MAGNETIC FLUX LEAKAGE PIGS OR ULTRASONIC PIGS? THE CASE FOR COMBINED INTELLIGENT PIG INSPECTIONS

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This paper describes a case study where a pipeline operator was faced with features in the pipe wall that proved difficult to conclusively identify. An ultrasonic (UT) pig inspection indicated that the pipeline contained numerous deep external defects. However, subsequent excavations indicated that the reported external defects were in fact mainly laminations and/or inclusions. To verify that this was the case for the whole pipeline the operator ran both a magnetic flux leakage (MFL) and an ultrasonic inspection tool in the same inspection programme, using the magnetic flux leakage tool to confirm the absence of part-wall defects and hence demonstrating the presence of laminations.

Introduction

Pipeline operators have a wide choice of inline inspection tools (pigs) that have the capability to deliver a consistently high-level of reporting of pipeline features and defects. The two main internal inspection technologies are magnetic flux leakage (MFL) and ultrasonic (UT). Each has its benefits, however, each has its inherent limitations and neither can identify all possible pipeline defects.

A case study is described in this paper where a pipeline operator was faced with features in the pipe wall that proved difficult to conclusively identify. An internal ultrasonic pig inspection had indicated that the pipeline contained many deep external defects. However, subsequent excavation and external inspection of the pipeline for verification indicated that the reported features were not as serious as initially thought: the defects identified by the external examinations were not all external defects but were, in fact, mainly laminations and/or inclusions in the pipe wall. The pipeline's operating conditions meant that laminations were not considered an integrity issue for this pipeline[1], whereas the reported external defects reported were. Consequently, the pipeline operator required a method of inspection that could conclusively identify the features in the pipeline, without any ambiguity regarding external features or laminations.

After consultation with Penspen Integrity, the pipeline operator opted to run both a magnetic flux leakage pig and an ultrasonic pig in the same inspection. The magnetic flux leakage tool used can detect metal-loss defects but not laminations. The ultrasonic tool used can accurately identify internal metal-loss, but can have difficulties when differentiating between external metal-loss and laminations. Consequently, the combined inspection can use the ultrasonic tool to identify the location of possible external metal-loss (or laminations) and the magnetic flux leakage tool can be used to confirm metal-loss, hence conclusively demonstrating where laminations are present in the pipeline.

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[1] A lamination is an internal metal separation creating layers that are generally orientated parallel to the pipe wall. A lamination is a defect in the body of the pipe and is a material/manufacturing defect. The presence of a large number of laminations in a pipeline is indicative of 'dirty' steel, possibly of poor quality. However, laminations have not generally been regarded as a significant problem[,,,], except under particular circumstances[], namely: (i) Laminations at an angle to the pipe wall can reduce the effective thickness of the pipe; (ii) Multiple laminations may present a leakage path; (iii) Hydrogen blisters can form as a result of the collection of molecular hydrogen in laminations or in clusters of inclusions in the pipe wall. The formation of hydrogen blisters is associated with sour corrosion. This liberates atomic hydrogen at the pipe surface, which can then pass through the pipe wall and collect at the laminations or inclusions, where it recombines to form molecular hydrogen[]. The internal pressure due to the molecular hydrogen within the voids can be very high, potentially leading to cracking and blistering.

When undertaking a pipeline integrity assessment it is important to take a holistic approach and use all available data. It is important to understand the nature and cause of features in a pipeline and to understand the significance of those features. Therefore, this paper discusses the importance of correctly characterising pipeline defects and describes the circumstances where two or more different methods to inspect a pipeline are needed to remove ambiguous reporting of pipeline defects. It describes the technical challenges presented by the combined ultrasonic and magnetic flux leakage inspection and the benefits that the combined inspection has. The paper briefly covers some of the project management issues that arise when using more than one pipeline inspection contractor. Finally, the paper describes the findings of the inspection programme.

Case Study

Background

The pipeline system described in this paper is a large diameter crude oil import line. The pipeline is located in the United Kingdom and is used to supply crude oil to onshore facilities. In turn, the onshore facilities supply an oil refinery. The identity of the pipeline will not be disclosed in this paper at the operator's request.

