yields a good agreement between experiment and simulation for the pure fluid results (Cv=0). Measurements have been carried out with variation of fluid velocity, particle concentration and particle material. Furthermore, SRC model results given in [3] are used as reference.

GLASS BEADS

Figure 6 shows comparisons of the modified Wasp model results for pressure loss vs. flow velocity against measurements and SRC model results from [3] for different particle concentrations.

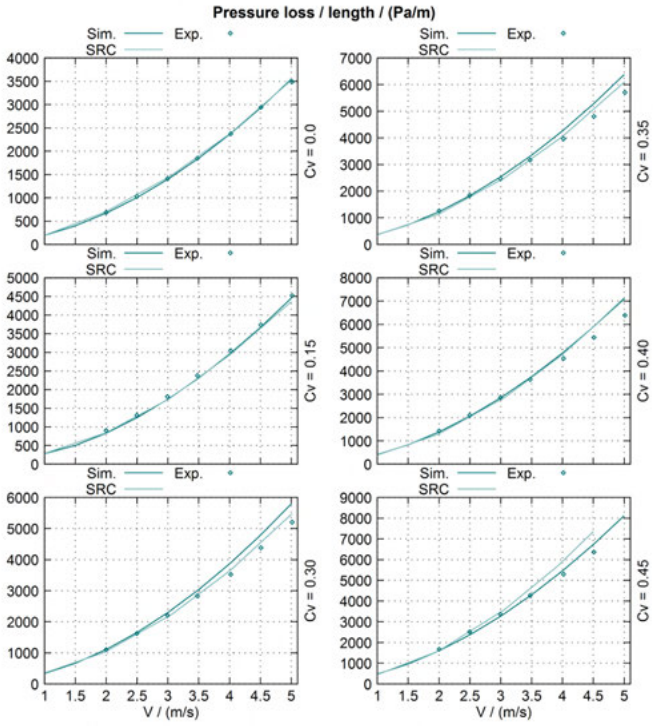


Figure 6: Comparison of the modelled pressure loss results for glass beads (Sim.) with the measurement (Exp.) and SRC model predictions (SRC) from [3].

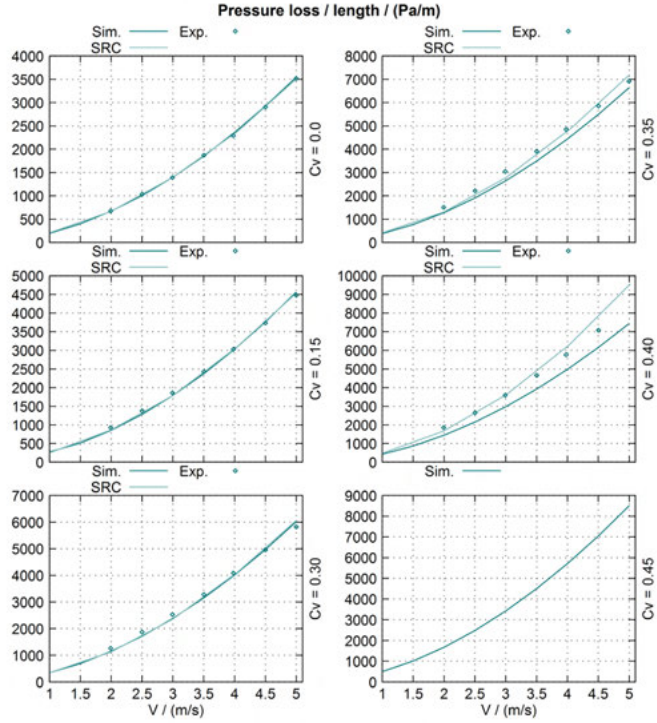


Figure 7: Comparison of the modelled pressure loss results for Ottawa sand (Sim.) with the measurement (Exp.) and SRC model predictions (SRC) from [3].

The slurry contained glass beads with a narrow particle size distribution with a mean diameter of 0.1 mm, a particle density of 2440 kg/m³ and a sphericity of 0.893. In general, there is a good agreement between the Wasp model predictions and the measurements for lower velocities which slightly deteriorates towards higher velocities for larger particle concentrations. The Wasp model results are comparable to the SRC model results, where the gradient of the pressure loss vs. velocity curve increases stronger towards higher particle concentrations for the SRC model than for the Wasp model and the measurements.

SAND

Figure 7 shows comparisons of the modified Wasp model results for pressure loss vs. flow velocity against measurements and SRC model results from [3] for different particle concentrations.

The slurry contained Ottawa sand with a narrow particle size distribution with a mean diameter of 0.085 mm, a particle density of 2660 kg/m³ and a sphericity of 0.709. No measurement data was given for the 45% volume fraction case, as it was not possible to maintain a continuous slurry transport at this particle concentration. As already observed for the glass beads in Section 4.1.1, there is a good agreement between the Wasp model predictions and the measurements for lower velocities which deteriorates towards higher velocities for larger particle concentrations. The Wasp model results are again comparable to the SRC model results, where the gradient of the pressure loss vs.

Hazard Rating		Mitigation Measures (Yes / No)	Definition *'Event' defined as pipeline rupture*
0	None	No	The event is not conceivable, even under exceptional circumstances
1	Negligible	No	The event is conceivable during the design life of the project but under exceptional circumstances

Table 1: Particle size distribution by volume of the zinc tailing slurry [5].

velocity curve increases distinctly stronger towards higher particle concentrations for the SRC model than for the Wasp model.

SLURRY WITH BROAD PARTICLE SIZE DISTRIBUTION

If the particle size distribution becomes broad, multiple particle size classes should be used for the modelling. To judge the performance of the modified Wasp model with multiple particle size classes, the pressure loss measurements for a zinc tailing slurry from [4,5,9] have been used.

The pipeline diameter was 105 mm, the pipeline roughness 0.3 mm and water with a temperature of 25 °C (ρl="997 kg/m³",μl=8.9e-4 Pa s) was used as carrier fluid. The slurry contained zinc particles with a particle density of 2820 kg/m³ and a sphericity of 0.6, which means that the particle

shapes deviated significantly from a sphere, the (volumetric) particle size distribution is given in Table 1.

As for the examples in Section 4.1, measurements are available for varying fluid velocity and particle concentration, in addition also SRC model predictions are given in [5]. Figure 8 shows comparisons of the Wasp model results for pressure loss vs. flow velocity against measurements and SRC model results from [5,9] for different particle concentrations. Again there is a good agreement between the Wasp model results and the measurements for lower particle concentrations, which worsens with increasing fluid velocity for higher particle concentrations. The SRC model predictions are similar to the Wasp model predictions, where the latter show a better agreement with the measurement data for lower particle concentrations.

CONCLUSION

A description of the different slurry flow regimes that may occur in horizontal pipelines has been given with a discussion of the main influence factors. Afterwards, modelling approaches for the homogeneous and heterogeneous slurry flows regimes have been shown. A modified form of the Wasp model was presented, which enables modelling of slurries in all slurry flow regimes and considers the particle shape. It was discussed how the presented slurry pressure loss models can be adapted for slurries with broad particle size distributions.

The pressure loss results from the modified Wasp model were compared against measurement results from three different experiments and against simulation results obtained with the SRC model. In general, a good agreement of the Wasp model results with the experiments and the SRC model results was observed. Only for larger particles concentrations and velocities the agreement of the predictions of both models with the measurements deteriorated, for lower particle concentrations the modified Wasp model was partially in better agreement with the measurements than the SRC model.

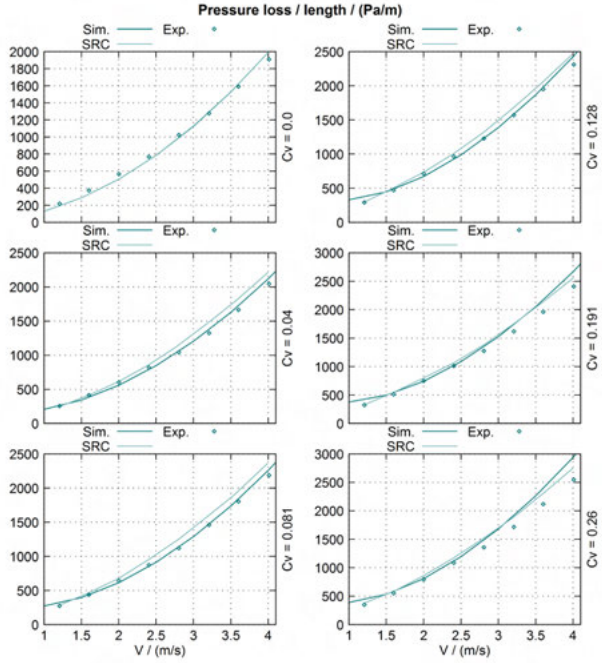


Figure 8: Comparison of the modelled pressure loss results for a zinc tailing slurry (Sim.) with the measurement (Exp.) and SRC model predictions (SRC) from [5,9].

References

1. B. Abulnaga. Slurry Systems Handbook. McGraw-Hill, USA, 2002.
2. M. Weber. Strömungsfördertechnik. Krausskopf-Verlag, Mainz, Germany, 1974.
3. J. Schaan, R. J. Sumner, R. G. Gillies an C. A. Shook, The effect of particle shape on pipeline friction for Newtonian slurries of fine particles. The Canadian Journal of Chemical Engineering 78:717-725, 2000.
4. D. R. Kaushal, Y. Tomita, R. R. Dighade. Concentration at the pipeline bottom at deposition velocity for transportation of commercial slurries through pipeline. Powder Technology, 125:89-101, 2002.
5. D. R. Kaushal, Y. Tomita. Solids concentration profiles and pressure drop in pipeline flow of multisized particulate slurries. International Journal of Multiphase Flow, 28:1697-1717, 2002.
6. S. A. Miedema, An overview of theories describing head losses in slurry transport - a tribute to some of the early researchers, OMAE 2013, 2013.
7. E. J. Wasp, J. P. Kenny and R. L. Gandhi, Solid-liquid flow slurry pipeline transportation, Trans Tech Publications, Clausthal, Germany, 3rd edition, 1979.
8. D. M. Newitt, J. F. Richardson, M. Abbot and R. B. Turtle, Hydraulic Conveying of Solids in Horizontal Pipes, Transactions of the Institution of Chemical Engineers, 33:93-113, 1955.
9. D. R. Kaushal, Y. Tomita. An Improved Method for Predicting Pressure Drop along Slurry Pipeline. Particulate Science and Technology, 20:305-324, 2002.
10. S. W. Churchill. Friction-factor equation spans all fluid flow regimes. Chemical Engineering, 84(24):91–92, 1977.
11. D. Brkić. Review of explicit approximations to the Colebrook relation for flow friction. Journal of Petroleum Science and Engineering, 77:34-48, 2011.
12. K. C. Wilson, G. R. Addie, A. Sellgren and R. Clift, Slurry Transport using Centrifugal Pumps. Springer Science+Business Media Inc., New York, USA, 3rd edition, 2006.
13. A. Haider and O. Levenspiel. Drag coefficient and terminal velocity of spherical and nonspherical particles. Powder Technology, 58:63-70, 1989.
14. J.F. Richardson, W.N. Zaki. Sedimentation and fluidisation: Part I. Transactions of the Institution of Chemical Engineers 32:35-53, 1954.
15. F. Proch, A. M. Kempf. Numerical analysis of the Cambridge stratified flame series using artificial thickened flame LES with tabulated premixed flame chemistry. Combustion and Flame, 161(10):2627 – 2646, 2014.

