UNDERSTANDING THE RESULTS OF AN INTELLIGENT PIG INSPECTION

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Introduction

Intelligent pigs are used extensively for inspecting pipelines. Their use has been increasing rapidly due to their proven benefits, expanding capabilities, and legislative requirements.

The result of an intelligent pig inspection is an inspection report with a list of defects. To gain the full benefit from an inspection the pipeline operator must understand the inspection process, and what the list of defects means for the immediate and the future integrity of the pipeline.

The Inspection Process

Running an intelligent pig in a pipeline is a significant project with potential safety and operational implications. Any pigging operation should be carefully planned to ensure that the correct tool is used, that appropriate pipeline cleaning is carried out, the pig will not get stuck, contingency measures are in place to locate and remove a stuck pig, and that safe procedures for pig launch, receive, and handling are followed. Guidance on managing an intelligent pig inspection is available[1].

Assessing Defects

There are a number of recognised defect-acceptance (or 'fitness-for-purpose') methods available for assessing these defects (for example ASME B31G, and API 579), but these methods are simply calculation methodologies; there are many issues related to the input data and the engineering assessment that also need to be resolved in order to have a full understanding of the pipeline condition. These include tolerances on pig data, the age of the pipeline, the product transported, the operation of the pipeline (cyclic pressures), thermal expansion loads, ground movement loads, and the type and cause of the defect.

Consequently, it is good practice to approach defect assessments holistically. This means that all aspects of the pipeline's integrity are taken into account, and it is not viewed simply as an exercise of inputting smart pig data into an equation and simply obtaining a predicted failure pressure for the defect.

This paper provides a process for reviewing any set of inspection data, and gives some simple guidance on understanding the results of an intelligent pig inspection, based on examples for calliper, magnetic flux leakage (MFL), ultrasonic (UT) metal loss, and UT crack detection inspections.

Overview

When the results of an inspection of a pipeline are received a staged process of review and assessment is recommended. This process is outlined in Figure 1.