The pipeline runs subsea from an offshore unloading facility, through an environmentally sensitive coastal area, and then runs under rural farmland before reaching the onshore facility. Due to the nature of the environmental area through which the pipeline runs, and the commercial significance of the pipeline, the integrity of the pipeline is of the utmost importance to the operator.

The pipeline was commissioned in the early 1970s and has been in continuous use. The offshore unloading facilities receive regular visits from tankers supplying crude oils. The pipeline was fabricated from materials contemporary to the time of installation and has no unique or unusual material features.

The pipeline is not 'piggable' by conventional means (not uncommon for loading lines of this nature) as it only has facilities for a pig trap arrangement at the onshore end of the pipeline. Piggable pipelines (such as transmission lines) can be inspected using conventional, unidirectional intelligent pigs, which are inserted into the pipeline at the upstream end, propelled through the pipeline by the conveyed fluid, and recovered the downstream end.

'Unpiggable' pipelines, such as the one discussed in this paper, require a different approach. They can be inspected using intelligent pigs; however, it is necessary for the pig used in the inspection to be launched and returned to a single pig trap. This means that the pig used for the inspection must be capable of reversing in the pipeline, and additionally there must be some method of propelling the pig through the pipeline, either by reversing the flow in the pipeline, through use of onboard motors, or by pulling the pig from the pipeline using a tether.

Prior to the inspection programme undertaken in 2003 described in this paper, the pipeline had been the subject to two internal inspections. The first inspection was undertaken in the early 1990s, at a time when the choice of intelligent pigs suitable for use in large diameter 'unpiggable' lines was limited. The tool that was used for this inspection was a bi-directional ultrasonic tool that was pumped from the onshore pig trap to the offshore end of the pipeline using seawater as a medium. The inspection was reported to be completed successfully and the results of the inspection indicated that there were no metal-loss features in the pipeline wall.

The second internal inspection of the pipeline was conducted in 1999 following a leak and successful repair in the pipeline. Again, a bi-directional ultrasonic tool was used to inspect the pipeline, although a different inspection company was contracted to undertake the inspection on this occasion. Again the pig was pumped from the onshore pig trap facility to the offshore end before being returned to the pig trap. The inspection was completed successfully, however, the reported results of the second inspection were considerably different to the

results of the first inspection. This time the inspection reported 360 features, of which one was reported to be an internal metal-loss feature and the remainder were reported to be external or 'general' features.

The reported defects were assessed by Penspen Integrity and were not considered to present an immediate threat to the integrity of the pipeline; however, the second inspection results gave the pipeline operator cause for concern. Repeated inspections of a pipeline over time inevitably result in differing outcomes. In part, this will be due to the potential for growth of defects in the pipe wall. However, to a large degree the reported defects are dependent on the sophistication of the technology that was employed by the inspection tools and the tolerances and thresholds that are used when reporting defects. Therefore, it is unsurprising that there was a difference between the inspection results, but further investigation was required to determine the extent of the metal-loss as reported in the latter inspection.

The pipeline operator excavated and externally examined a section of the pipeline that was reported to contain 44 metal-loss features by the 1999 internal inspection. All of the reported features in this section of the pipeline were classified as external or 'general' metal-loss features; there were no reported internal features at this location. The external ultrasonic inspection of the pipeline at this location indicated that there were 73 features. Two of the reported 73 features were external metal-loss; the remainder were assumed to be laminations and/or inclusions in the pipe wall, since no internal metal-loss features were reported in this pipeline section. This scenario was attributed to the inability of the ultrasonic technology employed to differentiate between external features and laminations due to ultrasound reflections from the surface of a lamination resembling the reflection obtained from the base of an external metal-loss defect (see Figure 1).

The Problem

The pipeline operator was faced with a problem. The internal inspection in 1999 had reported numerous external metal-loss defects at locations where the previous internal inspection had not. This meant that either technology had improved and hence the latter inspection was able to detect features that the original inspection had not reported, or there was the possibility of an active external corrosion mechanism. An excavation and external ultrasonic investigation had indicated that the majority of features located in one section of the pipeline were in fact laminations in the pipe wall. Additionally, the coating was in good condition and no problems were reported with the cathodic protection (CP) system indicating that external corrosion was not expected. This was a significant finding, as laminations in the pipe wall of this pipeline were not considered to be a pipeline integrity issue. However, this by no means confirmed that the external features reported in the remainder of the pipeline were also laminations. Consequently, a solution that could unambiguously identify and classify defects in the pipeline, including laminations, was required to verify that the reported defects were not metal-loss features. This was especially important, as an attempted excavation to confirm the nature of the worst reported feature in the pipeline (reported as a deep external metal-loss feature) was unsuccessful due to the soft terrain through which the pipeline passes.