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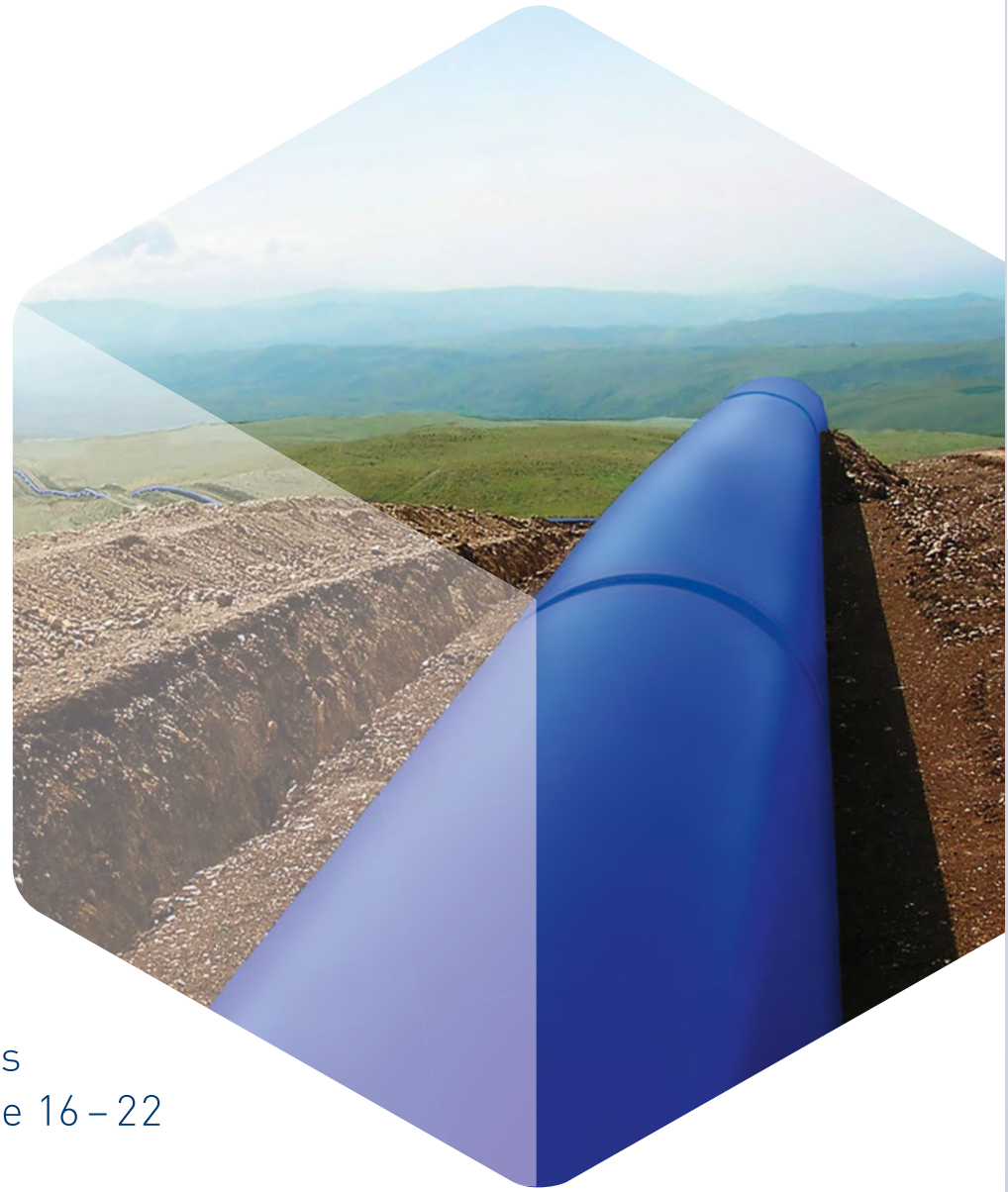

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Zero Harm As An Achievable Target - How To Build A Journey Towards Zero For People, Significant Impacts On The Environment And The Community

Julia L. Costa, Felipe P. Avelar > Nova Transportadora do Sudeste

Abstract

NTS is committed to ensuring everyone return home safely at the end of each day, and that our assets are operated in a safe manner. This commitment to safety is based on caring for employees, our contractors, the communities in which we operate and the environment.

We are certain that Zero Harm is an achievable target and for this we focus on three areas of action: Improve our facilities and equipment through technology and innovation; Implement an Integrated Management System to improve our practices and procedures; and Develop our people and transform NTS's Safety Culture.

This paper gives an overview NTS's Zero Harm strategy and its areas of expertise, presenting some of the projects with focus on risk reduction, the standard of the integrated management system that brings the implementation of processes and practices and the development of safety culture organization.

INTRODUCTION

NTS (Nova Transportadora do Sudeste S/A - NTS) transports natural gas through a 2,048-kilometer grid with contracted capacity of 158.2 million m³ of gas per day through 5 service contracts, connecting the states of the Rio de Janeiro, São Paulo and Minas Gerais, responsible for 50% of gas consumption in Brazil, the Brazil-Bolivia gas pipeline, one LNG terminal and two gas processing plants.

On April 4th, 2017, Petrobras finalized the sale of 90% of the company's shares in NTS to the New Infrastructure Investment Fund (FIP), managed by Brookfield Brasil Asset Management Investments Ltda., an affiliate of Brookfield Asset Management. On the same date, FIP sold a portion of its shares in NTS to Itaúsa - Investimentos Itaú S.A.

Our mission is to ensure the safe and sustainable transport of natural gas.

Our vision is to be recognized as a world-class company for excellence in the management of natural gas transportation, leading the transformation of this sector in Brazil.

Our values are: Respect for life and the environment, Integrity, Focus on result and Ownership.

Since natural gas transportation is a high-risk activity, with potentially catastrophic consequences for the health and safety of people and the environment we go through, NTS has defined Zero Harm as one of its strategic pillars.

The concept of zero harm works off the ideology that every employee, contractor, and visitor who enters a work site should be able to rely on an intact and safe working environment every single day. Sounds simple but implementing safe work strategies that result in a zero harm workplace has risen many issues throughout the business world. And the oil and gas industry would be no different.

The main issue with zero harm is the safe work strategies that are considered to be empty promises and unrealistic targets. Some people question how zero harm could ever be guaranteed when risk is always around us. For others, a zero harm target is seen as the only real way to show true commitment to your staff and their safety.

We know we need to implement strategies and have well-developed programs in place to detect and contain them at the earliest stage possible.

NTS has developed zero harm strategy through the creation of 03 programs. They are: "Our Facilities", "Integrated Management System" and "Our People". The figure below represents the NTS' Zero Harm Strategy.

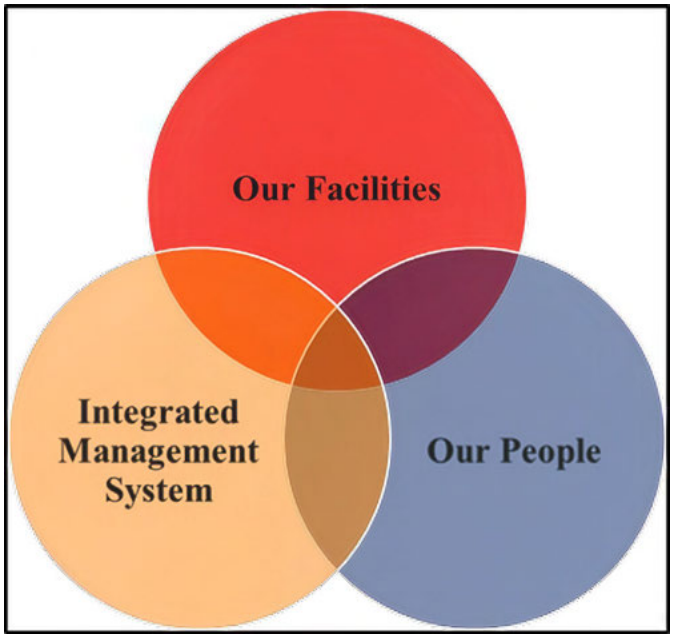

Figure 1: NTS's Zero Harm Strategy

For "Our Facilities", finding strategies to reduce both the risks and incidents of injuries, through technology and innovation, are key priorities.

For "Integrated Management System", the focus is on the implementation of an Integrated Management System to improve our practices and processes.

For "Our People", developing a culture that supports the Zero Harm aim will help both an organization and the people within that organization to make better choices when it comes to safety.

These programs were strategically prioritized according to the effort graph below.

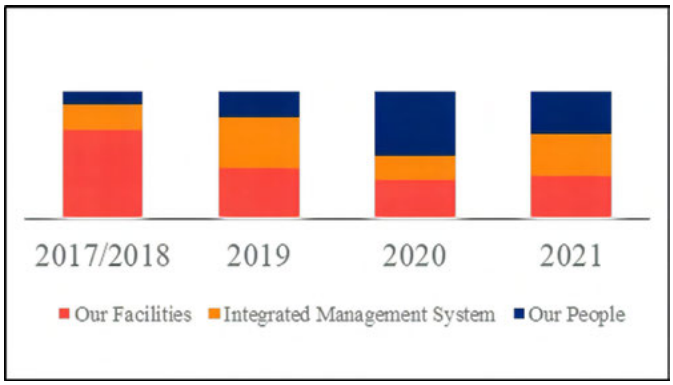

Figure 2: Effort over time

The prioritization of the programs follows the concept of risk control hierarchy. "Our Facilities" presents strategic engineering projects that can eliminate and/or reduce the risk of incidents. "Integrated Management System" features robust administrative controls that further reduce these risks. "Our People" presents controls focused on the human factor, the last protection barrier for incidents occurrence.

This article presents an overview of each Zero Harm related program as well as results so far.

OUR FACILITIES

The history of gas pipeline incidents in the world shows its main causes. The chart below shows the main causes of the incidents from 1993 to 2017, through information taken from the PHMSA - Pipeline and Hazardous Materials Safety Administration.

The operational safety of our existing natural gas transportation infrastructure (gas pipelines, delivery points, compressor stations and other facilities) must be attested to ensure the reliability, availability, physical and structural integrity of our assets.

To this end, NTS has defined some strategic projects related to our assets, with the objective of eliminating and/or reducing incident risks. We present below some of these projects.

STRESS CORROSION CRACKING (SCC)

SCC in pipelines is a type of environmentally assisted cracking. SCC results from the formation of cracks due to various factors in combination with the environment surrounding the pipeline that together reduces the pressure-carrying capability of the pipe. When a pipeline under higher pressures (stress) meets water due to coating failure, the minerals, ions, and gases in the water at the pipe surface create corrosion that attacks the pipe. SCC tends to propagate as crack clusters or "colonies" as pipeline stress opens cracks that are subject to corrosion, which are then corroded further, weakening the pipeline metal by further cracking.

NTS has been conducting inspections in its pipelines to identify the occurrence of SCC. For gas pipelines with suspected SCC, NTS has been conducting investigations and repairs, with significant reduction of the risk of rupture and/or failures in its pipelines.

Until the paper was sent, 6 (all pipelines susceptible to SCC) gas pipelines had already been investigated and more than 96 repairs that were caused by SCC had already been carried out.

CLASS LOCATION

Regulations for gas transmission pipelines establish pipe strength requirements based on population density near the pipeline. Locations along gas pipelines are divided

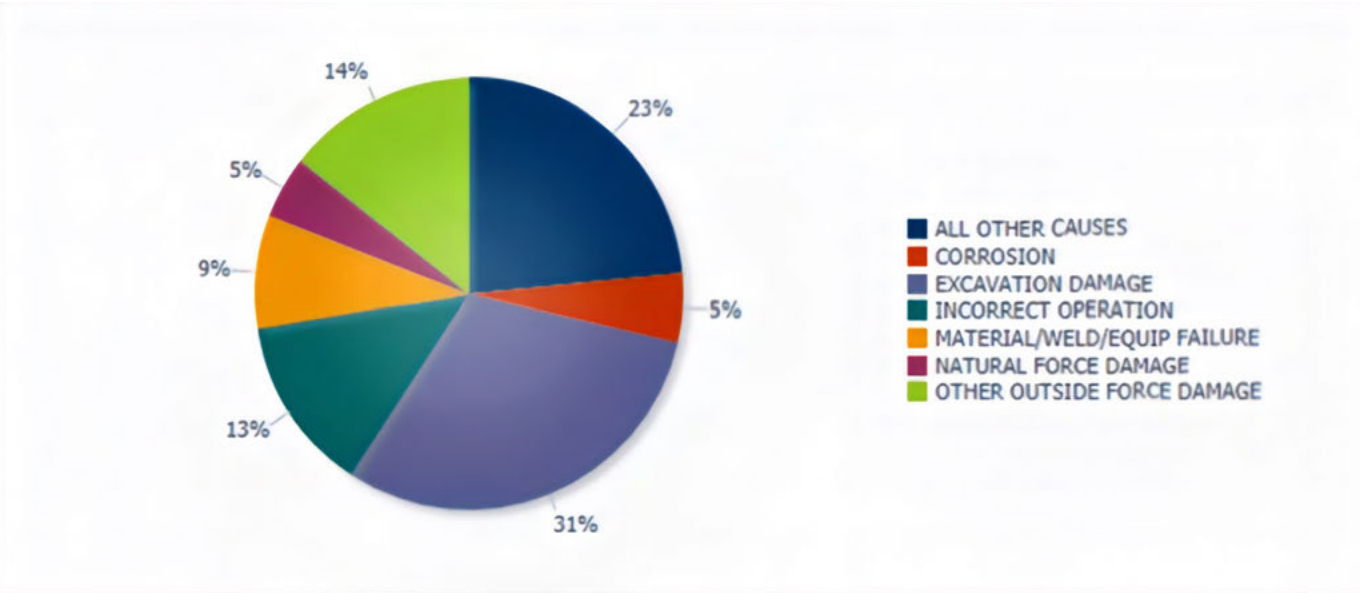

Figure 3: Serious incidents cause breakdown

into classes from 1 (rural) to 4 (densely populated) and are based upon the number of buildings or dwellings for human occupancy. Allowable pipe stresses, as a percentage of specified minimum yield strength (SMYS), decrease as class location increases from Class 1 to Class 4 location.