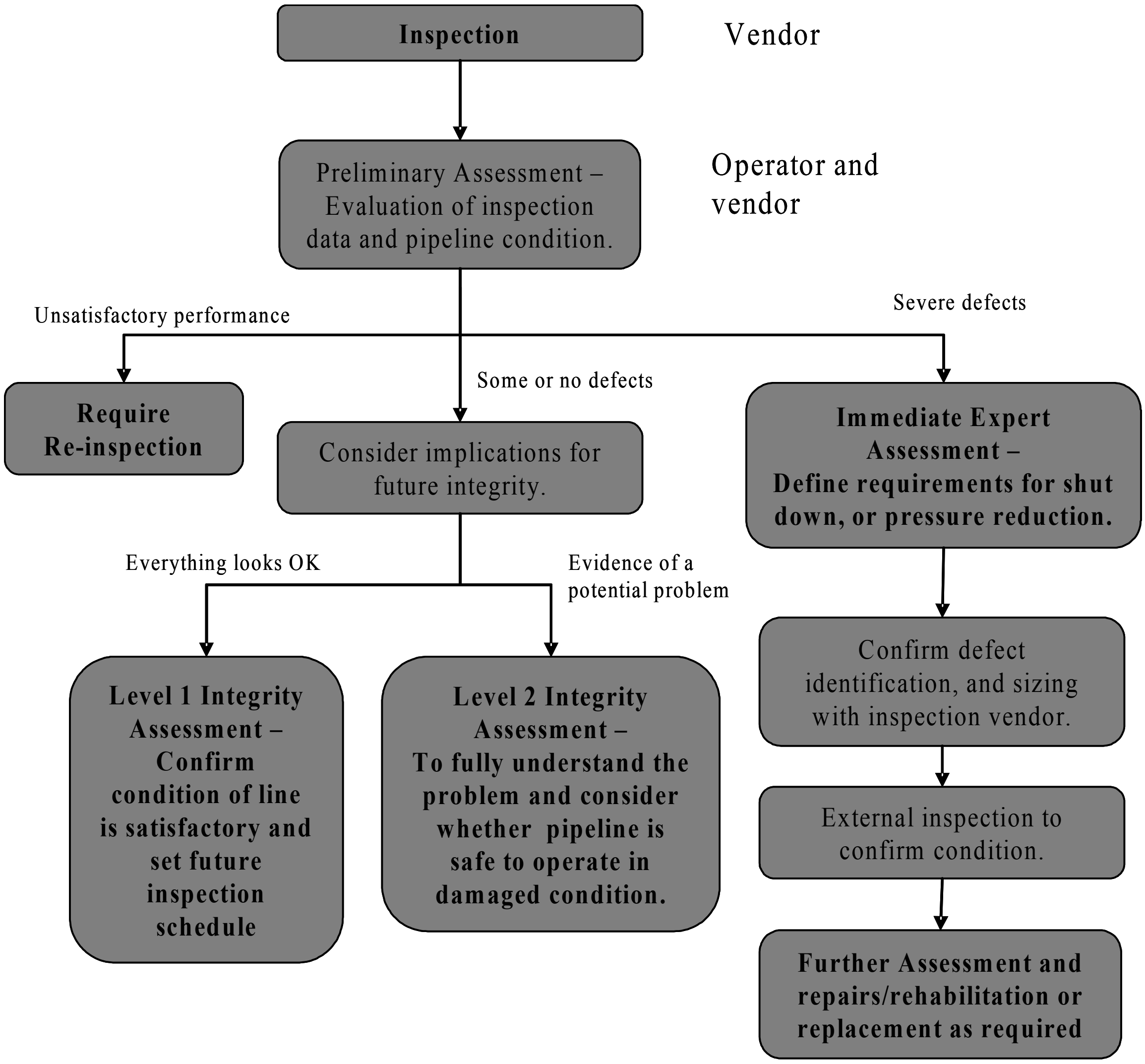

Figure 1 Assessing Intelligent Pig Data

Inspection

There are now published standards that help operators through the intelligent pig inspection process NACE RP 0102-2002□; API 1163□; and ASNT ILI-PQ-2005□. In addition there are standards such as API 1160□ and ASME B31.8S□ that provide guidance on the selection of pigs for detecting particular types of defects.

Preliminary Assessment

The first stage of assessing the results of an intelligent pig inspection is a review of the results by the pipeline operator, or their representative. This review has the following objectives;

a) To identify any potentially severe defects requiring immediate action.
b) To ensure that the inspection was successful, that is to ensure that data was collected for the required percentage of the line, and in particular that data has been collected for any locations that may previously have been identified as critical. It may be that the performance was not satisfactory or did not meet the

standards required by the contract. If this it the case, a re-inspection may be required.

c) To confirm that there is no ambiguity over the defects reported, for example due to terminology such as 'crack like' used to refer to defects.

d) To confirm that the defects reported are credible. That is, they are expected or there is a reasonable explanation for their presence. For example, numerous 'rock dents' are common in large diameter thin wall onshore pipelines; however, small diameter thick wall offshore pipelines should not contain a large number of dents.

e) Give a qualitative assessment of the condition of the pipeline: Are there many defects or just a few?

This initial review does not require a high level of expertise in pipeline defect assessment or a detailed understanding of the inspection technology. It does require an appreciation of pipeline defects, what causes them and their significance. It also requires an appreciation of the capabilities and limitations of the inspection technology. This review should not be carried out by someone with limited experience of pipeline integrity management.

If severe defects are reported, then immediate action will be required. This may be an immediate shutdown or pressure reduction, or rapid expert evaluation to consider the need for shutdown or pressure reduction. The significance of defects will depend on the pipeline design, materials and operation.

Severe defects include:

- Corrosion (or any metal loss) more than 80% through the pipe wall.
- Dents (or bore reductions) greater than 6% of the pipe diameter.
- Dents with associated gouging (metal loss), or cracking.
- Dents on seam or girth welds of poor quality.
- Cracks.
- Buckles.

The results of this review will dictate the need for further assessment. Of course with some pipelines there are known problems and the requirement for expert assessment of the defects will be obvious before the inspection is carried out.

If the inspection has not been satisfactory then a re-inspection may be required.

<u>Expert Assessment</u>

Following the preliminary assessment, some further assessment will be required. This may be:

i) A basic assessment limited to confirming that there are no significant problems, and setting the proposed date of the next inspection based on the predicted operating conditions.

ii) An integrity evaluation that provides an assessment of the overall condition of the pipeline, give recommendations for future repairs, estimates the potential growth or degradation rate of the defects and provided recommendations for future inspection to ensure defects can be repaired before they become critical.

iii) A detailed urgent defect assessment to evaluate the need for continued shutdown or pressure reduction and identify appropriate repair methods.