Inspection Options

A method of inspection was required that would conclusively characterise the features that had been reported in the pipeline as either metal-loss or laminations. The three inspection options that were identified were as follows:

1. External excavation and examination

Uncovering the pipeline would yield very detailed information regarding the defects at specific locations on the pipeline. This would be very valuable information, especially if the excavations were targeted to review areas of special interest. However, although this method can give some indications of the general condition of the line (c.f. verification excavation undertaken by the pipeline operator after the 1999 internal inspection) it cannot be used to conclusively classify all of the features identified on the pipeline due to cost and difficulties with accessing the pipeline, especially in the offshore section.

2. Re-inspect the pipeline internal using the ultrasonic intelligent pig

Re-inspecting the pipeline using an ultrasonic intelligent pig would provide useful information if features reported previously by the 1999 inspection had grown. Using the same tool would be advantageous as an inspection 'fingerprint' for the pipeline obtained during the previous inspection could be used for comparison. However, no further information would become available regarding the possible laminations in the pipe wall and therefore this was not a viable inspection in isolation.

3. Inspect the pipeline internally using a magnetic flux leakage intelligent pig

Internal inspection of the pipeline using a magnetic flux leakage intelligent pig would provide an alternative data set. Magnetic flux leakage pigs can detect changes in wall thickness and therefore are well suited to identifying metal-loss defects. However, laminations in a pipe wall do not result in metal-loss, therefore a magnetic flux leakage intelligent pig will not be able to identify a lamination in a pipeline.

The Solution

The optimum inspection programme for the pipeline was identified during discussion between the pipeline operator and Penspen Integrity. The decision was made to run both an ultrasonic intelligent pig and a magnetic flux leakage intelligent pig in the pipeline. This solution had two compelling advantages, which made the additional cost involved with the project justifiable.

Firstly, the composite inspection was scheduled for mid-2003. Consequently, sufficient time (circa 4 years) had elapsed since the previous ultrasonic inspection to allow for a meaningful comparison between the results of the 1999 inspection and the results to be obtained by the 2003 inspection[2]. Hence, using the same ultrasonic inspection tool was the preferable option since it would make direct comparison with the pipeline defect 'fingerprint' meaningful. Any reported features that had changed since the last inspection would be identified in this way.

Secondly, the magnetic flux leakage tool is capable of detecting metal-loss in a pipe wall. However, the laminations that were suspected in the pipeline would not have any associated metal-loss, meaning that the magnetic flux leakage pig would not be able to detect them.

Therefore, in the composite inspection, the ultrasonic intelligent pig is used to identify and size internal metal-loss features in addition to external metal-loss features and/or possible laminations (which it is not able to discriminate between). Where the ultrasonic pig reports external metal-loss and/or laminations, the magnetic flux leakage pig data is then used to classify these defects by

[2] A short re-inspection interval can result in difficulties differentiating between the tolerances associated with the inspection tool and the growth of features in the pipeline due to an active corrosion mechanism.

indicating whether metal-loss is present or not, hence removing any doubt regarding the nature of these defects. Additionally, the magnetic flux leakage intelligent pig can be used to verify the sizes of the features reported by the ultrasonic pig.

It was necessary to identify an intelligent pig company that could perform the required inspection once the decision was made to run both an ultrasonic intelligent pig and a magnetic flux leakage pig. At the time it was not possible for one intelligent pig contractor to supply both the ultrasonic and magnetic flux leakage pig, in part due to the large diameter, bi-directional requirement. Consequently, the pipeline operator contracted two companies to perform the inspections.

The Inspection

The pipeline inspection was conducted in mid-2003 with duration of approximately 10 days. The medium in the pipeline during the inspection was seawater, which was first pumped though the pipeline from a vessel at the offshore unloading facilities. The seawater was subsequently pumped from the onshore facility to the vessel and back again with each cleaning pig and intelligent pig run, before returning to the onshore facility for treatment and disposal.