NTS has a great work to do to implement mitigation actions in pipelines that are non-compliant according to the requirements of regulatory standards. In addition to meeting the regulation, there will be significant reduction of the probability of failures where the potential severity of the impact is high.

CATHODIC PROTECTION

Cathodic protection (CP) is a technique used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell. A simple method of protection connects the metal to be protected to a more easily corroded "sacrificial metal" to act as the anode. The sacrificial metal then corrodes instead of the protected metal.

NTS's strategy is to automate its cathodic protection system, from remote monitoring, obtaining long term reduction of its gas pipelines explosion risk.

RISK-BASED INTEGRITY MANAGEMENT

Integrity management involves the creation of a program that is based on data collection to evaluate the risks considering each pipeline or pipeline system. After risk analysis, pipeline integrity assessments and implementation of mitigation measures are performed.

NTS decided to implement a software to analyze quantitatively the risks associated with pipeline integrity, the ROAIMS (ROSEN Asset Integrity Management Software).

With this software we will quantify the risk scenarios of all our pipelines, evaluating and adopting appropriate risk control measures.

WARNING TAPE INSTALLATION

Illegal tapping is a major concern in pipeline industry, posing a threat for several operators. Illegal tapping is a criminal activity in which fuel is stolen from the pipeline using a "hot tapping" technique. The consequences of an accident could be extremely severe. The pipeline explosion in Mexico, in January 2019, resulted in 137 dead and dozens of injured.

In Brazil, the escalation of the issue is evident: In 2017 and 2018, about 27 million liters of oil and oil products were stolen. Thefts increased from 72, in 2016, to 261 last year.

In addition to illegal tapping, there is also other kinds of interference from third-party, such as civil works near the pipeline, that pose a risk to its integrity.

Although natural gas is not a fuel of interest, gas pipelines are mistakenly hit when criminals try to steal oil and oil product. In order to reduce the risks related, NTS has initiated a project to install warning tapes. These tapes are placed buried parallel and above the pipe, alerting anyone who performs an excavation on site, regardless of intent.

INTEGRATED MANAGEMENT SYSTEM

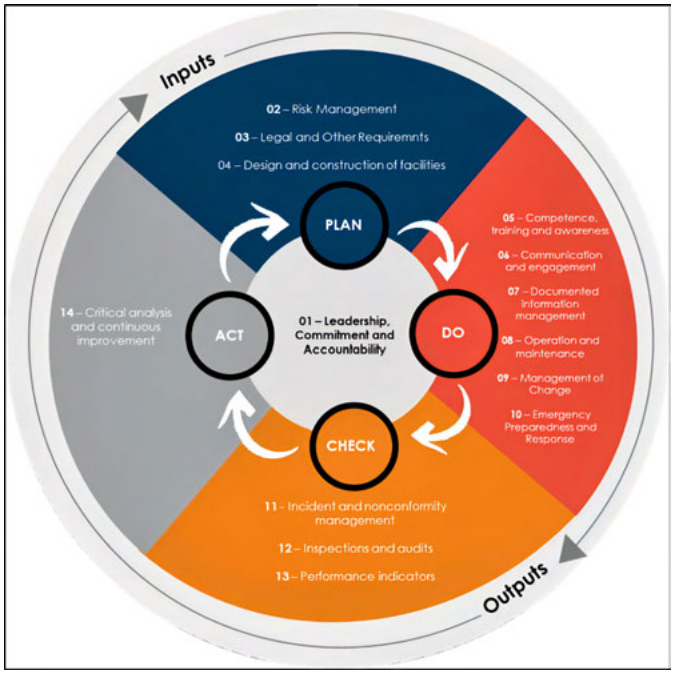

Figure 4: NTS's Integrated Management System Elements

Management System is the combination of procedures adopted to achieve its results in a more efficient way, allowing to plan, evaluate, monitor and control its processes, promoting operational excellence through continuous improvement.

NTS decided to structure a health, safety, environment, social responsibility and operational efficiency management system, called NTS's IMS Integrated Management System, providing guidance for the application of specific procedures.

NTS's IMS covers project development and execution activities, operation, natural gas measurements, planning and scheduling, integrity management, maintenance and decommissioning of assets.

NTS's IMS aims to identify and address aspects and risks to employees, the environment, community and facilities in order to manage them and reduce them to the lowest level reasonably achievable.

IMS is defined through the NTS's Sustainability Policy and the IMS Standard. NTS' Standard defines the structure through 14 (fourteen) elements, as shown in Figure 4.

NTS's IMS follows the commitments made for each element, as well as procedures that detail how the organization applies them.

With the implementation of IMS elements, NTS expects significant improvements in safety, reliability and environmental performance.

OUR PEOPLE

Respect for life and the environment and focus on results are core values for the NTS, which combined aims to achieve high levels of reliability and operational efficiency, mitigating health, safety and environmental risks.
The reinforcement of the culture is due to the following actions:

- Demonstrate concern for stakeholders and the environment;
- Open and effective communication;
- Promote mutual trust;
- Recognize safe behaviors;
- Understand and communicate risks;
- Protect our Employees from retaliation when reporting incidents, hazards, risks and opportunities;
- Guarantee qualification and training of Employees;
- Promote continuous improvement of practices and procedures.

The main factor of success in operational excellence is leadership. Leaders are focused not only on getting results, but on getting results in the right way, being in accordance with our values. They are able to manage the IMS by their actions, from reinforcing culture, incorporating operational discipline and working to ensure that they and all Employees meet the requirements of the management system. Through their commitment, they demonstrate that zero is achievable, whether for safety, health, environmental or operational incidents.

SAFETY CULTURE

The safety culture of an organization is the product of individual and group values, attitudes, perceptions, competencies and behavioral patterns that determine commitment, style and proficiency of an organization's health and safety management.

NTS aims to form a world class safety culture. For this we are based on the precepts adopted by DuPont.

There are three key components of a world-class safety culture:

- Leadership: Leading employees toward safety excellence.
- Structure: Organizational structures that allow the search for excellence in safety.
- Processes: Actions taken to evolution of safety performance.
- NTS will analyze its safety culture based on these 03 main focus areas. DuPont Bradley Curve, shown below, will help us to understand where we are.

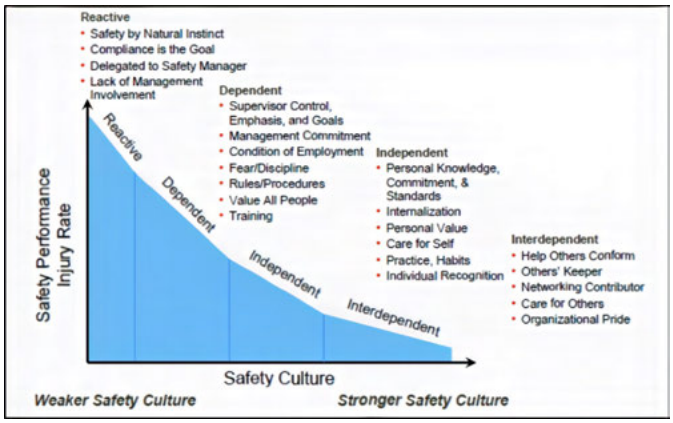

Figure 5: DuPont Bradley Curve

After the analysis and knowing where we are, NTS will apply structure actions to get the world class safety culture.

CONCLUSION

Natural gas transportation is a high-risk activity, with potential consequences of catastrophic incidents. Historical records indicate that the number of incidents is low when compared to other industries, however, when they occur, the number of injuries and fatalities is very high. This paper presented the NTS's Zero Harm Strategy to avoid the occurrence of incidents.

Zero Harm is an achievable target and, for this, NTS has defined 03 main areas: "Our Facilities", "Integrated Management System" and "Our People". Each program had its effort defined over time, following the concept of hierarchy of risk control.

For "Our Facilities" NTS used the history of the main causes of incidents of the natural gas industry in the world, as well as the reality of the company. Thus, defined strategic projects that aim to eliminate and/or reduce the risk of in-

cidents such as: Stress Corrosion Cracking, Class Location, Cathodic Protection, Risk-based Integrity Management and Warning Tape Installation. The projects have already started, and their results will be realized even in 2019.

For "Integrated Management System" we presented the structure of the NTS's Integrated Management System, which is composed of 14 (fourteen) elements: Leadership, commitment and accountability; Risk management; Legal and other requirements; Design and construction of facilities; Competency, training and awareness; Communication and engagement; Documented information management, Operation and maintenance; Management of Change; Emergency preparedness and response; Incident and non-conformities management; Inspections and audits; Performance indicators; and Critical analysis and continuous improvement. Each element of management system brings the NTS commitment to HSE, as well as the procedures that detail how the NTS applies each of them.

For "Our People" NTS decided to focus on developing our Safety Culture. We will conduct research to define the NTS's Safety Culture stage. To do this, we will use the Dupont Bradley Curve. This curve divides an organization's safety culture stages, from the reactive safety culture to the interdependent safety culture (World class safety culture). After knowing where we are in terms of safety culture, we will apply structuring actions to the evolution of the safety culture.

NTS values guide our actions and sustain core performance for the company to succeed.

We will develop our safety culture by attracting, developing and retaining individuals who share our commitment to Zero Harm.

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References

- ARRUDA, P.R.P. de. Técnicas de construção e montagem de gasodutos. Bahia: Escola
- Politécnica, 2006.
- ASME B 31.8 - Gas Transmission and Distribution Piping Systems. STANDARD by ASME International, 11/20/2018
- ASME B31G, Manual for Determining the Remaining Strength of Corroded Pipelines, A
- supplement to ANSI/ASME B31 Code for Pressure Piping, New York, 1991. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS.NBR ISO 9001/2015:
- Sistemas de Gestão da Qualidade. Rio de Janeiro, 2015.
- ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS.NBR ISO 14001/2015:
- Sistemas de Gestão Ambiental. Rio de Janeiro, 2015.
- ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS.NBR ISO 45001/2018:
- Sistemas de Gestão de Saúde e Segurança Ocupacional. Rio de Janeiro, 2015.
-
- ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS; NBR 12.712: Projeto de
- Sistemas
- de Transmissão e Distribuição de Gás Combustível.
- BRITISH STANDARDS INSTITUTIO; BS8010: Pipelines on Land: Construction And Instalation.
- GUEDES, Marcelino, 2019. Theft in pipelines: Integrated actions to save lives.
- KRZYWICK, Robert, 2011. Using the safety perception survey to acess your organization's safety culture.
- PETROBRAS N-0464 H: Construção, Montagem e Condicionamento de Duto Terrestre. Rio
- de Janeiro, 2004.
- RESOLUÇÃO ANP n° 6/2011: Regulamento Técnico de Dutos Terrestres, 2011.

