SMART UTILITY PIG TECHNOLOGY IN PIPELINE OPERATIONS

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ABSTRACT:

Pipeline operators have a requirement to inspect an oil or gas pipeline in order to assess its integrity. Of particular interest are the internal condition of the pipeline with respect to corrosion or debris, and the geometric shape of the pipeline.

SAAM® Smart Utility Pig technology has been deployed in these respects over the past 7 years in over 7,000km of pipeline. Over this time, the technology and analysis techniques have been developed, taking into account the experiences gained from previous surveys. This has led to recent improvements in the technology and increased confidence in the analysis results.

This paper describes the various capabilities of the smart utility pigging technology, giving examples from recent pipeline inspection surveys. These applications include: providing a vertical and horizontal pipeline profile, and using the results to monitor for movement or to assess pipeline strain; identifying mechanical damage, including bore restrictions, dents, illegal taps or offset couplings; providing an assessment of pipeline debris, estimating the remaining internal bore and determining the effectiveness of the pipeline cleaning program; and providing an assessment of internal corrosion.

The paper concludes with a brief description of special projects where the technology has been integrated with external sensors to provide additional information during a pig run, and a discussion of possible future improvements in the technology and data analysis.

SMART UTILITY PIG

The SAAM® Smart Utility Pig was developed by RST Projects Ltd., acquired by Weatherford Pipeline & Specialty Services in May 2002. The technology is based on the concept that, as a pig travels through a pipeline, it is affected dynamically by physical features of, or within the pipeline. Measurement of such pig dynamics, along with process conditions, provides the operator with information on the pipeline shape or integrity gained from routine cleaning pig operations [1].

The *SAAM* unit is a sealed cylinder that is fitted entirely inside a standard cleaning pig body [Fig. 1]. Typical measurements acquired are: pig vibration, differential pressure, absolute pressure, temperature, pig inclination, pig rotation and angular velocity. The acquired data is positioned in the pipeline using a 'weld counting' methodology in which each pipeline weld is identified from characteristic kicks in the vibration data and then tagged and reconciled with reference pipeline information. This allows the data to be presented with respect to distance rather than time.

VERTICAL & LATERAL OUT-OF-STRAIGHTNESS

Vertical out-of-straightness (OOS) calculations are carried out using the inclination data acquired by an on-board accelerometer [2]. This information is used to calculate a full-length elevation profile of a

pipeline from which local vertical OOS features are identified and profiled. Local features identified typically have a change in elevation of >0.5m over a distance <500m.
Lateral OOS calculations use the data acquired from two angular velocity sensors which measure changes in pig orientation in any direction. Using the vertical inclination data to remove the vertical component allows the calculation of the profile of the pipeline's shape at local lateral OOS features.

OOS analyses of recent *SAAM* inspections have provided operators with pipeline profiles that have allowed for assessment of potential pipeline movement, or for further calculations relating to pipeline strain. A smart utility pig has been used in 5 inspections over 5 years to monitor for pipeline movement in a 12" oil export pipeline which is prone to strong seabed currents. The operator was concerned that these currents could disrupt silt on the seabed resulting in a loss of pipeline support and consequently sagging of the pipeline. The initial inspections provided a benchmark elevation profile against which to compare profiles calculated by subsequent inspections [Fig. 2]. The fifth inspection, carried out in 2004 highlighted a 0.5m elevation trough over a length of 50m not seen in previous inspections [Fig. 3]. This was indicative of pipeline movement in line with the operators concerns.

Smart utility pigs have been deployed recently in new pipelines to calculate a benchmark of the pipeline's geometric shape by two successive surveys. This is used as the basis of any comparison against profiles generated by future inspections. Three initial inspections of a 10" oil pipeline in an environmentally sensitive region in 2003 provided the operator with a benchmark elevation profile and benchmark local profiles of all 3D OOS features in the pipeline [Fig. 4]. This was used by the operator as an input to strain calculations that confirmed to them that no excessive strains were acting on the pipeline at any point.

Data acquired from two inspections of a 24" offshore oil pipeline has been used by the pipeline operator as an input into further assessment of the pipeline profile. The full-length vertical profiles calculated from both inspections provided a benchmark elevation profile of the pipeline that can be compared against the results of any future inspections. One of the inspections provided readings from angular velocity sensors allowing an assessment of the lateral profile of the pipeline at local features identified from the data. Significant features were highlighted to the operator, and local 3D profiles provided of each feature [Fig. 5]. Further assessment of the pipeline profile by the operator confirmed the accuracy of the vertical and lateral profiles provided.

DEBRIS ASSESSMENT

One of the major uses of smart utility pig technology is to provide the operator with an assessment of debris within the pipeline from a routine pigging run [3]. This has been used extensively in recent years in the assessment of several types of debris including:

- Wax formation
- Hard wax
- Scale/hydrate
- Black powder
- Loose debris
- Liquid

Each of these forms of debris results in characteristic signals in the acquired data. In particular the vibration and differential pressure data, and changes in the pig inclination within the pipeline as it pitches over debris. In addition, with the exception of harder deposits, debris is generally a transient feature resulting in clear differences in the data between surveys.

An inspection was carried out in a 12" onshore gas pipeline with the objective of identifying suspected locations of 'black power' forming on the pipe wall. Two successive inspections were carried out, with both sets of resulting data analysed together. Through comparison of the two datasets, permanent bore restrictions were identified such as inline components or increased wall thickness sections. These were differentiated from bore restrictions caused by debris, which only occurred in one or other of the two surveys. This analysis highlighted to the client locations of

suspected black powder formation on the inner pipe wall [Fig. 6]. In addition, the relatively clean appearance of the pipeline in the second inspection provided information to the operator on the

effectiveness of the cleaning pig, indicating that the debris was removed relatively easily by a single pig run.