The onsite operations were managed by one of the intelligent pig contractors. The contractor was responsible for the installation of the temporary pig traps, pumps, pipework, etc. and for managing the pumping of cleaning pigs and intelligent pigs. The second contractor was responsible for manoeuvring their pig into the pipeline before handing over to the main contractor for pumping it through the pipeline.

One foam cleaning pig and approximately four bi-directional cleaning pig runs were required to make the pipeline sufficiently clean for the ultrasonic intelligent pig to be run. Pipeline cleanliness is particularly important for ultrasonic pigs as wax and deposits in a pipeline can foul sensors and wax on the pipe wall can cause signal attenuation, resulting in degraded results. The ultrasonic pig inspection was conducted over several days (due to pig and data acquisition set-up), with all data being gathered on the outward run of the pig.

On completion of the ultrasonic pig inspection the magnetic flux leakage intelligent pig was run in the pipeline. The magnetic flux leakage inspection was undertaken in approximately 10 hours (the time taken was more dependent on the battery life of the inspection tool). The magnetic flux leakage tool was able to gather data when running in both directions in the pipeline and hence effectively performed two inspections of the pipeline.

No significant problems were encountered during the inspection programme that affected the quality of the data that was obtained from the intelligent pig runs. Using more than one intelligent pig contractor was an unusual arrangement. However, the issues arising from this arrangement were mainly related to the definition of roles, responsibilities and liabilities in the event of an unforeseen occurrence, such as a stuck pig; these issues were addressed and resolved prior to the commencement of the inspection programme.

Assessment of Inspection Results

At the time of submitting this paper the inspection data from the pipeline inspection is being finalised, therefore a comprehensive comparison and pipeline integrity assessment has yet to be completed. However, some important preliminary conclusions can be drawn from the pipeline inspection since the ultrasonic pig data was available online during the inspection programme and the magnetic flux leakage pig contractor was able to quickly retrieve and review the data collected before leaving site.

The first significant conclusion that can be drawn from review of the online ultrasonic inspection data is that there were no indications of significant changes in the pipeline condition since the previous ultrasonic inspection, although this is subject to confirmation from the ultrasonic intelligent pig contractor. However, the magnetic flux leakage pig has identified some previously unseen metal-loss features in the pipeline and therefore these will require further assessment.

The second (and more important) conclusion that can be drawn is that the worst external metal-loss feature reported by the previous inspection, which was of greatest concern for the pipeline operator, was not reported as metal-loss by the magnetic flux leakage intelligent pig. This is excellent news for the pipeline operator, since this positively identifies the feature as a lamination, which is not an integrity concern for the pipeline.

Further analysis of the full sets of inspection data will be made when they become available and a pipeline integrity assessment will be undertaken. In the course of this work it is expected that further features in the pipeline will be re-classified as laminations, rather than metal-loss features as originally reported.

Conclusions

1. *Expert knowledge of feature significance and inspection tool capabilities has helped to identify a suitable inspection solution*

This paper has described a case study where a pipeline operator was faced with a specific problem, namely, suspected laminations in the pipeline wall reported as external metal-loss. A pipeline inspection solution was required that could remove the doubt that existed regarding the nature of the reported defects. The solution that was identified was to run two intelligent pigs, using different technologies, during the same inspection programme.

2. *Cost of combined inspection mobilisation less than separate inspections*

The resultant programme was undoubtedly more complex than a standard operation utilising one intelligent pig. Additionally, there was extra cost associated with the running of the second pig in the inspection. However, this additional cost was estimated to be in the region of approximately 20 percent of the final inspection cost, and therefore was not a great increase in the overall cost.

3. *Use of two inspection technologies improves feature identification*

The benefits of the additional information that has been obtained from the composite inspection are significant and are considered to outweigh the costs associated with obtaining it. The additional data obtained from the composite inspection will be used to categorically remove the uncertainly regarding laminations and/or metal-loss defects in this pipeline.

4. *Appropriate selection of inspection technologies improves pipeline integrity management*

This is the first use of a combined inspection on the reported scale that the author is aware of. The approach described is considered to be a significant move forward where pipelines are known to contain defects that are difficult to conclusively characterise. This approach has been useful for the operator of the pipeline described in this paper and is expected to prove useful for other pipeline operators faced with a similar situation.