The Impact Of Geohazards On The Trans Anatolian Natural Gas Pipeline Project - TANAP

Klaus Robl; Alper Taşdemir, Ahmet Şaşmaz > ILF Consulting Engineers Austria GmbH; TANAP

Abstract

The routing of a pipeline is one of the most critical but often underrated activities in establishing a pipeline and has a direct impact on all aspects of building the pipeline – design, construction, operation, maintenance and most importantly on the overall cost of the pipeline.

A key element which governed the route and design of the Trans Anatolian Gas Pipeline Project (TANAP) were geohazards. Geohazards pose major risks for pipeline infrastructure if not identified in early stages of a project. Early identification of natural hazards leads to optimized operability and minimized maintenance costs and thus is a considerable benefit for clients in technical and economic terms.

Landslides, seismically induced hazards such as active faults, liquefaction, lateral spreading, slope and river erosion, scour and karst areas did play a major role for pipeline routing, design and construction and will play likewise in the future during the operation phase of TANAP. Therefore a detailed multi staged assessment was performed to identify the various geohazards, to adopt appropriate mitigation measures where required and to minimize the remaining risks to an acceptable level. In general, the main rationale of the pipeline routing was the avoidance of geohazards by taking constructability and other constraints into account. If this was not practicably feasible, mitigation measures in accordance with international best practices were implemented.

INTRODUCTION

TANAP aims to convey natural gas from the Caspian region via Turkey to Europe. It is part of the Southern Gas Corridor, which consists of three main elements: the South Caucasus Pipeline (SCPX) running form Azerbaijan's giant Shah Deniz gas field through Georgia to Turkey, TANAP which traverses Turkey from East to West between Posof at the Turkish-Georgian border and Ipsala at the Turkish-Greek border and the Trans-Adriatic Pipeline (TAP) starting from the Greece/Turkey border, passing through Albania and being tied to Italy through the Adriatic Sea.

The pipeline has a length of 1811 km and crosses various forms of landscapes from coastal plains to high altitude mountain ranges, climbing to an altitude of 2,750 m above sea level. The pipe diameter is 56" for the first 1338 km and 48" for the remaining 455 km up to the Greek border. The Sea of Marmara is being crossed North of the Dardanelles Strait by 2x36" pipes each having a length of 18 km. In its final extension, the pipeline system will comprise of 7 compressor stations and produce 31 bcm/a gas throughput with a design pressure of 95.5 barg.

Figure 1: Overview of the TANAP route.

The various landscapes encountered along the pipeline route as well as the geotectonic position of Turkey at the boundary between the converging Eurasian and African Plates and its geological history make this country almost unique in terms of type and number of terrain and ground related geohazards, including landslides, active faults, seismicity, liquefaction, lateral spreading, karst and sinkholes, soil erosion, flooding, and fluvial erosion. Consequently pipeline route selection in Turkey is a rather challenging and all the more important part of the pipeline design process.

GEOHAZARD ASSESSMENT METHODOLOGY

Large scale constraints such as general geological conditions, topography / slope angles, landslide prone areas and seismicity were already addressed at the initial stage of the project during the selection of the project area and the project corridor. GIS Cost Distance analysis tools were introduced to process these constraints amongst others to compute so called cost corridor maps indicating route corridor alternatives with least resistance (Schwarz, Robl, Wakolbinger et.al 2015).

Google Earth as well as geological and topographical maps enabled the optimization of route corridor alternatives and the identification of - in terms of geohazards - critical route sections The feasibility of the preferred route corridor was finalized upon completion of several site visits for each route option.

With the provision of orthophotos, stereo-matched orthophotos and contour lines, landslides (mudslides, rotational slides, rockfall areas), slope erosion, areas with high groundwater, river erosion, and sediment accumulation as well as karst could be assessed in a much higher detail and transferred into the GIS data base which allowed further route refinements.

All recorded geohazards within 50m each side of the centreline were then verified in the field and risk assessed focussing on landslides, erosion, river crossings and karst. Several walkovers were carried out for the entire route to ensure that no geohazard was missed. Certain landslide prone sections, mainly narrow ridges bordered by landslides on both sides, received a detailed geomorphological mapping.

Geotechnical ground investigations with boreholes, inclinometers, trial pits and CPTs were made to investigate landslides, liquefaction areas and karst. Active faults were located and characterized by trenching and geophysical exploration methods such as seismic refraction and ground penetrating radar. A residual hazard register comprising of all geohazards located in the vicinity of the pipeline was developed to use as a reference while implementing regular survey walks on the pipeline right of way during the operation phase.

GEOHAZARDS ENCOUNTERED ALONG THE ROUTE

GENERAL

The encountered geohazards comprise of landslides, seismically induced hazards such as active faults, liquefaction, lateral spreading and subsidence, slope erosion karst, and river erosion. The latter one has been excluded from this paper as this topic is very comprehensive and should be evaluated separately.

Figure 2: Landslides (areas marked in red) at Meryem Daĝ mountain range, Erzincan Province, give a good example of the impact of geohazards on the alignment of TANAP.

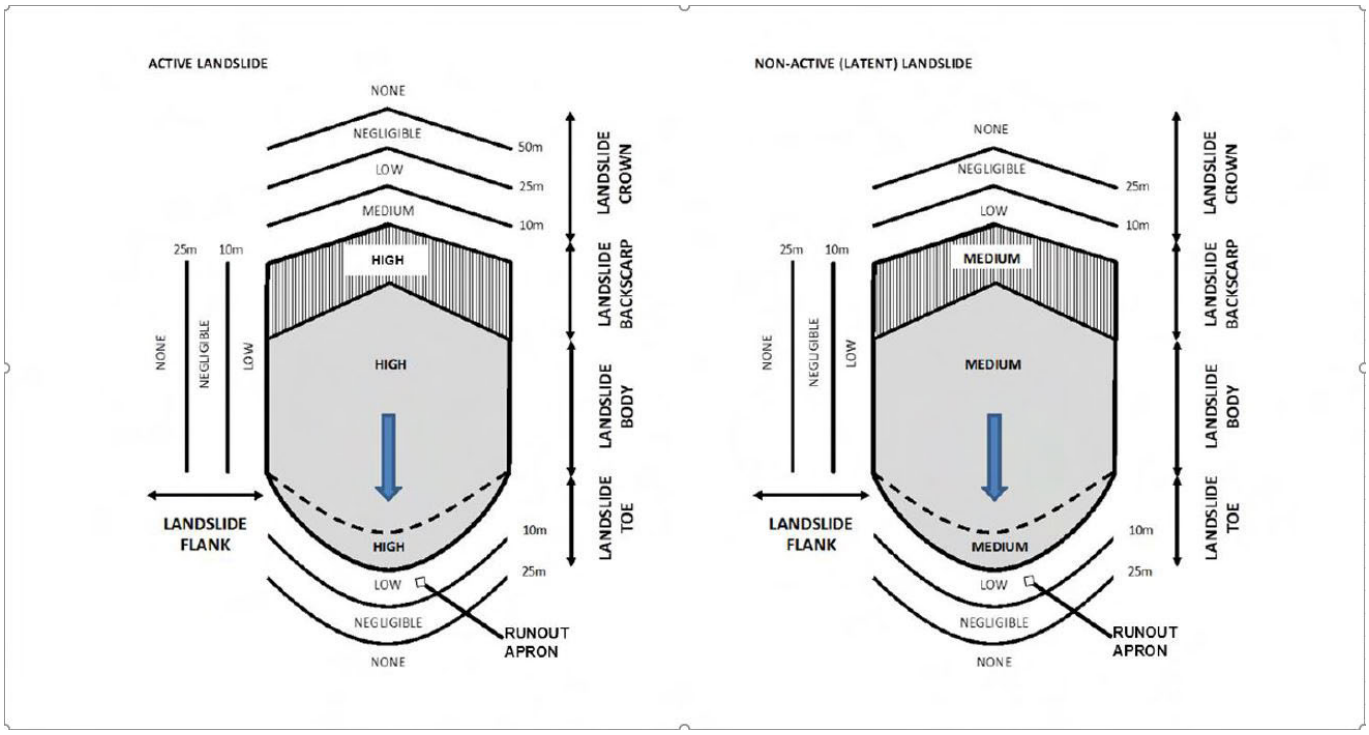

Figure 3: Generic rule set used for landslide hazard assessment (M. Lee)

LANDSLIDES

In mountainous terrain and areas with moderate to steep slopes landslides can pose a significant hazard to pipeline systems, because of the potential to cause large lateral or vertical displacements. This could compromise the integrity of the pipeline and result in leaks and ruptures during the operation phase of the pipeline. Landslides are one of the strongest constraints for pipeline routing due to the very limited technical measures to mitigate the risks. Therefore avoidance of landslides was key to a safe route.

Significant efforts have been made to identify landslides along the pipeline route. The route selection of the TANAP pipeline has been undertaken in accordance with international best practices by routing along ridge crests and spurs, minimising the exposure to side slope and avoiding all identified landslide features, irrespective of the activity state of the slide and, wherever possible, potentially unstable ground. However, routing the pipeline through mountainous terrain has inevitably led to certain sections of the TANAP pipeline being constructed in challenging conditions.

Generic "rule sets" that relate hazard class to landslide attributes that had been recorded in the field or determined from the GIS, have been developed considering the proximity to the pipeline, the position of the pipeline relative to the landslide, the activity state of the landslide and the thickness of landslide crossed by the pipeline.

As a result of route adjustments and some construction limitations only 50 landslides remained with a "Low" hazard rating while all others were graded as "None" or "Negligible" hazard. These 50 slides received utmost attention during construction. Further to that, all landslides within 50 m each side of the pipeline centreline will be inspected in the course of the annual geohazard surveys during operation phase.

SEISMICALLY INDUCED GEOHAZARDS

GENERAL

Due to its tectonic position between the converging African and Arabian Plates in the South and the Eurasian Plate in the North which results in the westward extrusion of the Anatolian Block, Turkey represents one of the most active seismic zones on earth. Seismically induced geohazards are widespread along the route and comprise of active faults / surface rupture, liquefaction, lateral spreading, landslides and ground shaking.

ACTIVE FAULTS

TANAP crosses nine active faults including the North Anatolian Fault Zone (NAFZ) which is crossed twice. The NAFZ is more than 1500 km long and has produced a series of devastating earthquakes in the 20th century. In 1939 a Mw 7.9 earthquake in the province of Erzincan resulted in a 322 km long surface rupture with a maximum horizontal displacement of 10,5m (Hartleb et al. 2006).

Most of the faults within the project area extend over large distances so that avoidance was in general not feasible. Therefore, finding the best possible crossing locations and the design and implementation of mitigation measures were the main objectives.

Site-specific geological, geomorphological, paleo-seismological and geophysical investigations as well as a probabilistic fault displacement hazard analysis were performed in order to locate the exact fault coordinates and to obtain all relevant fault parameters required for the subsequent pipe stress / strain analysis and the design of the pipeline fault crossings.

Hazard Rating		Mitigation Measures (Yes / No)	Definition *'Event' defined as pipeline rupture*
0	None	No	The event is not conceivable, even under exceptional circumstances
1	Negligible	No	The event is conceivable during the design life of the project but under exceptional circumstances
2	Low	No	The event might occur during the design life of the project under adverse climatic circumstances or a very low return period (very low frequency) very strong earthquake
3	Medium	Yes *Mitigation measure to be defined following detailed assessment*	The event possibly occurs during the design life of the project under very adverse climatic circumstances or a low return period (low frequency) strong earthquake
4	High	Yes	The event will probably occur during the design life of the project under adverse climatic condition
5	Extremely High	Yes	The event is expected to occur during the design life of the project

Table 1: Landslide hazard classification system

The fault crossing design is based on two conditions. These are (a) to make advantage of the high tensile strain capacity of a steel pipe and to avoid compression since the compressional capacity of a steel pipe is much lower and (b) to give enough room to the pipeline to allow it to move freely within the pipe trench during an earthquake.