Monitoring of wax deposits in an offshore 16" oil pipeline has been carried out by 6 inspections over 3 years. Wax formation in this pipeline has been identified by very characteristic data traces resulting in isolated anomalies in vibration and differential pressure. The rate of occurrence and magnitude of these anomalies reflects the severity of the wax formation. In general, wax formation anomalies are observed in the same general region of a pipeline over different inspections, but individual anomalies do not re-occur at the same locations. Hard wax was also identified in this pipeline downstream of the wax formation zone resulting in large peaks in differential pressure, over several kilometres due to the bore restriction caused by the wax. A decrease in vibration levels was also observed, along with a reduction in the kicks normally seen at welds, due to the wax limiting the pig's contact with the pipe wall. The results of these inspections have been used by the operator of this pipeline to track the extents of wax formation and hard wax zones over time [Fig. 7].

An inspection of a 12" deepwater gas pipeline was carried out to assess the amount of debris entering the pipeline from several well tie-in points along its length. The data around each tie-in point was analysed and an assessment provided to the operator of the nature of any debris occurring downstream of any of these points [Fig. 8]. The results were correlated with the pipeline elevation profile and showed that in some locations, debris was accumulating at elevation low spots in the pipeline immediately downstream of the well locations.

BORE RESTRICTIONS

Bore restrictions in pipelines, either inline components or mechanical damage, have been identified and located through analysis of the vibration and differential pressure data acquired during SAAM inspections. Differential pressure is measured across the carrier pig body and experiences an increased reading when an increased force is required to push the pig past an internal bore restriction, such as a valve, bend, dent or debris. Such restrictions can also affect the pig vibration along with the other data logged.

Smart utility pigs have been used analyse the passage of a cleaning pig through inline components to investigate damage to pigs noted during cleaning operations, or in recently acquired or constructed pipelines to ensure a clean passage of the pig through inline components. An inspection of a recently constructed 12" offshore oil pipeline in 2003 was carried out to confirm to the operator that cleaning pigs could pass through the various inline components without difficulty, in particular at a pigging jumper at the end of two flowlines. The data acquired during the inspection confirmed that the pig passed through these components without becoming held up, and no anomalous differential pressure readings were noted. However, on several occasions in other pipelines, data analysis has identified instances of a cleaning pig becoming held up at restrictions caused by inline components. Such features typically result in a gradual build up in differential pressure across the pig body, dropping sharply as the pig clears the restriction [Fig. 9].

Data acquired by smart utility pigs has also been used to identify bore restrictions caused by pipeline damage [4]. This could be a dent, flat spot or illegal tap. The operator of an 18" onshore gas pipeline was concerned that some dresser couplings situated after every third spool in the pipeline may have become misaligned. After two successive inspection runs, each coupling was identified by a larger than normal vibration kick and an anomalous angular velocity reading. Several couplings were highlighted and positioned where the pig became held up and stopped momentarily due to a restriction [Fig. 10]. This allowed the operator to locate and assess each feature individually.

Bore restrictions can also occur due to debris build-up on the internal pipe wall such as hard wax, scale or hydrates. Smart utility pigs cannot provide a direct measurement of the magnitude of the restriction. However in some cases, where several different references exist of known internal bores in a pipeline, the differential pressure readings at such known bore restrictions have used to calculate a best-fit curve of differential pressure against remaining internal bore. This was used in a 12" offshore oil pipeline to estimate the bore restrictions caused by debris attached to the pipe wall at several locations along the pipeline [Fig. 11]. Although the resulting values were not considered highly accurate, they were considered adequate to satisfy the operator that the debris did not cause a significant bore restriction.

CORROSION ASSESSMENT

Experience gained over recent years has improved the capabilities of corrosion assessment using the data acquired by smart utility pigs. This assessment is based on the concept that corrosion results in a generally increased surface roughness of the internal pipe wall, and this is manifested in an increased pig vibration as it passes through a corroded region, reflected in the vibration data [5]. Pig vibration is also affected by several other factors, therefore two successive inspections are normally carried out and analysed together in order to eliminate the effects of debris, velocity excursions or other transient features from the data.

A corrosion assessment inspection of a 16" offshore oil pipeline was carried out in 2003. A previous intelligent pig inspection identified corrosion across the first 1000m of the pipeline. However, the presence of wax in the pipeline at the time of the intelligent pig survey resulted in no data being acquired for the remainder of the pipeline, and the operator was concerned that the corrosion may extend further downstream. The vibration data acquired in the two *SAAM* inspections was analysed in order to eliminate transient effects and identify permanent anomalies most likely to be indicative of corrosion. These were compared with the results of the intelligent pig inspection to determine the characteristic vibration signal at regions of corrosion. A strong correlation was identified between clusters of metal loss features identified by the intelligent pig, and increased smart utility pig vibration [Fig. 12]. The elevation profile of the pipeline, calculated from the inclination data, also highlighted a correlation between the locations of corrosion and elevation low spots in this region [Fig. 13]. The information gained on the type of vibration signal indicative of corrosion at the beginning of the pipeline allowed the vibration data for the remainder of the pipeline to be analysed for further anomalies indicative of corrosion. This analysis confirmed to the operator that no significant corrosion occurred later in the pipeline, and also provided a baseline of the pipeline's internal condition against which to compare the data from future inspections, in order to monitor for increases in corrosion.