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Fig ic Inspection

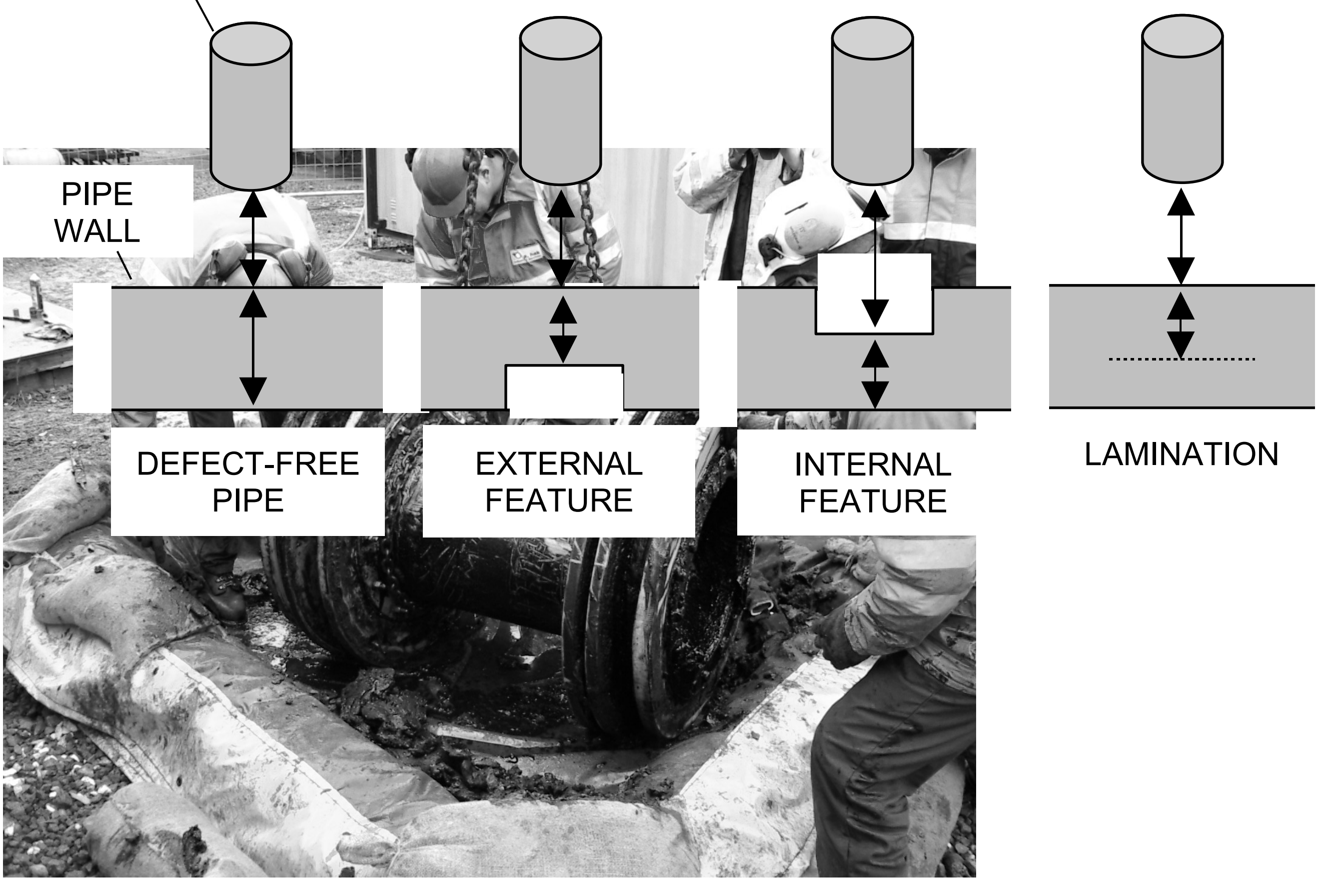

Figure 2: Inspecting the Cleaning Pig

Figure 3: Manoeuvring the Ultrasonic Pig into the Pipeline

Figure 4: Manoeuvring the Magnetic Flux Leakage Pig into the Pipeline