Fitness for Purpose[1] Assessment

A ‘fitness-for-purpose’ assessment (better described as an ‘engineering critical assessment’ [,]), calculates the failure condition of a structural defect and compares it with the operating condition of the structure.

The fitness for purpose of a pipeline containing a defect may be estimated by a variety of methods ranging from previous relevant experience, to model testing, or analytically. These latter assessments can be by:

- Generic methods [,],
- Traditional pipeline industry methods [-],
- Recognised pipeline codes developed using the traditional methods [,],
- Publications from pipeline research groups [-],
- ‘Best practice’ publications emerging from Joint Industry Projects [-].

Key Considerations

Any operator conducting a fitness for purpose calculation should consider the following[, ,]:

- Understand the defect – what caused it, how it may behave.
- The engineer doing the assessment - experience, training, independence, overview, support.
- Assessment methods – use best practice.
- The consequences of the defect failing.

Further details of these considerations are given in Reference .

Input Data

The type and level of detail of information that is required in any assessment depends on the depth and scope of the assessment. The issues that typically should be considered include[]:

1. The pipeline – geometry, materials, operation, environment, history, etc..
2. Stresses – all loads acting, future changes, cyclic loads, construction, residual, etc..
3. Inspection method – capability, reliability and accuracy.
4. Defect – cause, dimensions, type, location, growth, etc..
5. Consequences – leak, ignition, pollution, etc..

Further details are given in Reference .

Considerations when Using Intelligent Pig Data.

The following points should be considered when using intelligent pig data to aid a fitness-for-purpose assessment[]:

[1] We use ‘fitness for purpose’ in the pipeline integrity business as ‘a failure condition will not be reached during the operation life of the pipeline’. Note that fitness for purpose also has a (different) legal meaning, particularly in the construction business, with differing liability.

- Pigs cannot detect all defects, all of the time.
- Pigs measurements have associated errors.
- Pigs cannot discriminate between all defects.
- Treat simple defect assessments by pigging companies (e.g. the 'ERF') with care – they may not be appropriate for all defects and all pipelines.
- Use all available inspection data – e.g. past inspection reports.
- Location – defect location accuracies of pigs vary and have errors.
- Origin – always be able to explain the presence of a reported defect.

Confirmatory Inspection/Verification.

Although continuous improvements are being made to the accuracy of intelligent pigs the defects are sometimes under or over reported in size. This may be for a variety of reasons. Therefore in onshore applications confirmatory dig and inspection of defects is always recommended irrespective of whether repairs are required.

The dig should also be used as an opportunity to gather additional information which feeds back into the overall assessment, particularly when inspecting external corrosion defects where the corrosion mechanism is not fully understood. This information includes:

- Defect size and orientation
- Coating condition
- Soil type, moisture content etc
- Soil resistivity
- CP potentials
- Bacterial enumeration if bacteria are suspected

Inspection is more difficult in offshore applications but external defects can be inspected visually by ROV if the pipeline is not buried and diver inspection of risers can help to confirm the measurements.

Benefits of the Integrity Assessment

An integrity assessment that takes into account the issues outlined above will:

- Provide the operator with best possible understanding of the current condition of the pipeline, and whether it is safe to continue to operate it.
- Identify degradation mechanisms and give conservative estimates of the rate of degradation.
- Identify other issues that may affect the feasibility of repair or rehabilitation (e.g. location).

The rest of this paper provides some guidance to assist with the preliminary assessment on what may be reported by different types of inspection, and what the reported features may indicate for the overall condition of the pipeline.

Geometry Pig

Geometry pigs (calliper pigs) are intended to identify changes in the pipe internal bore, in particular features such as ovality and dents. They may also identify restrictions due to debris, partially closed valves, etc. Typically geometry pig run specifications should require the reporting of any bore reduction greater than 1 % or 2 % of the pipe external diameter.

There are two basic types of calliper pig, single channel and multi channel. Single channel pigs will report the change in bore and the location on the pipeline. What they will not identify is the orientation of the dent.

Ovality

Ovality is generally not a problem for pipeline integrity, unless there are significant overburden loads. On a new pipeline; however, ovality in excess of code limits may be an indication of poor construction, and should be rectified by the construction contractor. Note that excess ovality may be found at field bends and can result in high stress concentrations, possibly leading to the development of fatigue cracks, if the pipeline is subject to significant pressure or temperature cycles.