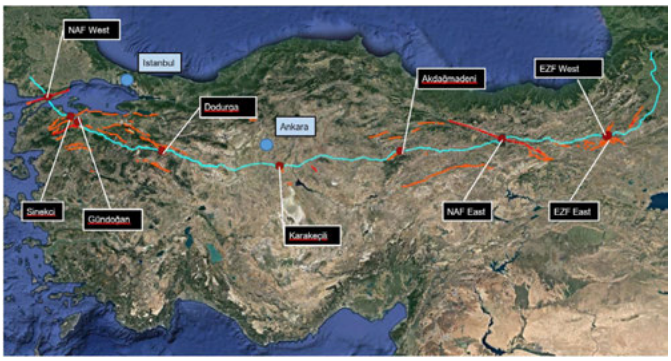

Figure 4: Fault crossings along the pipeline route; NAF – North Anatolian Fault, EZF – Erzurum Fault

The first condition could be fulfilled by selecting the optimum crossing angle which was derived from FE pipe stress analysis and strongly depends on the type of fault movement. The second principle was achieved by a wide pipe trench with shallow side walls and a loose cohesionless backfill.

A drainage system against buoyancy issues and in areas with cold winters an insulation layer were installed between backfill and topsoil to prevent the formation of ice within the backfill.

LIQUEFACTION AND LATERAL SPREADING

Liquefaction of soil is caused by a loss of shear strength due to the increase of pore water pressure by cyclic loading during earthquakes and may lead to pipeline buoyancy, vertical settlement and lateral ground movement.

Based on available ground investigation data a screening process for the entire pipeline was conducted to identify sections with liquefaction potential, by taking soil type, groundwater level and soil density into account. For these sections a detailed liquefaction and lateral spreading assessment including CPT investigations, subsequent liquefaction and buoyancy calculations as well as pipe stress analysis were conducted. The liquefaction assessments identified liquefaction hazards covering a length of 35 km and lateral spreading risks at 9 different locations - all of which were located at major river crossings – which could not be avoided by routing.

The liquefaction risk was mitigated using screw anchors. Lateral spreading was mitigated by burying the pipeline below the critical soil layer. Vertical settlements have not been considered critical due to sufficiently long transition zones.

SLOPE EROSION

While slope erosion has only a small impact on the pipeline route, its effects, when not mitigated, could lead to exposure of the pipeline due to loss of backfill.

The soil erosion assessment methodology used the internationally recognised Universal Soil Loss Equation (USLE) to predict the amount of soil loss due to erosion (t/ha/yr) and was helpful in identifying measures to reduce the soil loss.

The Universal Soil Loss Equation used in the soil loss assessment predicts the long-term average annual rate of erosion on a slope by using the following parameters: rainfall intensity, soil type, topography, vegetation cover and management practices. This erosion model, originally developed to predict soil loss in agriculture, is also applicable to non-agricultural conditions such as construction sites. The equation is written as follows:

$$A = R \times K \times LS \times C \times P \quad [1]$$

Where, A is potential long-term average annual soil loss in t/ha/yr, R is rainfall and runoff factor by geographic location, K is soil erodibility factor, LS is slope length gradient factor, C is vegetation and management factor, and P is support practice factor.

The thresholds for acceptable soil loss on the Tanap project were as follows:

- For sensitive sites (discharge to a water course), acceptable soil loss, A = 5 t/ha/yr
- General sites, acceptable soil loss, A = 10 t/ha/yr

Slopes with calculated A values higher than the relevant limits required to take mitigation measures. Mitigation measures were either reducing the length of the slope by installation of slope breakers, or reducing the exposure of the soil by re-vegetating or placing jute mats.

KARST

East of Sivas City, the route runs 92 km through one of the world´s largest gypsum karst terrains. Furthermore vast and heavily karstified limestone plateaus had to be crossed Northwest of Erzincan on a length of about 40 km .

Based on the morphology a karst classification, comprising of 6 karst types, was set up. A genetic karst model was developed in order to understand in which karst type the

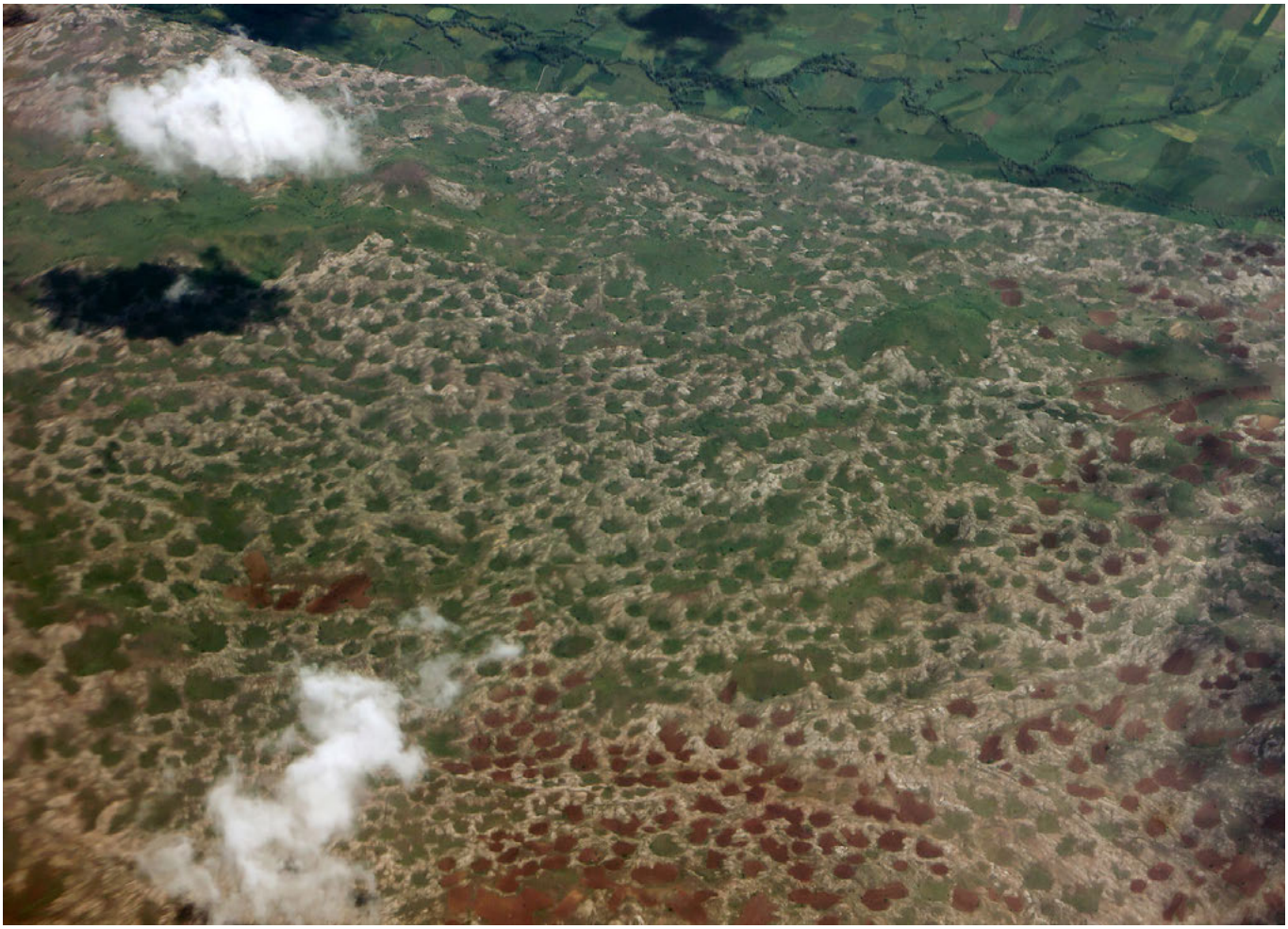

Figure 5: Polygonal gypsum karst of Sivas, aerial view

largest cavities had to be expected. Subsequently the karst hazards and mitigation measures could be defined for each karst type. The hazards associated with karst along the pipeline route comprise collapse dolines and subsidence sinkholes, soil loss through internal erosion and pinnacled bedrock. Field mapping showed that initial collapse dolines may be up to 20m wide but such events are extremely rare, while suffosion, the internal erosion of soil and transport into karst voids, is widespread.
Since the gypsum karst of Sivas covers an enormous area of 2140 km² (Doğan and Yeşilyurt 2019) it was not possible to avoid it by the pipeline route. Therefore pipeline routing focussed on avoiding or minimizing the crossing length of karst types exhibiting higher risks such as karst margins, plateaus next to poljes and doline floors. Special bedding requirements were defined to mitigate risk from pinnacled rockhead. Controlling the drainage was one of the most important measures to limit suffosion processes.

To prevent loss of bedding / padding, the pipe trench was lined with geotextile. Pipe stress analysis proofed that in the unlikely event of a collapse doline the pipe will be capable of spanning 30m wide gaps which is far beyond the maximum credible initial collapse width of 20m. Karstic voids encountered during construction were choked and sealed.

CONCLUSIONS

Geohazards are widespread throughout Turkey. A pipeline route crossing Turkey East to West will therefore face major challenges.

TANAP demonstrated that the involvement of geohazard experts at early stages of routing studies and investing into detailed ground investigations were highly profitable from which TANAP benefited greatly in design, construction and operation. The routing did not change only CAPEX but it also dramatically affects OPEX. This is underlined by the fact that no major geohazard, no additional landslide, could be identified after FEED phase.
Mitigation measures cover all identified geohazards by means of (a) route adaptions and avoidance and (b) by construction measures.

Apart from the huge importance of geohazards route selection also had to take into account a multitude of other constraints. Consequently it was the main task to find the safest and most stable route in the area of conflict between constructability, economic, social and environmental constraints and operability. A team of highly experienced geohazard and routing experts, adopting the best industry practice as well as introduction of the latest GIS technology were key factors for the successful completion of these tasks in spite of having a tough project completion schedule on the desk.

ACKNOWLEDGEMENTS

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References

1. Cruden,D.M.,Varnes, D.J.,1996, Landslide Types and Processes, Transportation Research Board, U.S. National Academy of Sciences, Special Report, 247: 36-75
2. Doğan, U., Yeşilyurt, S., 2019, Gypsum Karst Landscape in the Sivas Basin; in Landscapes and Landforms of Turkey (World Geomorphological Landscapes), pp 197-207, Springer
3. Emre, Ö., Duman, T.Y., Özalp, S. et al., 2018, Active fault database of Turkey. Bull Earthquake Eng 16, 3229–3275
4. Hartleb, D. et al 2006, A 2500-yr-long paleoseismologic record of large, infrequent earthquakes on the North Anatolian fault at Çukurçimen, Turkey, in GSA Bulletin (2006) 118 (7-8): 823-840.
5. Lee, E.M., Jones, K.C. 2014, Landslide Risk Assessment, Default Book Series
6. Schwarz, L., Robl, K., Wakolbinger, W. et al, 2015, GIS Based, Heuristic Approach for Pipeline Route Corridor Selection, in Engineering Geology for Society and Territory – Volume 6, pp 291-294, Springer
7. Sweeney, M. (ed.), 2005, Terrain and geohazard challenges facing onshore oil and gas pipelines. Thomas Telford, 758 pp., London.
8. Waltham, T., Fookes, P. 2005, Engineering classification of karst ground conditions, Speleogenesis and Evolution of Karst Aquifers.
9. Wischmeier, W.H., Smith, D.D. 1978, Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agriculture Handbook No. 537. USDA/Science and Education Administration, US. Govt. Printing Office, Washington,