CONCLUSIONS & FUTURE DEVELOPMENTS

Recent projects have shown smart utility pig technology being used as an effective tool for monitoring a pipeline's shape and internal condition. It is also used increasingly as a method of providing a baseline, both for shape and condition, of a newly constructed pipeline to provide a basis for comparison against future inspections during the length of the pipeline.

For recent special projects the smart utility pig technology has been extended to include external odometers, liquid sensors or caliper arms. The data logged from these sensors were analysed along with data measured by the standard instrumentation. This included combining the data from liquid sensors with the elevation profile calculated from the inclination data to determine if liquid was accumulating at elevation low spots in a gas pipeline, and combining the data from caliper arms with standard data to aid in data positioning and identification of components such as bends or valves.

The PIPEAIMS joint industry project is nearing completion, which includes development of a *SAAM* tool containing all the standard instrumentation along with an improved corrosion detection capability. Further developments are also underway into improving data analysis capabilities. An OOS validation project is in progress with the objectives of improving vertical and lateral OOS capabilities and determining the optimum pig configuration that will provide the

most accurate results. Automation of lateral OOS calculations is also being developed using the data from tri-axial accelerometers measuring the pig rotation to automatically determine bend direction.

REFERENCES

[1] – Short, Gordon. "Smart Utility Pigging – It's Role in Pipeline Inspection". PPSA, November 2002.

[2] – Moore, Dave; Snodgrass, Bob and Nicholson, Barry. "Smart Utility Pigs Used to Determine & Monitor Pipeline Out-of-Straightness With Specific Reference to Inspection of BP Alaska's 10" Northstar Crude Oil Pipeline". International Pipeline Conference, Calgary, Canada, October 2004.

[3] – Case, Richard; Hare, Simon and Snodgrass, Bob. "Smart Utility Pigging During Deepwater Flowline Cleaning Demonstrated by Weatherford". Pipeline & Gas Journal, December 2003.

[4] – Short, Gordon and Russell, Dave. "Pipeline Mechanical Damage: Detection, Assessment and Monitoring Using the SAAM Pipeline Inspection Tool". Brazilian Petroleum & Gas Institute 3rd Seminar on Pipelines, November 2001.

[5] – Flett, Dave and Short, Gordon. "New Approach to Pipeline Condition Monitoring of the Beatrice 16" Oil Export Pipeline". International Pipeline Conference, Calgary, Canada, October 2002.