Dents

Dents are potentially significant defects and require careful evaluation. Even a smooth dent (with no associated metal loss) may have a short fatigue life, and dents with gouges in or that affect a weld may have low burst pressures and short fatigue lives. Dents may be co-incident with ovality, both the ovality and dent should be considered in any assessment, as the combination will lead to a higher stress concentration. The critical parameters required to assess the significance of a dent are:

- Depth (percentage of external diameter)
- Curvature – kinked dents, or sharp dents, have high strains, high stress concentrations, and are more likely to have cracks associated with them than smooth dents.
- Orientation – dents at the top of the pipe, in onshore pipelines, are unlikely to be constrained (see below), and are more likely to be due to external interference, and more likely to have associated metal loss than dents at the bottom of the pipeline. Dents at the bottom of the pipeline are generally constrained (the weight of the pipe and cover restrict movement due to changes in internal pressure) and are hence less likely to develop fatigue cracks.
- Length (this can be an indicator of the curvature).
- Pressure in the line during the inspection – the dent depth will change with the internal pressure. Assessment methods are often based on the dent depth measured at zero internal pressure.
- The presence of metal loss (a gouge) in the dent. A dent and gouge is a severe form of damage that usually requires repair.
- The presence of a weld in the dents. Dents on welds are severe damage that are likely to require repair.

A typical calliper report will give the dent location, the dent depth, and may give the dent orientation. Geometry pigs cannot detect external metal loss, although the presence of a seam or girth weld may be identified. Hence, assessing the results requires the consideration of other information.

Geometry Pigging - Onshore

What to look for in a geometry pig report of a dent in an onshore pipeline:

1. A dent is near the top of the pipe (between 8 o'clock and 4 o'clock) may be mechanical damage, and may have an associated gouge not reported by the geometry pig. Conversely, a dent near the bottom of the pipe is likely to be a rock dent, and hence less significant.

2. If the dent has a depth of more than 2% of diameter it is likely to be either a constrained rock dent (not serious) or in service damage (possibly serious). Construction dents due to handling, etc., will usually be ‘pushed out’ by the hydrotest. Dents less than 2% of diameter are generally acceptable, provided there is no gouging or weld associated.
3. If the dent a depth of more than 6% of diameter, it may exceed code limits. Codes limit dent depth to 6% of diameter, but note that this is due primarily to the potential restriction of pig passage.
4. Is the dent at a location where third party damage is credible (e.g. near a road crossing)?
5. Are there any records of recent excavation work in the vicinity of the dent?
6. Is there an explanation that could be used to show that mechanical damage is unlikely – e.g. the dent may be on a field bend and have been caused by the bending machine?
7. Is there any evidence of coating damage in the area of the dent from a recent coating survey. For in service mechanical damage to result in a gouge, the coating would have to be damaged.

It should be noted that for onshore pipelines which tend to have a relatively thin wall, dents due to rocks in the trench or handling damage during construction are common, but are generally not a significant problem for pipeline integrity.

Geometry Pigging - Offshore

Offshore pipelines tend to have thicker walls than onshore lines, and often have a concrete coating to provide stability. Consequently, dents are much less common than for onshore pipelines.

A dent reported in an offshore pipeline may be residual construction damage: sometimes during pipelay in bad weather the pipe will impact the rollers on the lay barge stinger, or may be bent over the end of the stinger. This type of damage should be identified by a pre commissioning survey. It should be noted that the damage may not be at the bottom of the pipe, as some twisting of the pipe as it goes from the barge to the sea bed is possible. If the damage was caused during construction then it will have been subject to a hydrotest, and consequently may be acceptable even if it exceeds standard code limits.

Alternatively the dent may be due to impact by a ship anchor, trawl gear, a dropped object (e.g. a stabilisation block), or, in shallow water, by a ship.

What to look for in a geometry pig report of a dent in an offshore pipeline:

1. Depth – the dent depth provides a primary indication of the potential severity.
2. Shape - the shape of the dent may provide an indication of the cause of the damage, for example if the dent is due to an anchor snag there may be denting to both sides of the pipe (see Figure 2). The shape of the dent may also give some indication of the possibility of associated metal loss.
3. Location – the location of the dent will provide some indication of the possible cause.

4. Seabed scars – sonar survey data can provide clear evidence of scars on the seabed caused by objects being dragged across it.
5. Shipping incidents – If a ship drags an anchor, etc., the details should be reported. These reports can provide an indication of the cause of the incident, the size and mass of the anchor, etc..