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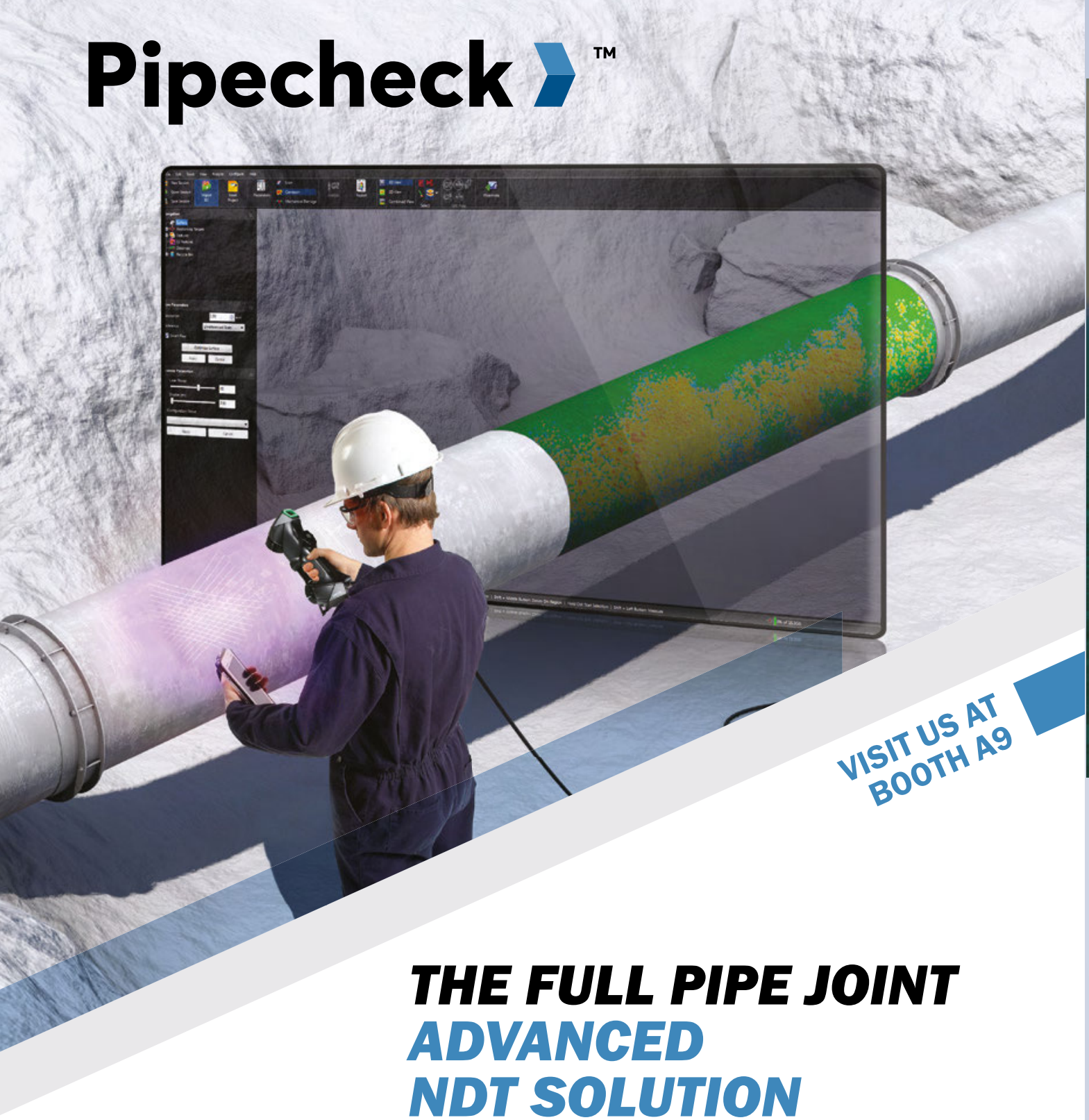

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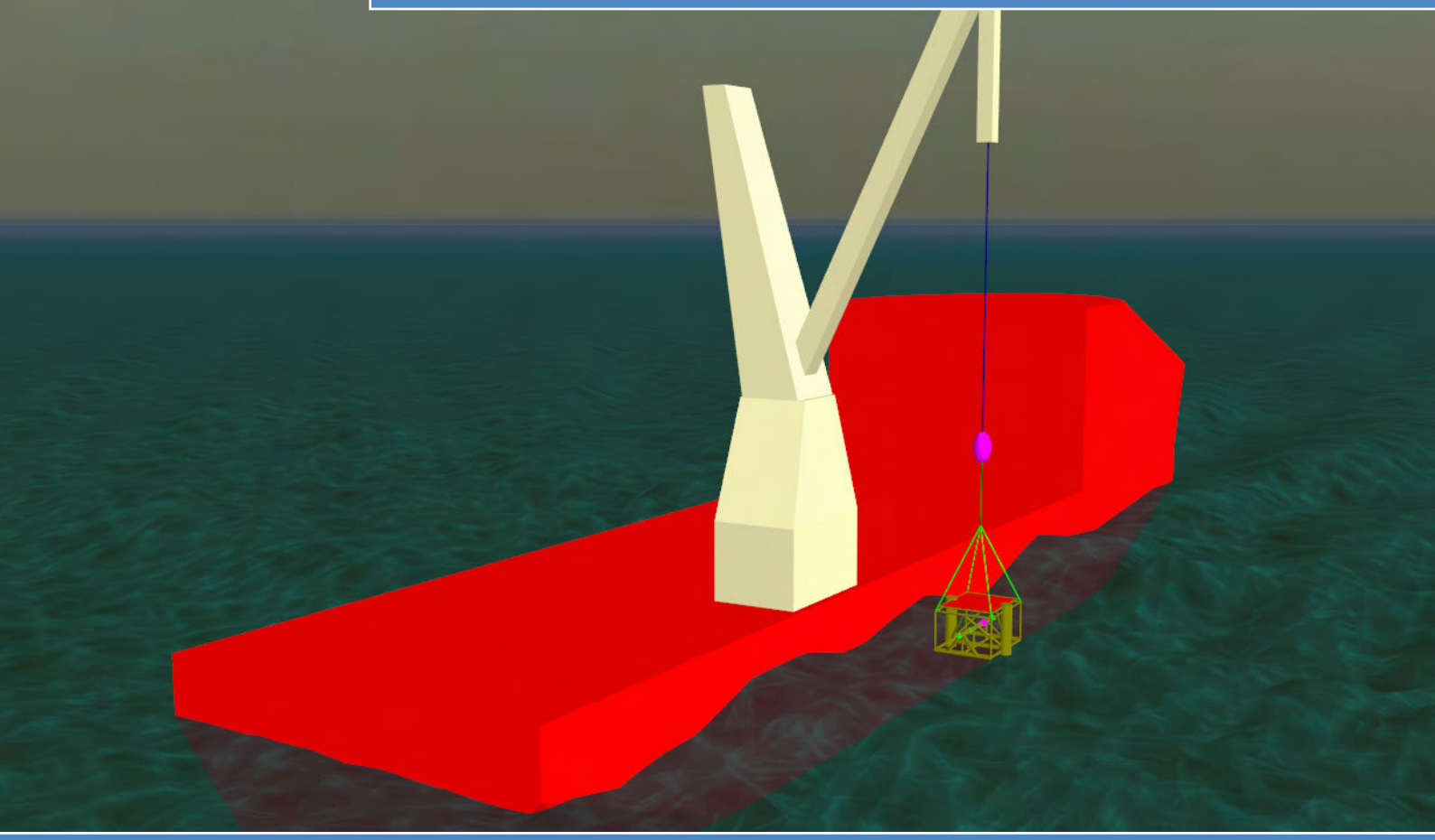
Motion Method Selection For Improved Accuracy Of Time-Domain Analysis For Subsea Installation



Hayley Welsh, Mahan Adib > PDi Ltd.

Abstract

When installing subsea structures and pipelines, the ability to capture the worst case loading and limiting sea states during the installation analysis can improve safety offshore and lower the operational risks. Therefore, it is important to select the correct analysis method to obtain the most accurate results.

Time-domain irregular wave dynamic analysis is performed using OrcaFlex as this is representative of a real sea state as opposed to regular wave. For irregular wave analysis, DNVGL-RP-N103 recommends performing a 3-hour simulation to ensure adequate statistics. However, this is very computationally expensive to perform due to the large quantity of load cases required. Therefore, it is common practice to analyse a short simulation period (e.g. 100s) that incorporates the expected worst-case loading during a 3-hour simulation at the point of interest on the vessel, such as crane tip or tensioner exit.

A short simulation can be defined by the largest rise/fall of a wave or extreme vessel response (max/min heave, velocity or acceleration). Knowing which method will capture the worst-case loading and associated limited sea states is critical in the analysis. As such, a study was performed using OrcaFlex to determine which method correlates most with the worst-case loading for subsea structure and pipeline installation.

The study involved running a 3-hour simulation to determine the time at which each extreme amplitude occurs for a range of wave heading/period combinations, using a static model containing just the installation vessel. The analysis was then re-run for a 100s duration, with the simulation starting at least 50s before the extreme amplitude time occurrence, using a static model of the complete subsea installation scenario. The outcome of the study was to suggest the most suitable method for obtaining the worst case loading for installation of subsea structures, pipelines and umbilicals.

INTRODUCTION

Due to the dynamic nature of waves, the response of structures and flowlines when subjected to this type of loading requires dynamic analysis. The purpose of performing dynamic analysis is to determine the maximum allowable sea state at which no integrity criterion is breached when the system (i.e. vessel and structure/flowline) is subject to environmental loads for a given period.

DNVGL-RP-N103 [1] states that structures with a significant dynamic response require stochastic modelling of the sea surface and its kinematics by time series. A sea state is specified by a wave spectrum with a given wave height, frequency, mean propagation direction and spreading function. It is also described in terms of its duration of stationarity, typically taken as 3 hours. Simulating a 3-hour wave condition of a system is a very time-consuming process and is not practical when performing dynamic analysis under strict time constraints. Therefore, an alternative approach can be taken that involves correlating the maximum structure/flowline loading with extreme vessel response to waves and identify a shorter time period (e.g. 100s) in which these events will likely occur.

Examples of "extreme kinematic criteria" includes the maximum vessel heave motion, velocity or acceleration, taken at the point of interest such as crane tip for structure deployment or tensioner exit for flowline installation. Based on the assumption that the vessel response is independent of the structure/flowline, the use of displacement RAOs can be justified. Therefore, it is possible to determine the time occurrence of the vessel's extreme motions using models that only contain the vessel object, rather than having to explicitly model the structure or flowline.

This means that a motion study can be performed prior to performing dynamic analysis of the system to determine the shorter time period within the 3-hour simulation for a given environmental condition.

The purpose of this study is to determine the extreme motion response that would generate maximum structure/flowline loading and capture the limiting sea state based on a shorter simulation approach.

BASIS OF ANALYSIS

This paper covers the extreme vessel response study for 1-off umbilical, 1-off rigid pipeline and 1-off manifold structure.

- Umbilical:
115mm OD, submerged weight = 11.9kg/m, bending stiffness = 2.4kN.m2

- Rigid Pipeline:
10" OD x 20.6mm WT, API 5L X65 grade, 32.6mm 4LPP coating

- Manifold Structure:
9.3m x 6.7m x 4.0m, weight in air = 94Te, submerged weight = 77.0Te

A normal lay configuration was considered for both umbilical (Figure 1) and rigid pipeline installation (Figure 2), with the umbilical being installed through a moonpool and the rigid pipeline from a stern lay ramp.

