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PIPELINE MECHANICAL DAMAGE: DETECTION, ASSESSMENT AND MONITORING USING THE SAAM® PIPELINE INSPECTION TOOL

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Abstract

This paper presents the results of work carried out by RST Projects Limited using the SAAM® pipeline inspection technology to detect, assess and monitor mechanical damage and changes in the internal bore of hydrocarbon pipelines.

One of the most important uses of SAAM® has been to detect, locate and monitor mechanical damages and changes in the internal bore of hydrocarbon pipelines. This paper explains how SAAM® can be used in this role and specifically the types of features which can be detected. These include dents, ranging from those which are so severe as to cause damage to the carrier pig through relatively small features, as well as flat spots caused by field bending and manufacturing defects. Examples of each are presented. A discussion of how this technology can be used as a routine condition-monitoring tool to provide early warning of the presence of mechanical damage is also included.

The paper draws upon experiences gained on projects in the UK, Middle East and Africa and wherever possible makes use of case studies.

Introduction

RST Projects Limited, a Scottish pipeline inspection company, has developed the SAAM® technology, an innovative system that allows the internal inspection of pipelines while they are cleaned. The development is a result of many years of experience in the pipeline industry and research into how internal variables within a pipeline can affect the behaviour of cleaning pigs. The aim was to develop a 'black box flight recorder' which when fitted on board a traditional cleaning pig would measure changes in the dynamics of the pig as it travels through the line. The result, after an initial 3 years R&D programme, was the SAAM® (Smart Acquisition Analysis Module) system, a cost effective, low risk and easy to use pipeline inspection technology. SAAM® was deployed operationally for the first time in July 1997.

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1 - **Background**

The safe and continuous operation of hydrocarbon pipelines requires the pipeline operator to have the most up-to-date information to hand regarding the condition of his pipeline. It is clear from a number of surveys that the most common cause of pipeline failure is third-party external damage, caused by e.g. ploughing of buried lines, or the impact of trawl gear against (unburied) sub-sea lines. Furthermore, in many areas in the world, the effects of sabotage or vandalism must also be considered.

For example, according to the US Department of Transport, [1], of the more than 900 pipeline failure incidents in the continental United States in the years 1997-2000, around a third were due to third-party damage incidents. A major study of pipeline leakages, undertaken in 1998 by Concawe confirmed this figure.

In locations where the pipeline is relatively inaccessible, the obvious standby of visual inspection is not an easy option to implement, and quite significant damage may go undetected for considerable periods of time. The continued operation of upstream oil and gas pipelines in these often rather inaccessible locations requires the ability to monitor the line condition remotely. In many cases, there will be no simple way to detect even relatively gross line damage by means of an exterior survey. The use of semi-intelligent or Smart Utility Pigs for these applications seems to offer the best way forward.

These smart utility pigs have been developed during recent years to perform a variety of functions with the minimum disruption to operations. RST Projects SAAM® tools are a good example of the capabilities of these types of tool. They are able to record temperature, pressure (both absolute and differential), inclination (acceleration) and vibration. Other instrumentation can be integrated with the data recorder as required for specialist applications. These devices have found a number of applications in the North Sea and other upstream oil and gas regions, such as the detection and monitoring of pipeline out-of-straightness features (mapping) [2], the identification, location and monitoring of dents, status of in-line components, internal anomalies and zones of wax formation. Other applications include logging of pipeline process data, diagnosis of pigging problems, and facilitating the optimisation of pigging programmes.