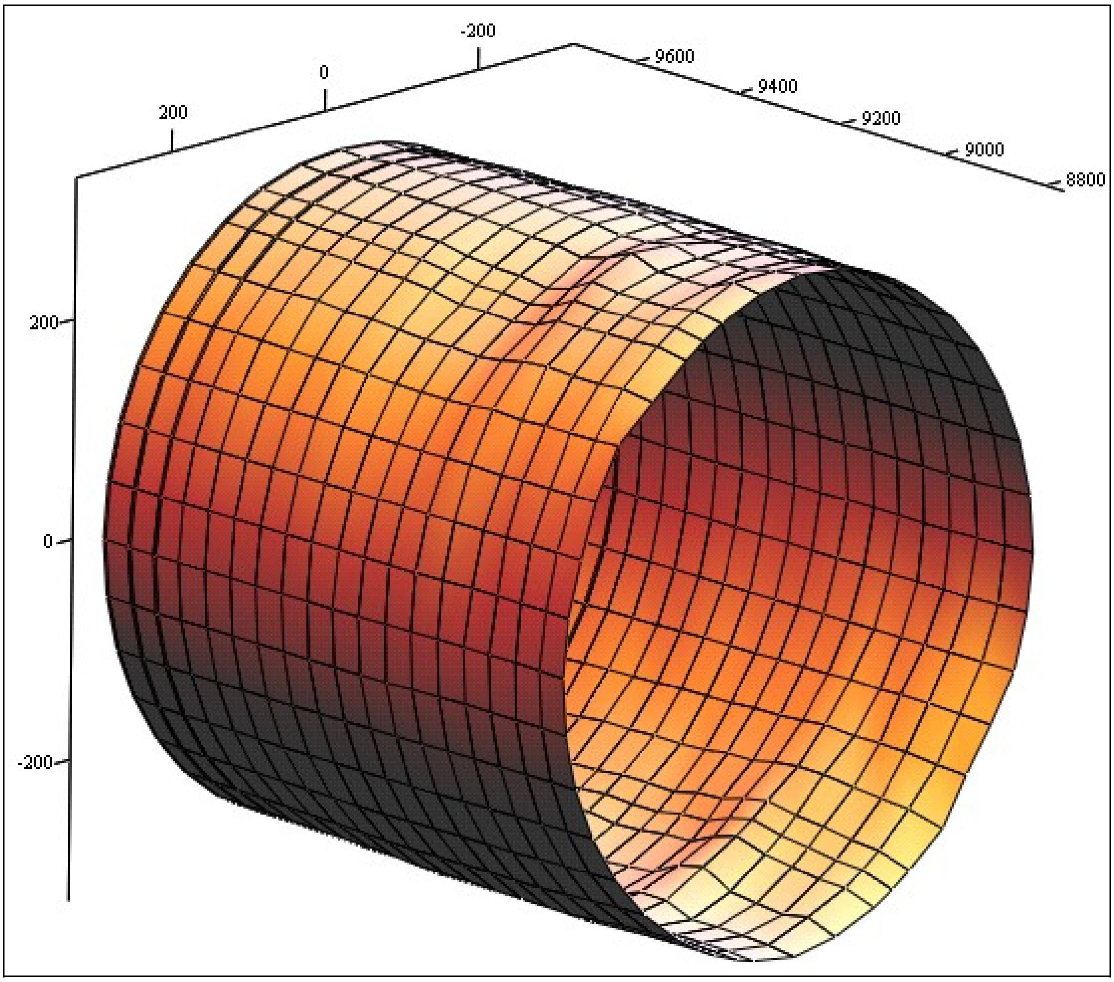

Figure 2 Model of Denting Caused by An Anchor Snagging A Pipeline

As stated previously, dents on offshore pipelines are unusual and if one is reported then external inspection is prudent. This should confirm the presence or otherwise of any weight coat damage, anti corrosion coating damage, gouging, or the presence of welds.

Mapping Pig

Mapping pigs are designed to plot the route of the pipeline. They tend to be used if the as laid information is poor, if there is concern over possible ground movement, if upheaval or lateral buckling is suspected, or if it has proved difficult to locate defects reported by other inspections.