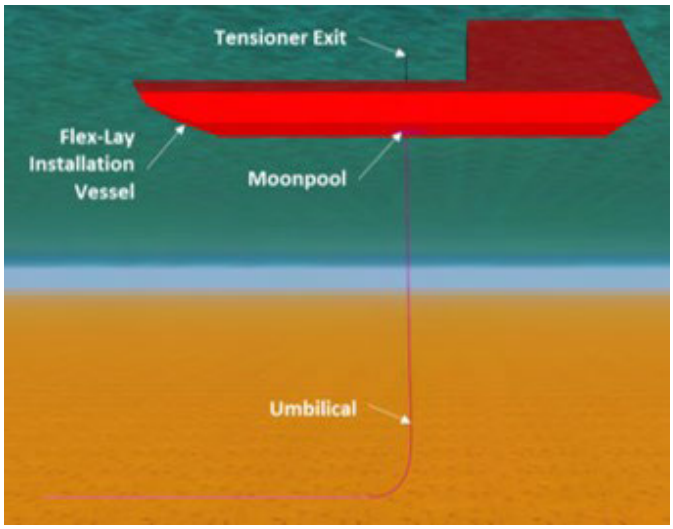


Figure 1: Typical Umbilical Installation Model

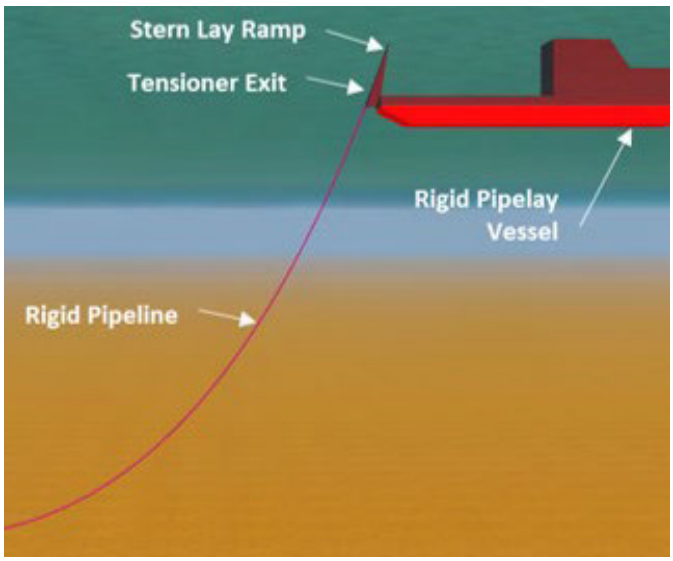


Figure 2: Typical Rigid Pipelay Installation Model

Stages of manifold deployment (Figure 3) considered include lowering through the splash zone and near the seabed prior to landing the structure.

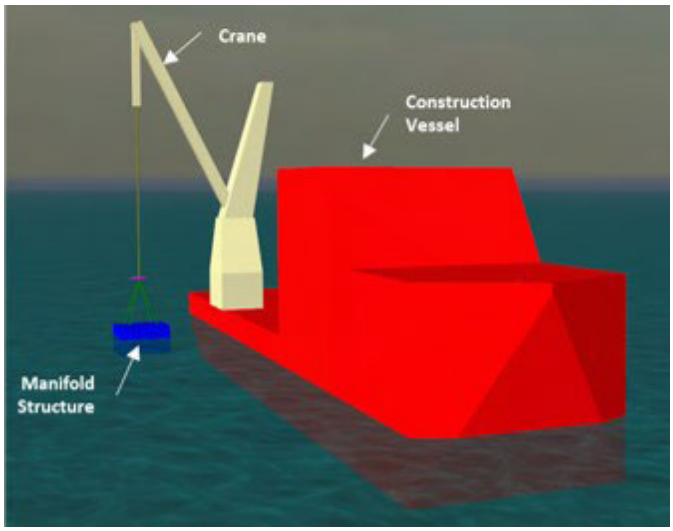


Figure 3: Typical Structure Deployment Model

The analysis was conducted using OrcaFlex version 10.3d. OrcaFlex is the industry standard marine dynamics program developed by Orcina for static and dynamic analysis of a wide range of offshore systems, including all types of marine risers (rigid and flexible), global analysis, moorings, installation and towed systems.

Table 1 summarises the environmental parameters used as part of this study.

Parameter	Umbilical	Rigid Pipeline	Structure	Unit
Wave Spectrum	Irregular Wave - ISSC			-
Tp Range	6-16, 1s step			s
Hs Range	0.5-4.0, 0.5m step			m
Wave Direction	0-180, 15° steps		Head Seas ±15°	Deg
Water Depth	100, 1000	157	1480	m

Table 1: Environmental Parameters gallowgate

The wave heading convention used for the analysis is presented in Figure 4.

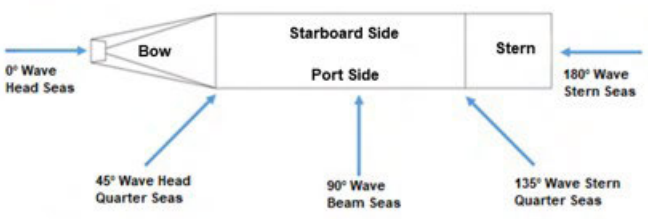


Figure 4: Wave Heading Convention

The design criteria for determining the allowable sea state are as follows:

- Umbilical — Minimum Bend Radius
- Rigid Pipeline — Maximum Stress
- Structure — Maximum Sling Tension, No Slack Slings

METHODOLOGY

A sensitivity analysis was performed to determine which vessel response would be the most limiting for the umbilical and rigid pipeline installation, and structure deployment.

It was assumed that structure deployment would be limited by the motion amplitude at the crane tip, whereas umbilical and rigid pipeline installation would be limited at the tensioner exit. Cases analysed are as follows:

- Maximum heave (mean position to crest)
- Minimum heave (mean position to trough)
- Maximum vertical velocity
- Minimum vertical velocity
- Maximum vertical acceleration
- Minimum vertical acceleration
- Largest rise/fall of the wave elevation

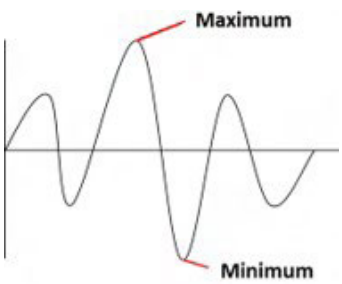


Figure 5: Motion Parameter

Note: largest rise/fall of the wave elevation is independent of point of interest on the vessel.

For each analysis type, a full 3-hour simulation was run to determine the time origins at which each maximum amplitude occurs using a static model containing just the installation vessel. The analysis was then re-run for a 100s duration, with the simulation starting at least 50s before the extreme amplitude time occurrence, using a static model of the complete subsea installation scenario as per the environmental conditions outlined in Section 2 to determine the allowable sea state of each wave heading/period combination.

An allowable sea state table was generated for each vessel motion type based on the design criteria specified in Section 2. Table 2 shows an example of the allowable sea state table for the umbilical installation maximum heave motion scenario.

The results from each vessel motion study were combined to present the worst case allowable sea state table from which each vessel motion study could be assessed, as shown in Table 3 for the umbilical installation.

Table 4 shows the allowable sea state comparison table for the umbilical case based on maximum heave motion. This table was generated for all vessel motion types and largest rise/fall of a wave.

Where a cell shows '-', this signifies that the allowable sea state is equal to that reported in the combined motion allowable sea state table in Table 2. Cells that contain a value, represent wave heading and period combinations where the sea state was greater (i.e. less conservative) than that reported in the combined table, with the cell value being the difference between the allowable sea state from the combined motion table and the allowable sea state table of a given motion type. Refer to Table 4 for further explanation.

	Limited Hs (m) - Max. Heave										
Wave Directions (Deg)	Tp = 6	Tp = 7	Tp = 8	Tp = 9	Tp = 10	Tp = 11	Tp = 12	Tp = 13	Tp = 14	Tp = 15	Tp = 16
(Stern Seas) 0	4.0	3.4	3.7	3.3	3.5	2.8	3.2	2.8	2.5	2.7	2.3
15	4.0	3.3	3.6	3.2	3.4	3.2	3.1	3.2	2.5	2.7	2.3
30	4.0	3.3	3.4	3.2	3.1	3.0	2.9	3.0	2.4	2.7	2.2
45	4.0	4.0	3.3	2.9	2.8	2.9	2.2	2.4	1.9	2.2	2.4
60	4.0	3.1	2.7	2.0	2.2	1.8	1.8	1.8	1.8	2.1	2.0
75	2.5	1.6	1.4	1.4	1.3	1.2	1.6	1.5	2.0	1.7	1.7
(Beam Seas) 90	1.9	1.2	1.2	1.2	1.1	1.3	1.4	1.5	1.6	1.5	1.5
105	3.0	1.6	1.4	1.4	1.3	1.4	1.5	1.7	1.8	2.0	1.8
120	4.0	4.0	3.0	2.0	2.2	1.8	1.9	1.9	1.9	2.2	1.9
135	4.0	4.0	4.0	3.7	2.8	2.5	2.5	2.5	2.1	2.4	1.9
150	4.0	4.0	4.0	4.0	3.8	3.2	2.7	2.6	2.4	2.8	2.0
165	4.0	4.0	4.0	4.0	4.0	3.6	2.7	2.8	2.6	3.0	2.0
(Head Seas) 180	4.0	4.0	4.0	4.0	4.0	3.7	2.7	2.9	2.6	3.2	2.0

Table 2: Max. Heave Allowable Sea State Table – Umbilical

	Limited Hs (m) - All Motions										
Wave Directions (Deg)	Tp = 6	Tp = 7	Tp = 8	Tp = 9	Tp = 10	Tp = 11	Tp = 12	Tp = 13	Tp = 14	Tp = 15	Tp = 16
(Stern Seas) 0	4.0	3.4	3.7	3.3	3.5	2.8	2.8	2.8	2.3	2.6	2.3
15	4.0	3.3	3.6	3.2	3.4	2.8	2.8	2.7	2.2	2.5	2.3
30	4.0	3.3	3.4	3.2	3.0	2.7	2.7	2.5	2.1	2.4	2.2
45	4.0	4.0	3.3	2.9	2.7	2.4	2.2	2.2	1.9	2.2	2.0
60	4.0	3.1	2.4	2.0	2.0	1.8	1.8	1.8	1.8	2.0	1.9
75	2.4	1.6	1.4	1.4	1.3	1.2	1.4	1.4	1.4	1.7	1.7
(Beam Seas) 90	1.8	1.2	1.2	1.2	1.1	1.1	1.2	1.3	1.2	1.5	1.5
105	3.0	1.6	1.4	1.4	1.3	1.3	1.5	1.5	1.4	1.6	1.7
120	4.0	4.0	2.8	2.0	2.0	1.8	1.8	1.8	1.7	1.8	1.9
135	4.0	4.0	4.0	3.6	2.8	2.5	2.3	2.3	2.1	2.2	1.9
150	4.0	4.0	4.0	4.0	3.8	3.1	2.7	2.6	2.4	2.4	2.0
165	4.0	4.0	4.0	4.0	4.0	3.4	2.7	2.8	2.4	2.6	2.0
(Head Seas) 180	4.0	4.0	4.0	4.0	4.0	3.7	2.7	2.9	2.4	2.6	2.0

Table 3: Combined Allowable Sea State Table – Umbilical

	Allowable Hs (m) - Max. Heave										
Wave Directions (Deg)	Tp = 6	Tp = 7	Tp = 8	Tp = 9	Tp = 10	Tp = 11	Tp = 12	Tp = 13	Tp = 14	Tp = 15	Tp = 16
(Stern Seas) 0	-	-	-	-	-	-	0.4	-	0.2	0.1	-
15	-	-	-	-	-	0.4	0.3	0.5	0.3	0.2	-
30	-	-	-	-	0.1	0.3	0.2	0.5	0.3	0.3	-
45	-	-	-	-	0.1	0.5	-	0.2	-	-	0.4
60	-	-	0.3	-	0.2	-	-	-	-	0.1	0.1
75	0.1	-	-	-	-	-	0.2	0.1	0.6	-	-
(Beam Seas) 90	0.1	-	-	-	-	0.2	0.2	0.2	0.4	-	-
105	-	-	-	-	-	0.1	-	0.2	0.4	0.4	0.1
120	-	-	0.2	-	0.2	-	0.1	0.1	0.2	0.4	-
135	-	-	-	0.1	-	-	0.2	0.2	-	0.2	-
150	-	-	-	-	-	0.1	-	-	-	0.4	-
165	-	-	-	-	-	0.2	-	-	0.2	0.4	-
(Head Seas) 180	-	-	-	-	-	-	-	-	0.2	0.6	-

Table 4: Allowable Sea State Comparison Table – Umbilical, Max. Heave Motion

Wave Direction [Deg]	Tp [s]	Allowable Sea state, Hs [m]		Difference between Allowable Sea State. Hs [m]
		Max. Heave Motion	Combined Motion	
0	6	4.0	4.0	0.0
0	12	3.2	2.8	0.4

Table 5: Difference between Allowable Sea State – Combined Motion vs. Max. Heave

To compare the sea states for each motion type against the combined allowable sea state, the ratio of number of cases with no difference, i.e. '-', to the total number of cases is calculated. For example, there are 90 cases equal to the combined allowable sea state in Table 3.3, with the total number of cases being 143. Therefore, the ratio is calculated as 90/143 = 63%.