Figure 1 – SAAM Smart Utility Pig

Figure 2 – Local Vertical OOS Feature Comparison From 3 Separate Surveys

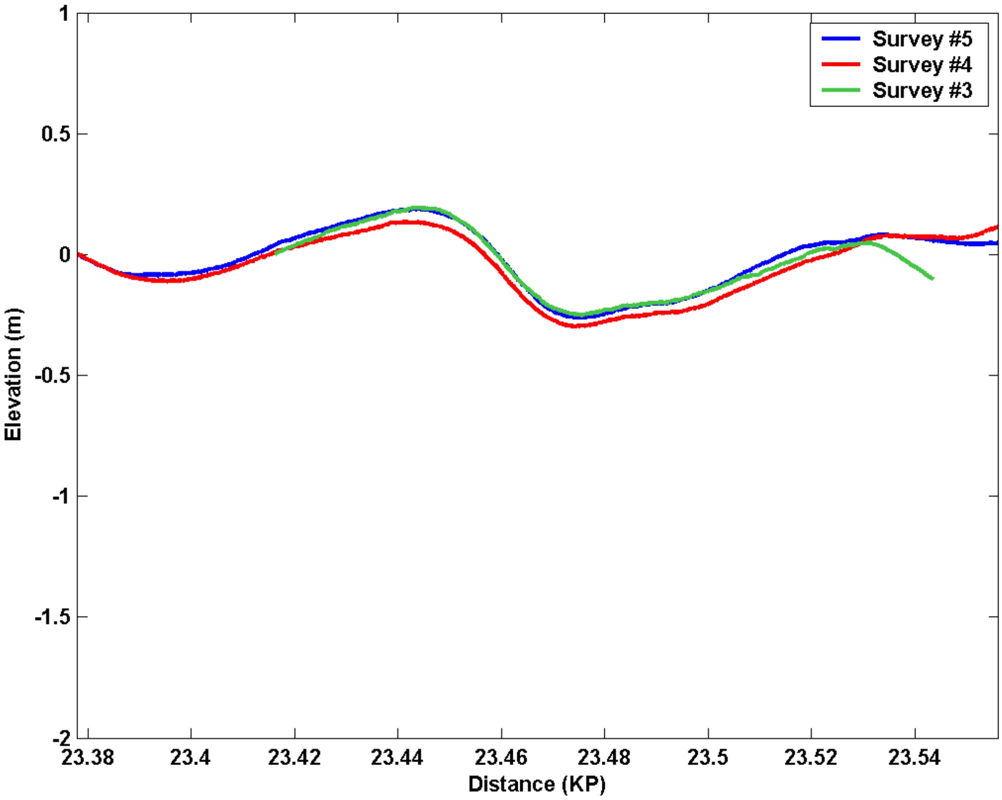

Figure 3 – Identification of Newly Formed Vertical OOS Feature

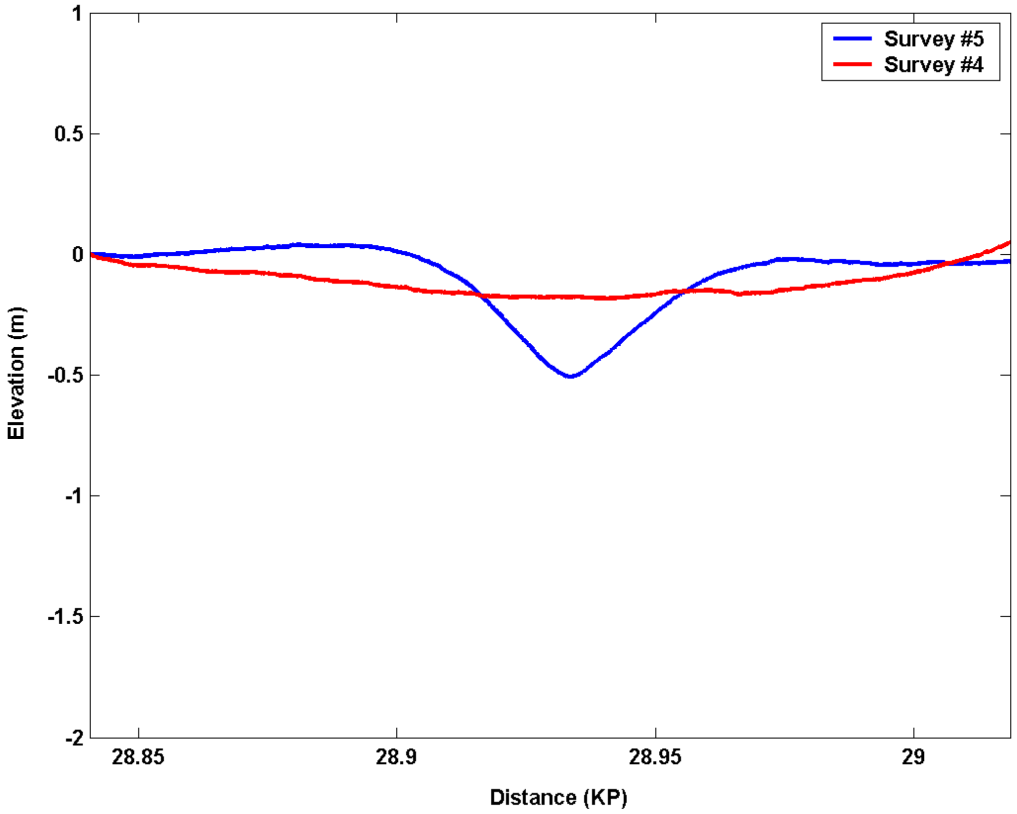