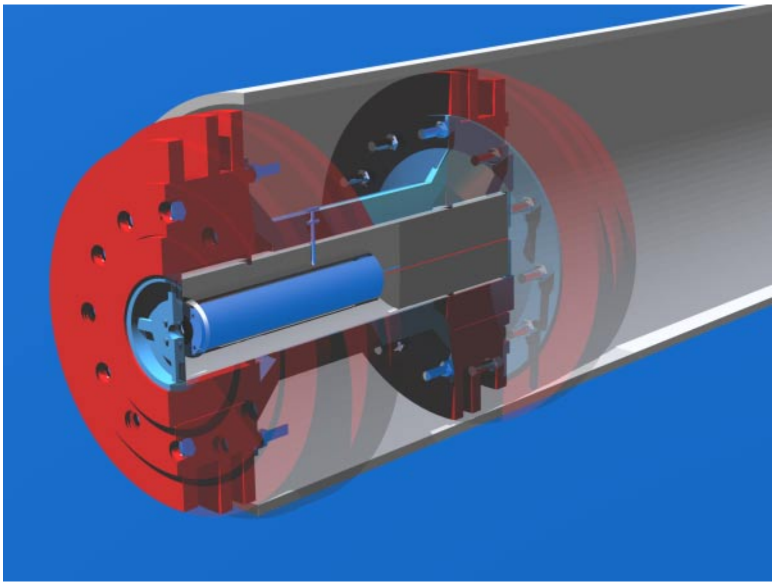

Figure 1 - SAAM® Unit in Pig

The essential philosophy behind the use of these tools is to highlight changes that may be occurring in the pipeline by the use of regular surveys. This methodology is made practical by the relatively low per kilometre survey cost, and the potential to incorporate these inspections into a routine cleaning operation. Figure 1 shows a typical way in which a smart utility pig can be mounted in a standard cleaning pig. Current versions can be deployed in lines down to 6" diameter, and survey transit times of up to 14 days are achievable. The SAAM® technology is now fully field proven with some 3,000km of pipelines having been surveyed so far. The technology aims at facilitating the condition monitoring and decision-making process for pipeline operators.

It is the purpose of this paper to discuss a number of situations in which these techniques have proven useful for the detection of pipeline damage.

2 - Basis Of Technique For Detection Of Pipeline Out-Of-Roundness

Consideration needs to be given to the mechanisms by which pipeline damage can be detected by the instrumentation onboard a standard SAAM® unit. Considering the motion of a pig through a pipeline, it is obvious that the main effect is the interaction between the pig disks and the pipe-wall. The obvious outcome of this is that the driving differential pressure necessary to move the pig down the pipeline depends upon this interaction. Thus this value is in some sense at least characteristic of a given pig in a given line.

Vibration is also experienced by all pigs to a greater or lesser extent as they travel down a line. If the disk/wall contact is well lubricated and motion is steady, as for a large diameter pig in an oil line, the normal level of vibration will be quite low. For poorly lubricated motion (gas or water), especially at low velocities, were the pig is more likely to experience stick-slip motion, background levels of vibration can be very high. It has also been observed that spirally-wound line pipe also tends to give rise to higher vibration levels.

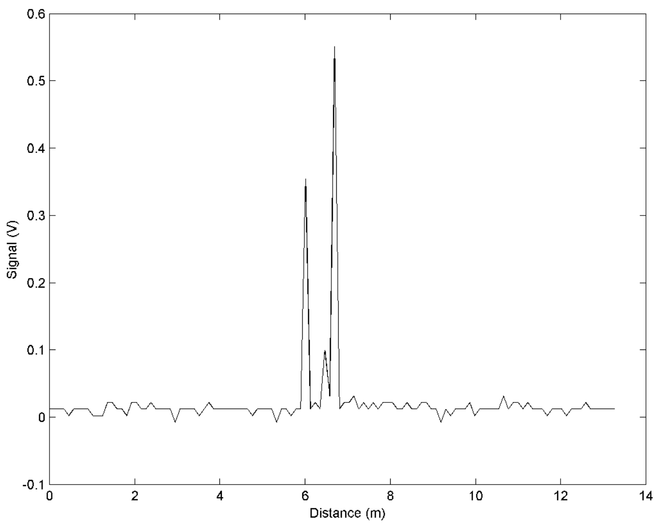

Figure 2 - Vibration Signal at Weld

The vibration is measured by RST's Smart Utility Pig in a direction co-axial to the motion of the pig. In normal use this means that the only source of major disturbances in the vibration signal is the 'judder' as the pig passes over each weld. This has a characteristic double peak structure as a bi-di pig passes a weld, as each set of disks (front and rear) traverse the weld. Figure 2 shows a typical signal. Under some circumstances (slow motion) it is possible to distinguish further structure due to the seal and guide disks in each set. These weld kicks are the principal means by which the progress of the pig down the line is monitored.

A third detectable effect is the tendency of the pig to hold up at obstructions, visible as an acceleration feature, where the pig stops and then sets off again. This type of effect is occasionally seen at welds in oil pipelines, particularly where the pig is 'tight', but is much more common in gas lines, where the compressibility of the line fluid allows momentary fluctuations in pig sped much more readily.

During RST's experience in running inspections with these tools, a wide range of different anomalies have been observed in the full range of pipelines. The following types of anomaly will be considered in detail below: changes in pipe specification; flats spots and out-of roundness; and dents and mechanical damage.

3 - Detection Of Changes In Pipeline ID

All this leads naturally to the consideration of the effects on these readings caused by restrictions in the line. The main effect caused by mechanical damage which is visible in SAAM® data is the increased resistance to the motion of the pig. This is manifested in a number of different ways which are detectable by instrumentation on board a Smart Utility Pig. First and most obviously, a significant obstruction, particularly any reduction in internal bore or out-of-roundness will cause a rise in differential pressure as the pig passes the obstruction.