If the intention is to look into problems associated with movement, the data can be used to estimate the bending strains in the pipe. It is a common misconception that multiple inspection sets are needed to asses the condition of the pipeline. Multiple data sets are needed to monitor movement; however, the bending strains can be estimated using the pipe curvature given by one set of data. The strains can then be compared with allowable limits. The bending strain associated with features such as field bends and the curves due to laying pipe on an uneven sea bed should be within the strain limits of the material or design standard.

When assessing the total strain in the pipe it is necessary to consider not only the bending but also any strains due to; pipe lay; extension (for example where a pipe has been dragged by an anchor); internal pressure; and thermal expansion.

<u>MFL Inspection</u>

Intelligent pigs that use the principle of Magnetic Flux Leakage (MFL) to detect anomalies in pipelines are now in widespread use. The primary purpose of MFL pigs is to detect corrosion defects and give an estimate of the size of the defect. Early tools were only able to detect significant defects and would not discriminate between internal and external features. The latest tools are able to detect defects of less that 5% of the pipe wall thickness, these very shallow defects may be difficult to see on visual inspection. The technology moved forward rapidly in the 1980s and 1990s; one of the driving forces for the improvement was the involvement of British Gas in developing tools for the UK gas pipeline network. This section provides an overview of the types of defects that may be reported by an MFL inspection and what these may mean for the integrity of a pipeline.

<u>Manufacturing Defects</u>

MFL pigs will identify local changes in the pipe wall thickness. The manufacture of line pipe will often result in many small areas where the pipe is thinner, for example where a hard spot has been ground out in the pipe mill. These variations are expected and are reflected in codes such as API 5L which allows isolated reductions in wall thickness of up to 12.5% of the pipe wall thickness. The standards also often allow an under tolerance on the nominal pipe wall thickness. Experienced data analysts can identify particular attributes of the MFL signal associated with a manufacturing defect that mean they can confidently classify the defect as manufacturing-related. Where there is any uncertainty the analyst should classify the defect as metal loss.

Modern MFL inspections will often report many thousands of manufacturing defects. In general manufacturing defects are not considered to be significant as they, are generally shallow, will have been subject to a hydrotest, and are unlikely to be growing. There are certain cases where a manufacturing related metal loss defect may be significant, for example:

- Manufacturing defect in a dent – this is a dent with associated metal loss and is potentially a severe defect that will need repair.
- Manufacturing defect close to corrosion defects – defects that are close together may interact and result in a lower combined failure pressure. The combined corrosion and manufacturing defect will not have been subject to the pre commissioning hydrotest.

In some cases relatively deep manufacturing defects are reported. These can usually be shown to be acceptable by confirming that there is no credible cause other than manufacturing, the defect has been subject to a hydrotest, and the probability of growth due to corrosion is low (for example by showing that the coating condition is good). In addition, manufacturing defects reported to be deep may simply be a result of the tolerances of the inspection system where sometimes defects will be oversized.

MFL pigs will not detect all manufacturing-related defects - for example, they are unlikely to detect features such as laminations. Laminations, however, are rarely a significant concern for pipeline integrity, unless the pipeline carries a sour product.

Corrosion

MFL inspections generally report corrosion as ‘metal loss’. There may be a comment that it is ‘possibly corrosion’, or that it is ‘not manufacturing-related’. To make an assessment, an understanding of the cause of the corrosion is critical. External corrosion may have been caused before the pipe was coated, particularly for pipelines that were coated ‘over the ditch’. Internal corrosion may have occurred while the pipe was in transit to the construction site, or while it was in storage at site (see Figure 3).

Figure 3 Pipe in Storage With Surface Internal Corrosion

Various evidence from the inspection, combined with basic information on the pipeline construction and operation, can be used to identify the probable cause of the corrosion.

Internal Corrosion

Active internal corrosion is likely to be extensive, that is, it occurs in more than one location. It also tends to occur at the bottom of the pipe where water and debris can collect. Erosion corrosion can result in metal loss at the outside of bends, and top-of-line corrosion results in defects at the top of the pipe, where water condenses due to the cooling effect of water outside the pipe, although it should be noted that condensing conditions also cause corrosion in the lower quadrant of the pipe as well.

Different patterns of internal corrosion that may be seen in intelligent pig data are considered below:

- Isolated internal corrosion at random orientation. This may be manufacturing or pre-construction damage.
- Shallow lines of internal corrosion that do not run across girth welds (see Figure 4), and which change orientation from one pipe to the next. This may be corrosion caused during transport or storage.