Figure 4 – Example Full-length Elevation Profiles and Benchmark Profile

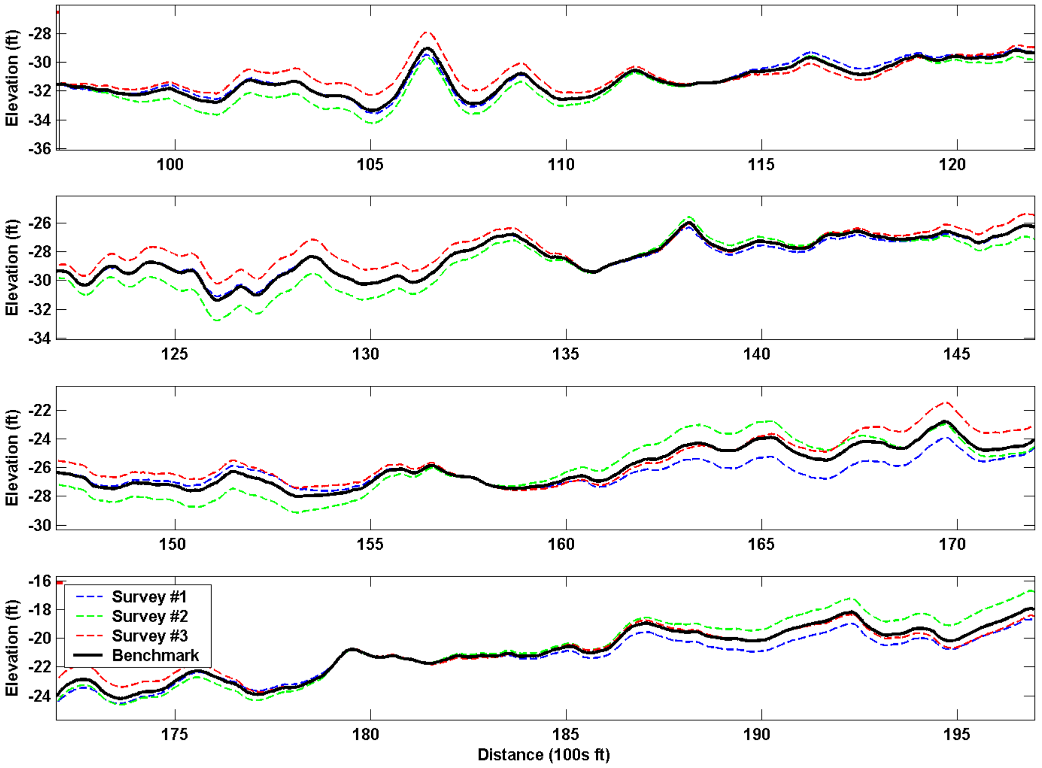

Figure 5 – Plan and Elevation at 3D OOS Feature

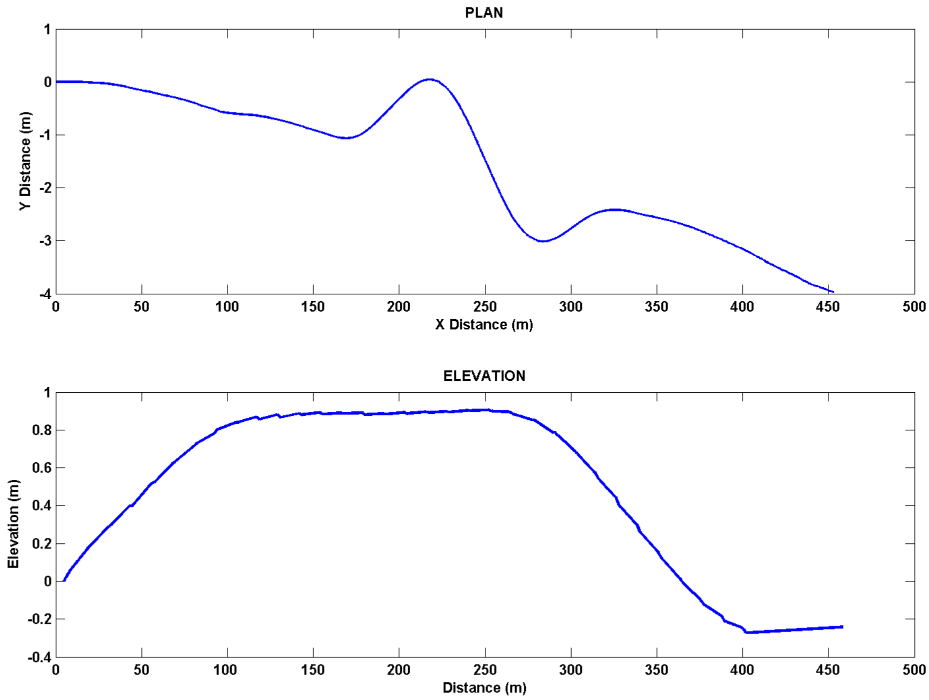

Figure 6 – Zone of 'Black Powder' Debris Cleared By First Survey