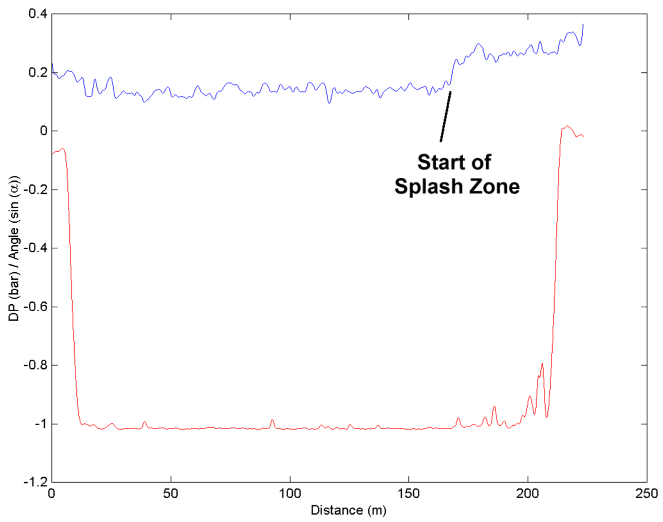

Figure 3 - Differential Pressure in Pipeline Riser

As an example, the case of a simple change in line specification from normal to heavy-wall pipe may involve an overall change in ID (for OD controlled line sizes) of only a few millimetres. For pigs for which the disks are sized to be suitable for the larger internal diameter, this type of spec change can cause the driving DP to increase by 50% or more. An example of this is Figure 3, showing the top of a pipeline riser in the UK sector of the North Sea. The figure shows the driving differential pressure increasing from 0.10-0.15 bar in the normal part of the line to 0.25-0.30 bar in the heavy wall pipe at the splash zone and above. Similarly Figure 4 shows pressure/vibration signals for a transition from heavy wall into standard line pipe for a water-driven pig in an 18" line. The change in ID here is 6mm, and again the DP is almost twice as high in the heavy-wall section. In this case it was fairly clear that the pig's guide disks, which were sized for the larger diameter part of the line, were interfering with pipe-wall in the heavy-walled section. It is this that is responsible for the significant increase in vibration also apparent in the figure.

The most important conclusion is that a relatively small change in pipeline internal diameter can cause a major change in the differential pressure and vibration characteristic recorded by a Smart Utility Pig.

4 - Detection Of Flat Spots In Pipelines

The previous section covered the characteristics of known (and planned) changes in the internal bore of a pipeline. While this can be of interest under certain circumstances, the more general problem of detecting shorter, unplanned changes in the internal bore, both in terms of out-of-roundness features such as ovality or flat spots, and in terms of dents and mechanical damage, has much greater application.

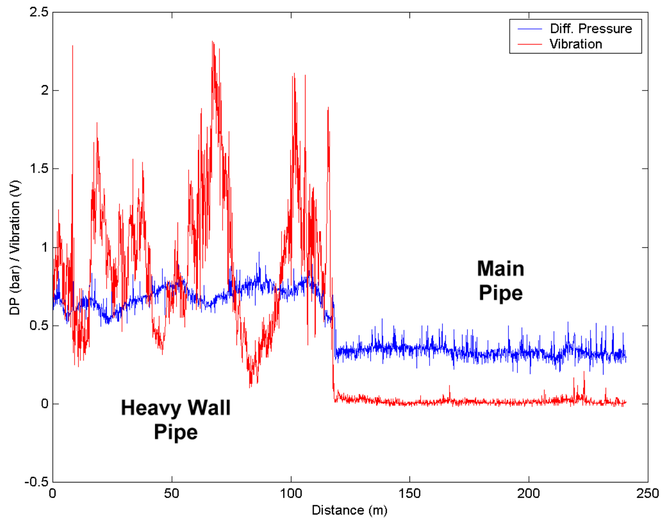

Figure 4 - Differential Pressure at ID Change

Considering flats spots first, these can be expected to be very similar to changes in pipe specification, the difference being that the magnitude of the effects on the differential pressure and vibration characteristics are expected to be much smaller.