- Shallow general internal corrosion at low points on the route, and at the bottom of the pipe. This may be ‘operational’ corrosion. It could also be corrosion caused by allowing untreated water to enter the pipeline during construction. The possibility that this is active corrosion should be considered, for example, if the pipeline transports waxy crude oil and cleaning pigs are run weekly then it is unlikely to be active corrosion.
- Numerous deep internal corrosion pits at the bottom of the pipeline at low points on a crude oil pipeline that is not used continuously and is only rarely cleaned. This is likely to be active microbially assisted internal corrosion.
- Numerous deep internal corrosion pits at the bottom of the pipe and close to girth welds. There are likely to be active preferential weld corrosion. There may be more severe defects actually in the weld that it is difficult to detect or size from the pig data.

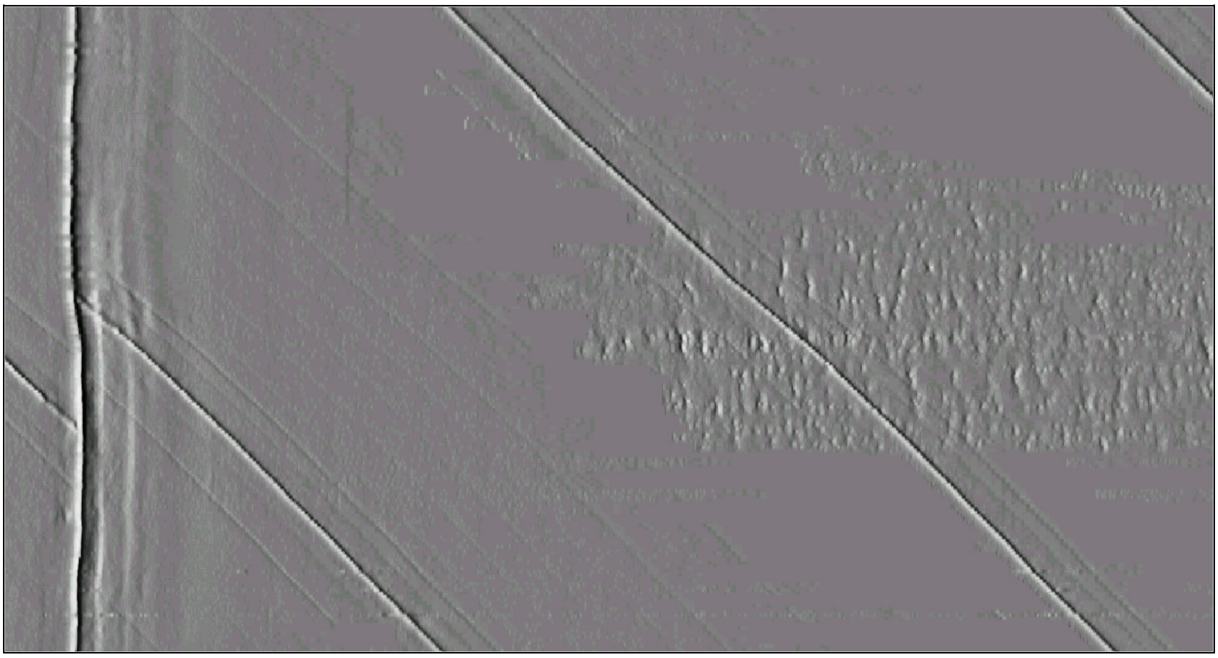

Figure 4 Light Internal Corrosion In a Spiral Wound Pipe

External Corrosion

Active external corrosion requires some damage to the coating and for the cathodic protection (CP) system to be ineffective. Active external corrosion may be isolated due to a combination of a small coating defect and a localised problem with the CP system, or it may be extensive due to widespread coating degradation and poor cathodic protection. In attempting to understand the cause of external corrosion defects an understanding of coating types, soil conditions and CP system performance is needed. External corrosion is relatively common in onshore pipelines as the soil conditions and any local infrastructure can combine to damage the coating and make effective CP difficult. For offshore pipeline external corrosion is relatively unusual as the seawater is an ideal medium for the CP system, although external corrosion can occur on the riser, particularly in the splash zone, and on the topside pipework.