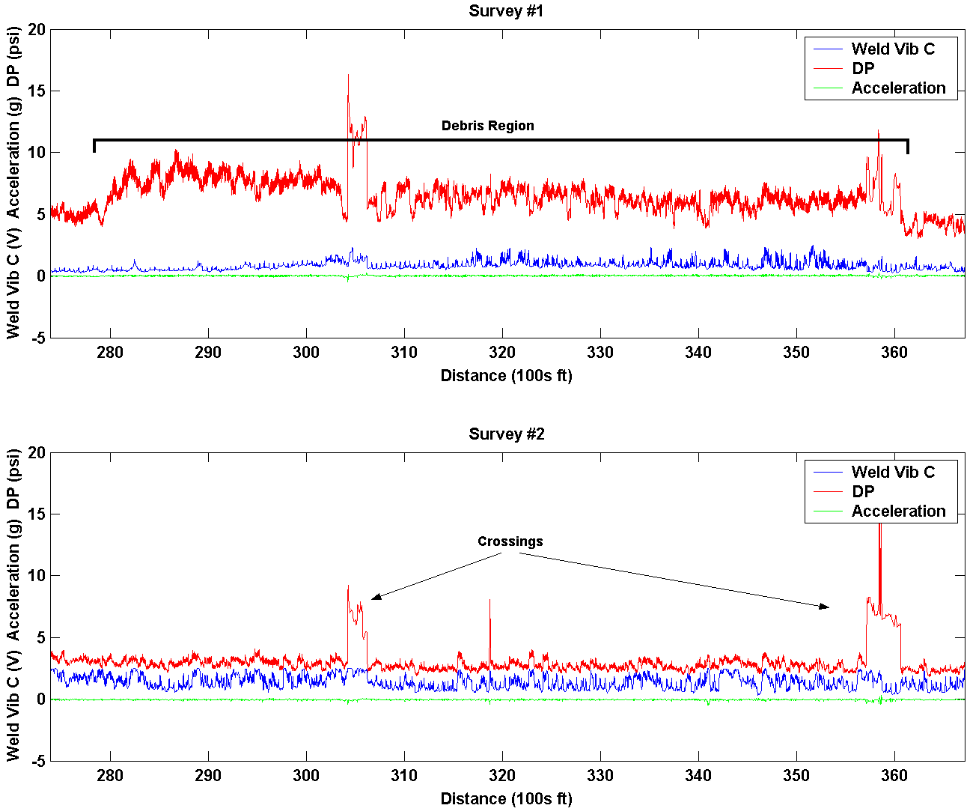

Figure 7 – Monitoring of Wax Accumulation

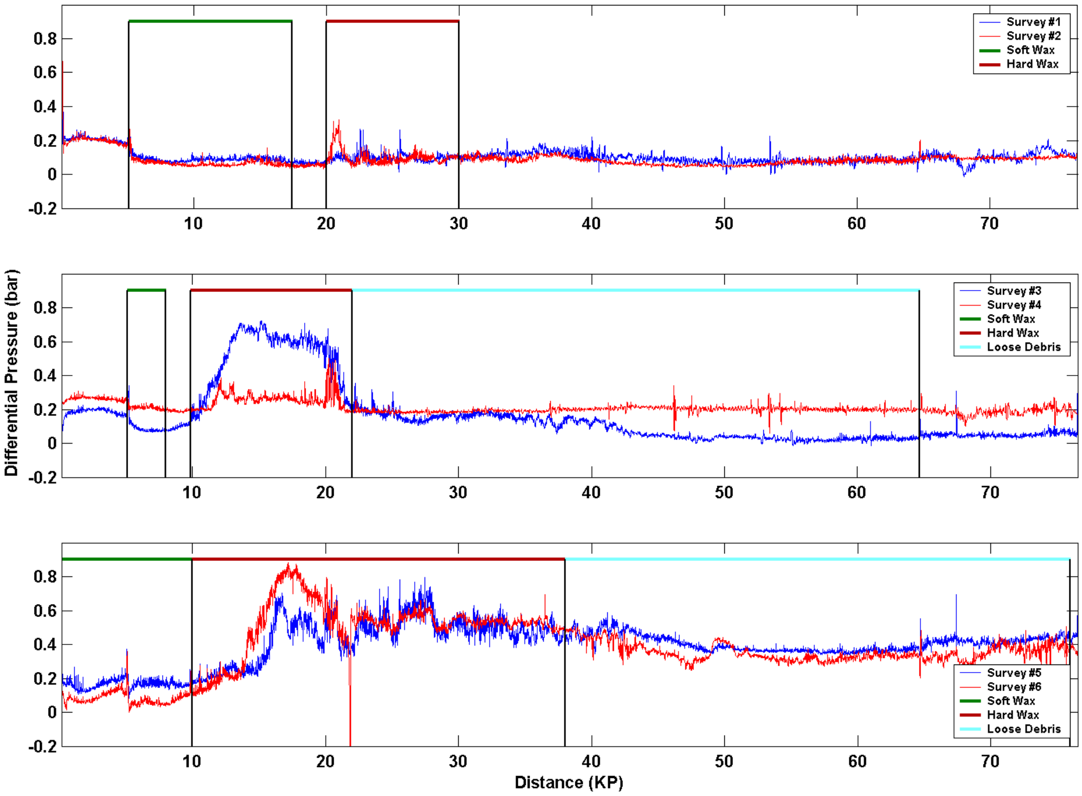

Figure 8 – Debris Downstream of Well Tie-in Point

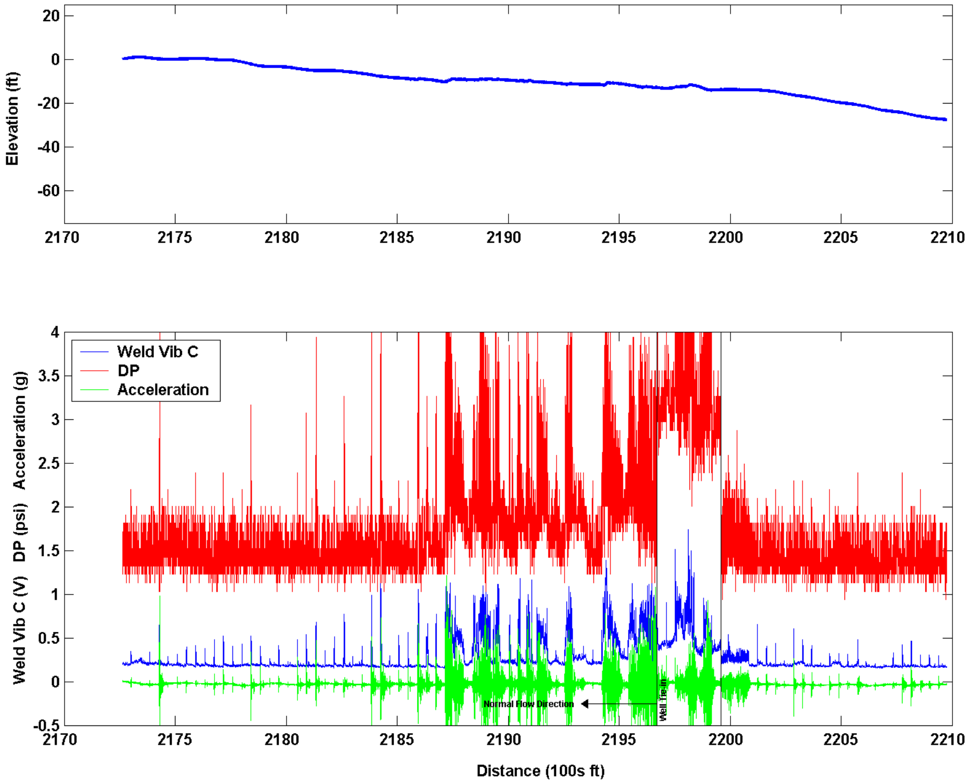

Figure 9 – DP Build-Up as Pig Stops at Bore Restriction at Valve