Figures 5 and 6 show two examples of flat spots from a 32" oil export line. This line lies onshore, and has numerous bends of a few degrees where the pipe was cold-bent on site during construction. In Figure 5, the feature shows up as an increase in DP from 0.35 bar to 0.45 bar. This is a rise of 50% rather than 100% or more, as was the case for the overall change in diameter. Figure 6 shows a slightly larger feature, with and increase in DP from 0.3 to 0.5 bar. In both these cases the accelerometer inclination trace shows that this peak coincides with a downward bend by a few degrees. In this particular pipeline the operator was aware that the process by which these bends were formed was likely to have resulted in the formation of a flat spot on the outer side of the bend.

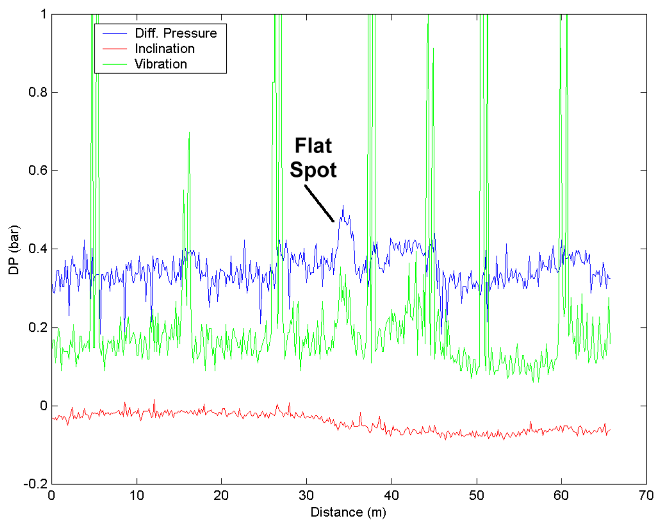

Figure 5 - Example of Pipeline Flatspot

In both cases the vibration also shows a peak at the same location. Perhaps the most important characteristic to note here is the relatively smooth DP profile.

5 - Dents And Other Out-Of-Roundness Features

Dents caused by actual impacts against the pipeline differ from the types of features discussed above in that the beginning and end of the feature will tend to be much more sudden. Figure 7 shows an example of this from the same pipeline discussed in the previous section. Here the peak in DP, although comparable in size to the features caused by simple out-of-roundness, rises much more sharply. Interestingly the peak in vibration is much shallower than that in the out-of-roundness. This dent is known to be on the underside of the pipe, and to be relatively shallow.

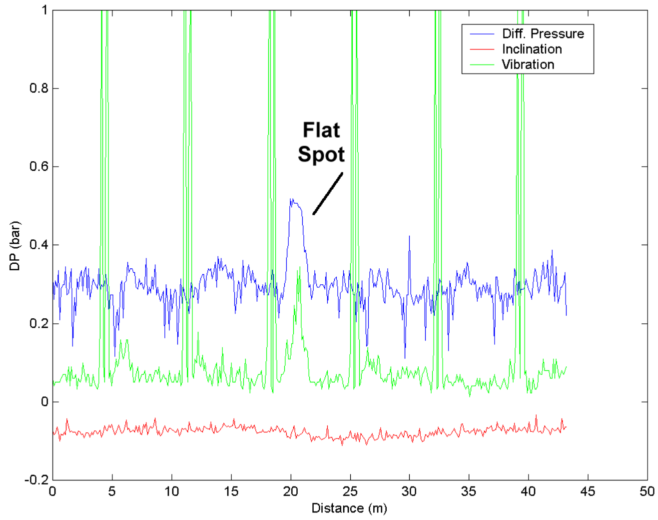

Figure 6 - Example of Pipeline Flatspot

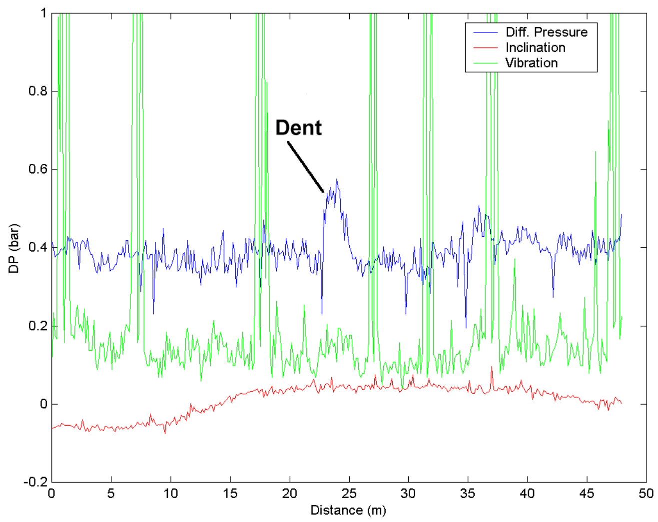

Figure 7 - Example of Dent

For comparison, Figure 8 shows the effect of a much more severe dent. Here the pig is significantly obstructed by a feature, known to be on the top of the line, and to be sufficiently deep to interfere with the pig body in an 18" line. This figure shows first the pig running into the dent, with the driving pressure rising to around 0.8 bar. The pig then runs into the part of the line which was sufficiently damaged to interfere with the pig body. It is possible to see the pig being forced nose down in the inclination trace.