Different patterns of external corrosion that may be reported on an onshore pipeline are considered below:

- Isolated pits at any orientation on a pipeline with a good quality coating (e.g. fusion bonded epoxy). These may be active corrosion sites and could be related to effects such as AC interference. The corrosion growth rate may be relatively high.
- Shallow general corrosion at arbitrary orientations. If the pipe was coated over the ditch this may be corrosion caused while the pipe was in transit or storage.
- General corrosion towards the bottom of the pipe (see Figure 5), at low points on the pipeline route. This is the typical pattern of external corrosion where the coating has become degraded. The corrosion tends to the bottom of the pipe due to differential aeration and to low points on the route as these tend to be wetter than high ground.
- General corrosion close to the girth weld. These may be active corrosion defects and are likely to be a result of problems with the application of the field joint coating, which as a field-applied coating may not be as good as a factory-applied coating factory. The growth rate may be low unless the pipeline is operated at elevated temperature (e.g. >30deg C)
- Corrosion along the seam weld. These may be active and could be related to 'tenting' of a tape wrap type of coating (see Figure 6)
- Multiple deep corrosion pits (see Figure 7). These are may be active and may be related to microbially assisted corrosion. The growth rate is likely to be high.
- Lines of corrosion around the 4 o'clock or 8 o'clock position. This may be active corrosion due to the 'rucking' of a tape wrap coating that may occur due to high soil shear stress (see Figure 8).

Tape wrap coatings are often problematic as they can become disbonded from the pipe, allowing water into contact with the steel, but will shield the pipe surface from the CP system.

Figure 5 General Corrosion at the Bottom of the Pipe

Figure 6 'Tenting' Of A Tape Wrap Coating

Figure 7 Multiple Deep Pits

Figure 8 Rucking of a Tape Coating

Gouges

Damage such as a gouge may be reported as a 'metal loss' anomaly. If the damage is towards the top of the pipe, in an onshore pipeline, and/or appears long and narrow then it may be a gouge (see Figure 9). There may be some evidence of denting which can be identified in the inspection data, or the metal loss may be at a location where excavations are known to have taken place.

Figure 9 Gouges

Ultrasonic Metal Loss Inspection

Ultrasonic inspections intended to detect metal loss will tend to report very similar patterns of internal and external corrosion to those reported by MFL pigs. They will also identify manufacturing defects such as laminations, but as stated previously, laminations are not usually a problem for pipeline integrity as they do not significantly reduce the strength of the pipe and they will have been present when the pipeline was hydrotested. Under certain circumstances laminations can be an issue, for example laminations can lead to blistering, if the pipeline carries high levels of hydrogen. Inclined or sloping laminations may also be a source of fatigue cracking in pipelines subject to severe cyclic loading.

Crack Detection, TFI and EMAT Tools

There are a number of other types of intelligent pig available. These tend to be specialist inspections required under specific circumstances. The crack detection and EMAT tools in particular are under continuous development. As with all intelligent pig tools, their accuracy is increasing with experience and development. This is not just because of technological improvements to the pig but also because the database of defects and corresponding signal response increases. Whilst the UT crack detection tools have been shown to accurately locate and size stress corrosion cracking there are many other types of cracks (for example seam weld cracks) and features that may appear similar to cracks to the inspection data analyst. Until a tool has been used on a particular crack type the ability of the analysts to accurately size that particular type of crack should be treated with some caution. The assessment should consider the likely accuracy of measurement by asking for the number of times this particular tool has been used to detect this particular type of crack and how many confirmatory inspections were carried out i.e. how big is the database of defects that the analyst is using?

Summary

Intelligent pigging is a costly and disruptive activity. However, it provides a huge quantity of very useful information on the pipeline. A knowledge of pipeline integrity issues, pipeline operation and inspection technology can be combined to optimise the assessment of the data.

A preliminary assessment of the results of an intelligent pig inspection is a critical step in ensuring that the correct action is taken regarding pressure reductions, repair, and further assessment. This preliminary assessment must be carried out by someone who:

- Knows the pipeline design, construction and operation.
- Understands the inspection technology
- Is aware of the significance of different types of pipeline defect.

The following key points should always be considered when reviewing an inspection report.

1. Can the cause of any defects reported be identified and are they credible?
2. Is it possible that the defects may be growing, and what mechanisms are there for this?
3. What is the growth rate?
4. Does the data suggest an unexpected type of defect and if so was the tool suitable for measuring this defect or does a different tool need to be run?
5. The assessment should use as built and operational records and previous inspection and monitoring data to establish as clear a picture as possible.
6. Even if no defects require repair which defects require confirmatory inspection?

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