RESULTS

UMBILICAL INSTALLATION

Table 6 summarises the umbilical installation results for the number of cases equal to the lowest allowable calculated sea state for each extreme vessel response analysed. This is based on a total of 143 wave heading/period combinations.

Minimum velocity at the tensioner exit has the most cases equal to the lowest allowable calculated sea state for umbilical installation in shallow and deep water. This suggests that all umbilical analysis should consider this vessel response when applying wave loading.

Table 7 summarises the allowable sea state for the different umbilical configurations. The majority of cases agree, with the exception of the largest rise or fall scenario which shows a higher sea state in deep water.

Based on the results presented in Table 6 and Table 7, the recommended extreme vessel response to specify the short simulation time origin is minimum velocity at the tensioner exit.

RIGID PIPELINE INSTALLATION

Table 8 summarises the rigid pipeline installation results for the number of cases equal to the lowest allowable calculated sea state for each extreme vessel response analysed. This is based on a total of 143 wave heading/period combinations.

Minimum velocity at the tensioner exit has the most cases equal to the lowest allowable calculated sea state for rigid pipeline installation in a shallow water depth. This suggests that all pipeline analysis should consider this vessel response when applying wave loading. Table 9 summarises the allowable sea state for the rigid pipeline.

The allowable sea state is the same for all extreme vessel responses analysed when pipeline installation is in a shallow water depth. Based on the results presented in Table 8 and Table 9, the recommended extreme vessel response to specify the short simulation time origin is minimum velocity at the tensioner exit.

Installation Product	Water Depth [m]	% No. of Cases = Lowest Allowable Calculated Sea States						
		Max Heave	Min Heave	Max Velocity	Min Velocity	Max Accel.	Min Accel.	Largest Rise or Fall
Umbilical	100	63%	76%	60%	88%	69%	52%	51%
	1000	62%	63%	57%	93%	62%	57%	50%

Table 6: Allowable Sea State Comparison Results – Umbilical Installation

Installation Product	Water Depth [m]	Allowable Sea state, Hs [m]						
		Max Heave	Min Heave	Max Velocity	Min Velocity	Max Accel.	Min Accel.	Largest Rise or Fall
Umbilical	100	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	1000	1.0	1.0	1.0	1.0	1.0	1.0	1.1

Table 7: Allowable Sea State Summary – Umbilical Installation

Installation Product	Water Depth	% No. of Cases = Lowest Allowable Calculated Sea States						
		Max Heave	Min Heave	Max Velocity	Min Velocity	Max Accel.	Min Accel.	Largest Rise or Fall
Rigid Pipe	157m	43%	55%	35%	88%	55%	38%	42%

Table 8: Allowable Sea State Comparison Results – Rigid Pipe Installation

Installation Product	Water Depth	Allowable Sea state, Hs [m]						
		Max Heave	Min Heave	Max Velocity	Min Velocity	Max Accel.	Min Accel.	Largest Rise or Fall
Rigid Pipe	157m	1.4	1.4	1.4	1.4	1.4	1.4	1.4

Table 9: Allowable Sea State Summary – Rigid Pipe Installation

Installation Product	Water Depth	% No. of Cases = Lowest Allowable Calculated Sea States						
		Max Heave	Min Heave	Max Velocity	Min Velocity	Max Accel.	Min Accel.	Largest Rise or Fall
Manifold Structure	Splash zone	39%	39%	30%	39%	45%	42%	42%
	Near Seabed	30%	18%	30%	45%	52%	45%	27%

Table 10: Allowable Sea State Comparison Results – Structure Deployment

Installation Product	Water Depth	Allowable Sea state, Hs [m]						
		Max Heave	Min Heave	Max Velocity	Min Velocity	Max Accel.	Min Accel.	Largest Rise or Fall
Manifold Structure	Splash zone	1.0	1.0	1.0	1.0	1.0	1.1	0.9
	Near Seabed	0.5	0.7	0.5	0.5	0.5	0.5	0.5

Table 11: Allowable Sea State Summary – Structure Deployment

STRUCTURE DEPLOYMENT

Table 10 summarises the structure deployment results for the number of cases equal to the lowest allowable calculated sea state for each extreme vessel response analysed. This is based on a total of 33 wave heading/period combinations.

Structure deployment analysis in the splash zone region and near the seabed shows that maximum acceleration results in the most cases being equal to the lowest calculated sea states. Table 11 summarises the allowable sea state for the different stages of structure deployment.

The majority of extreme vessel responses agree in terms of allowable sea state, with the exception of minimum acceleration and largest rise/fall for the splash zone region and minimum heave for the near seabed case.

Based on the results presented in Table 10, the recommended extreme vessel response to specify the short simulation time origin is maximum acceleration at the crane tip location. However, Table 11 shows that largest rise/fall of a wave reported the minimum allowable sea state from all motions analysed when the structure was in the splash zone region. Therefore, it is recommended that two motions are checked for structure deployment; maximum acceleration and largest rise/fall of a wave. Due to structure deployment analysis requiring less load cases compared to umbilical and pipeline installations, it is feasible to consider two different motion types when analysing structures.

CONCLUSIONS & RECOMMENDATIONS

In conclusion, this study has been able to characterise the recommended motion response that will generate maximum structure/flowline loading and capture the limiting sea state based on a shorter simulation approach.

The minimum velocity allowable sea state comparison table for umbilical installation in shallow and deep water showed the most correlation with the combined allowable sea state table, with 88% of cases matching for shallow water and 93% of cases matching for deep water. The lowest calculated allowable sea state reported in the combined sea state table was captured by all extreme vessel responses in both shallow and deep water. The largest rise/fall of a wave motion captured the lowest allowable sea state in shallow water but showed a higher sea state in deep water, therefore, confirming that this motion response should not be used to characterise the short simulation time origin.

Rigid pipeline installation in shallow water showed most correlation with minimum velocity at the tensioner exit, with 88% of the minimum velocity comparison table being equal to the lowest allowable sea states reported in the combined motion results table. All extreme vessel responses, along with the largest rise/fall of a wave, captured the lowest allowable sea state reported in the combined allowable sea state table.

Structure deployment through the splash zone and near the seabed correlated mostly with maximum acceleration at the crane tip. However, difference between each of the motion responses in terms of number of cases equal the lowest calculated sea state reported in the combined results table, is marginal compared to umbilical and rigid pipeline installation. The lowest calculated allowable sea state in the combined motion table was captured by the largest rise/fall of a wave motion response but all extreme vessel motion responses reported a higher sea state. Therefore, for structure deployment it is recommended that both maximum acceleration at the crane tip and largest rise/fall of a wave are assessed.

The recommended motion response for each product type presented within this paper is summarised in Table 12.

Installation	Recommended Motion Response
Umbilical	Minimum Velocity
Rigid Pipeline	Minimum Velocity
Structure Deployment	Maximum Acceleration, Largest Rise or Fall of Wave

Table 12: Recommended Motion Response

FUTURE WORK

The work presented as part of this paper was based on project specific cases. To fully understand the correct approach to take when characterising the short simulation period, further work would be required to understand the effect of the varying following parameters:

- Water depth (shallow and deep water)
- Product size, weight and stiffness
- Structure weight, size and layout

ABBREVIATIONS

4LPP	4-Layer Polypropylene
OD	Outer Diameter (mm)
Hs	Significant Wave Height (m)
ISSC	Pierson-Moskowitz Wave Spectrum
RAO	Response Amplitude Operator
Tp	Peak Wave Period (s)
WT	Wall Thickness

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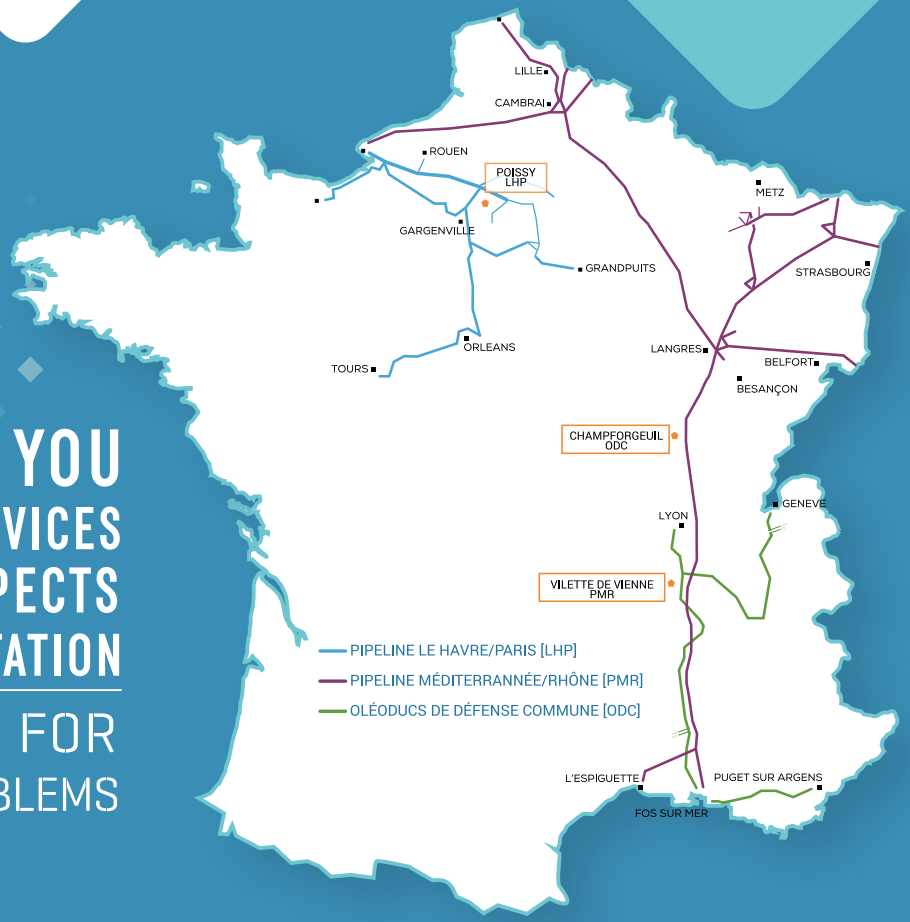

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In the next Edition of **ptj:**

April 2020

Leak Detection/Monitoring

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Pipeline Technology Journal

In the next Edition of **ptj:**

Leak Detection/Monitoring

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Event Calendar		
Global Petroleum Show	9 - 11 June 2020	Calgary, Canada
UESI Pipelines 2020 Conference	9 - 12 August 2020	San Antonio, USA
IPC - International Pipeline Conference	28 September - 2 October 2020	Calgary, Canada
Infrastructure Development in Africa (IDA)	10 - 12 November 2020	Tunis, Tunisia

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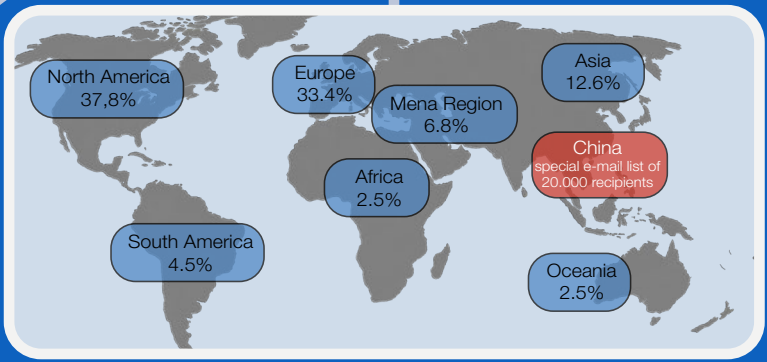

ptj-brand-audiences

Audience Job Levels

- 11% CEO
- 20% Director
- 26% Manager
- 43% Executive

A manifold database
We deliver content to local practicioners and global decision-makers alike, making the ptj-brand a suitable tool for global knowledge distribution as well as developing and upholding overall visibility in the global pipeline industry.

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- 23% Operators
- 61% Techn. / Service Providers
- 11% Researchers
- 4% Authorities