Figure 9 shows the state of the carrier pig after impact with the restriction.

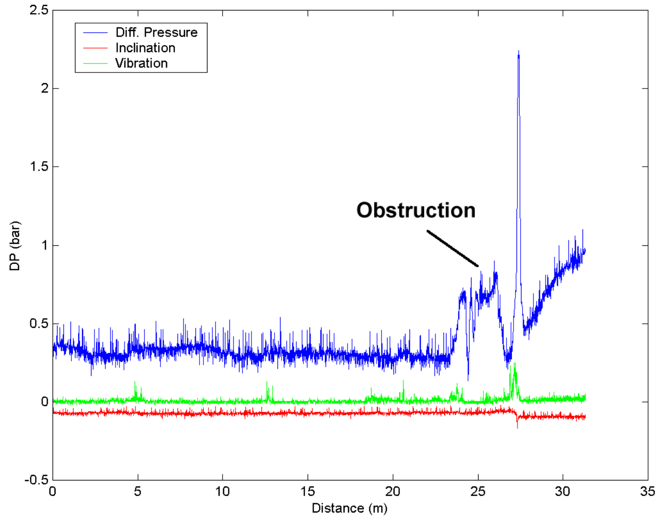

Figure 8 - Example of Pipeline Obstruction

6 - Limitations Of Technique

There are still a number of obvious limitations to the use of this technique at present. The most obvious of these is that at present only an indication of the presence of dents and other out-of-roundness features can be obtained, along with perhaps a qualitative measure of their size. No information on the absolute size of features is generated, nor of their position on the pipe's circumference.

Other issues that still require to be dealt with include the problems of detecting dents which happen to be close to welds. The vibration signature in this case will be obscured, and although it is not normal to see peaks in differential pressure at welds, this behaviour has been observed to occur. In particular this is thought to be present where there is significant (excessive) weld penetration. This problem can be tackled in many cases by using the regularity of the pattern of the weld vibration trace to 'pre-whiten' the vibration time series, in effect removing the welds. Anomalies in the vibration (and DP) characteristics should then show up much more clearly.

Figure 9 - Damaged Pig

Disk wear too, may cause difficulties in comparing like with like, even within the same pipeline and the same survey, if conditions are such that considerable wear occurs during a single pigging run.

The biggest obstacle to the successful detection of mechanical damage features in a pipeline using smart utility pigs such as SAAM® lies in the difficulty of amassing sufficient information on known features, across a wide range of lines sizes and flow conditions.

7 - Future Developments

The obvious next step is to advance the extent to which these types of anomaly can be recognised and even measured using these Smart Utility Pig techniques. RST Projects are currently engaged in a test programme which will completely characterise the pig's behaviour at a restriction in a test situation. Together with a growing database of characteristics for pig behaviour this will provide a route to the validation of the SAAM® tool's ability to reliably detect dents and other anomalies. This will allow confidence limits to be developed as to the smallest features (in both length and depth) which can be detected, and begin to put a quantitative calibration of the tool in place.

It should be fairly clear that, particularly when the normal motion is as smooth as shown in Figure 2, that any slight hindrance to the pig's passage is likely to be evident as a disturbance in the vibration trace. This is, in itself, not evidence of mechanical damage, or even of a defect. In any given single pig run, it is perfectly conceivable that dynamic effects, associated with the motion of the pig, could cause a similar disturbance, which, after all, causes an unsteady flow situation in the line during the pigging run.

On the other hand, if repeated surveys of the same line come up with the comparable results, the cause must obviously be sought in some local defect in the line. This has the weakness that only inferential evidence is available regarding possible damage, however, by comparing data traces with those caused by known types of defect it is possible to obtain at least qualitative information regarding the line condition. In the case of significant out-of-roundness, where there is some reasonably large part of the pipeline's circumference that is distorted, the effects on DP will be very similar to those described above. The magnitude of the DP increase, of course may be significantly less.

This is the major benefit of the smart utility pig approach. The low cost of incorporating an inspection capability into a routine pipeline cleaning programme, by fitting inspection technology inside a standard cleaning pig allows the frequent monitoring of pipeline conditions, and gives early warning of when damage has occurred.

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