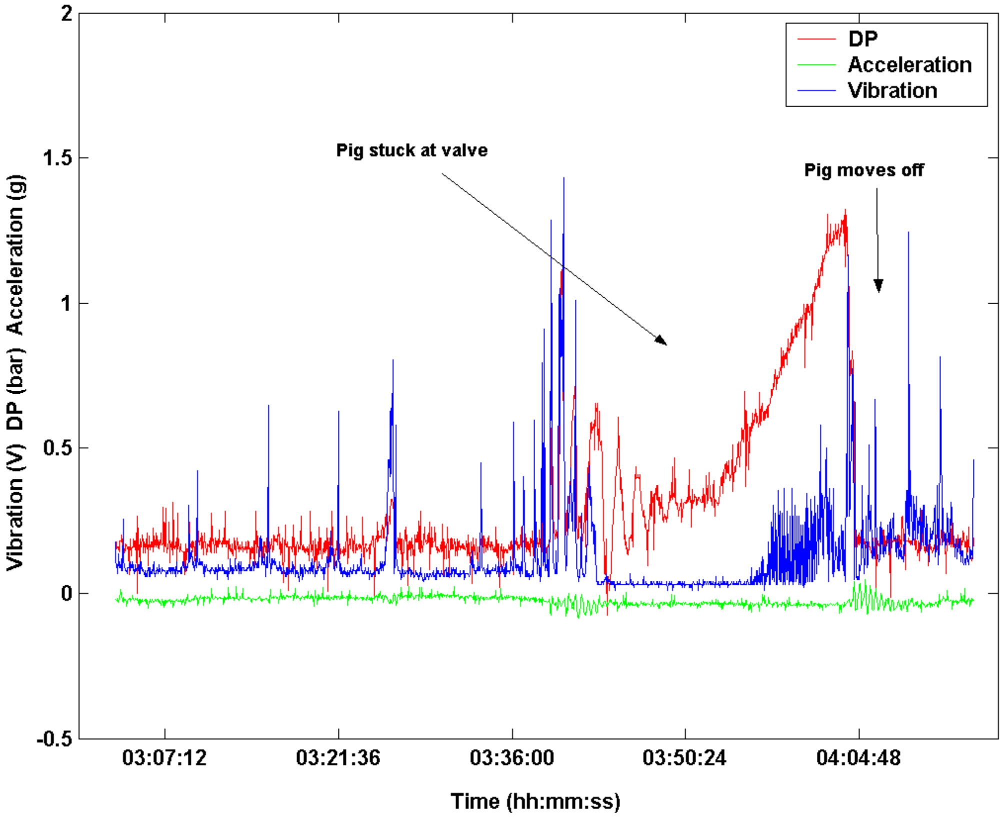

Figure 10 – Pig Stopping at Bore Restriction at Coupling in Pipeline

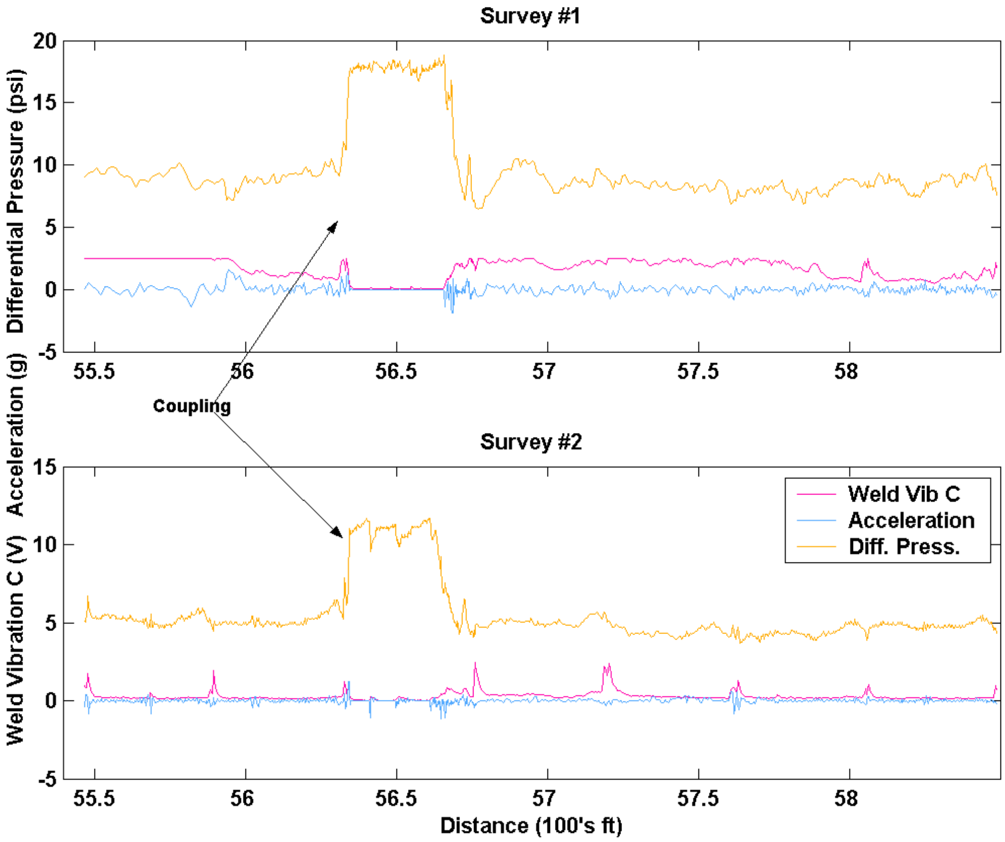

Figure 11 – Estimation of Bore Restriction Caused by Pipeline Debris Using DP Reading

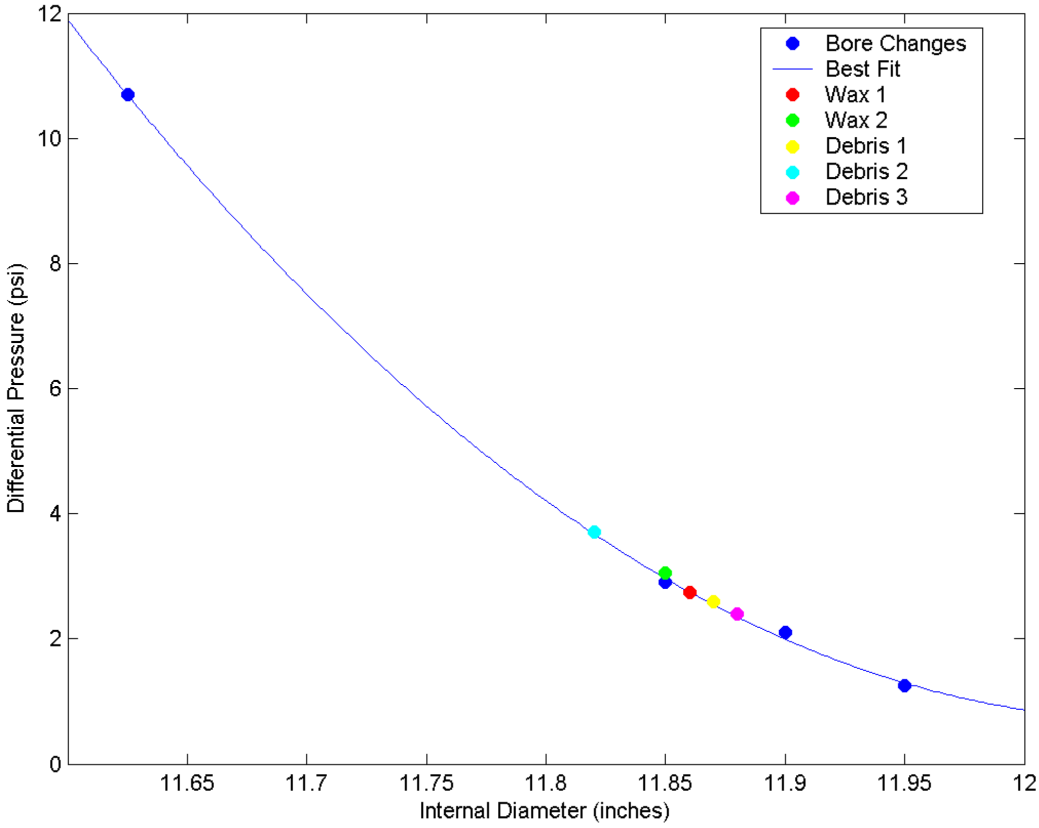

Figure 12 – Correlation of High Vibration Signal With Known Metal Loss Features

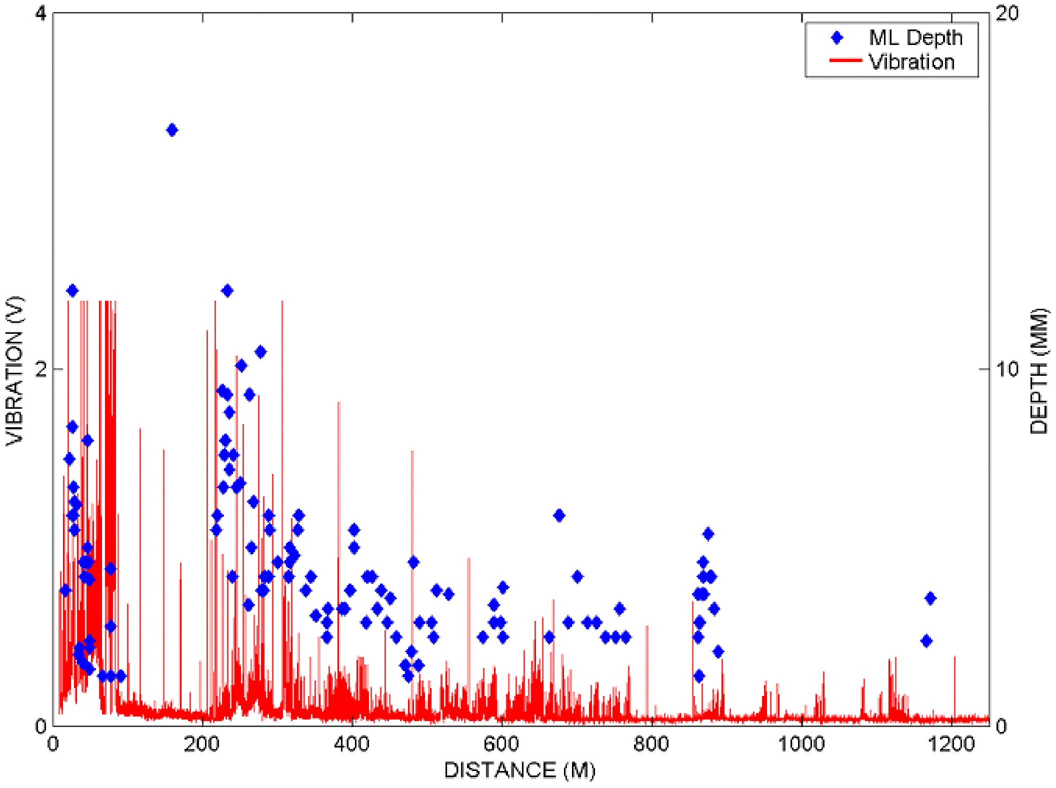

Figure 13 – Vibration Signal Against Elevation Highlighting Corrosion at Low Spots