Testing of Low Cost Instruments for the Identification of Wax in a Hydrocarbon Pipeline.

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Abstact

The present paper describes a summary of experimental work in support of a new philosophy, proposed and developed by R.S.T. Projects Ltd, whereby low cost instrumentation is installed inside a conventional bi-directional or foam pig. Two methods have been investigated.

The first, more speculative, technique investigates how the pipeline acoustic response to an 'active' sound source is affected by the nature of an internal wax coating. Preliminary results from 'static' acoustic tests are presented which indicate that differences in wax coating (type and thickness) can be detected. Further extensive investigation is required to adapt this for a moving pig and develop the appropriate signal processing techniques. This method may constitute an effective means of determining the degree to which a line is coated with soft wax as the absorption characteristics are particularly effective in changing the acoustic response of the pig.

The second technique used an on-board accelerometer to measure the vibration signal of the pig. The results indicated that the intensity and acceleration frequency spectrum of the signal may be related to the internal coating of the line. The condition of the pig disks may also be inferred.

Key Words: Pigging, pipelines, monitoring, wax, inspection

Introduction

The internal inspection of pipelines has come to rely on a sophisticated level of instrumentation. So called "intelligent" pigs are capable, under the best of conditions, of identifying problems relating to cracking, pitting, corrosion and pipeline geometry – Cordell (1999) for a general discussion. In the majority of cases the pigs have been specifically designed to perform the particular inspection. Examples of the application of such tools may be found in the papers by Crouch et al (1996) (magnetic flux leakage and ultrasonic), Willems and Barbian (1995) (ultrasonic) and Wade and Adams (1995) (Geometry). Jansen and

Festen (1995) provide an overview of the most important methods for metal loss and crack detection and consider their benefits and drawbacks whilst Pitchford (1999) presents an industry specification of the requirements for intelligent pig inspection systems. The cost of running such tools, which is high, arises not only from the deployment of the pig, but also because of the extensive project engineering and pre-inspection cleaning that is required. A further consideration is that the effectiveness of these measurements is often highly dependent on the condition of the line, which at present can be ill defined. Beller (1995) stated "no one tool exists which can detect all possible flaws". He goes on to say "it is of great importance that the right tool is chosen". The present paper describes experimental work in support of a new philosophy, proposed and developed by R.S.T. Projects Ltd. Which attempts to provide a better basis for the decision making process

A combination of low cost instruments is installed inside a conventional bi-directional or foam pig that can be run as part of the normal pigging programme. The substantially lower mobilisation and running costs enables a greater monitoring frequency. Appropriate analysis of the change in instrument response along the line and from each deployment will provide an enhanced understanding of the change in pipeline condition. This will provide a better basis for any decision to modify operations or deploy a particular inspection tool. At present several low cost data loggers exist but these provide only simple analysis of, for example differential pressure, acceleration and temperature. The new approach requires that the *individual* affect of *different* line properties on *each* instrument is known and that these be considered in combination for the different pig runs. The paper addresses two aspects of this problem. Firstly it investigates a new 'way out' method and secondly seeks to show that detailed characteristics of the internal coating can be identified using a standard accelerometer.

The first method involved determining the response of the line to an active acoustic signal. This will depend on the mechanical vibration characteristics of the line, which is dependent on its geometrical and material properties (Timoshenko et al 1974), and those of the internal coating, which can change the reverberation within the pipe.

The second, more conventional instrument measured the pig acceleration response. This has, previously, been used to determine gross features of the line such as blockages. The present study was aimed at indicating the degree to which the accelerometer signal could be correlated with the internal condition of the pipe.

Experimental Facility

Pipe Test-line

The major consideration was to be able to run a pig large enough to hold the proposed instrumentation. An eight-inch pipe was considered, as this would have provided ample space for on-board instruments, power, and data acquisition. This was discounted due to the added cost arising from materials, valves and particularly the pump required to generate the desired flow rates. The final design incorporated 6-inch nominal inside diameter, steel tubing. The power to the pig instrumentation was provided, by a light umbilical trailing behind the pig, through which the data could also be acquired to a Pentium PC. Although the scale of the results may differ from larger lines (i.e. intensity and frequency response), the comparative measurements for the different conditions should be consistent.

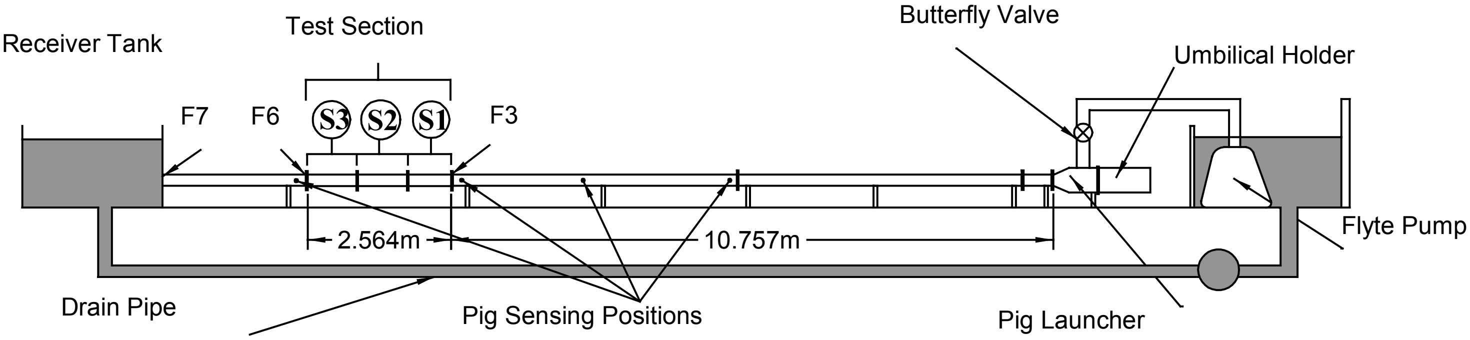


Figure 1: The Pig Test Rig

The line consisted of two long sections, to allow the pig to reach steady state, followed by the test section – see Figure 1. The full test section was made from three, shorter pipe lengths approximately 0.8m in length. This allowed different internal conditions to be simulated if required. The upstream, middle and downstream tube lengths will be referred to as S1, S2 and S3 respectively. A pressure dial monitored the drive pressure.

The Drive Pump

A Type B2151 Flyte pump capable of producing a pressure of 3.5 bar, at a flow rate up to $0.03m^3\ s^{-1}$ was placed at the upstream end of the line. This was sufficient to insert the pig into the line and drive it at a constant speed of around 1 ms^{-1}. The flow was controlled using an in-line butterfly valve.

Pig Launcher

This consisted of an eight-inch diameter steel tube with an eight inch to six-inch concentric reducer, to guide the pig into the line. Behind this section, a PVC umbilical storage unit was attached. This contained the coiled umbilical and had with a suitable gland to allow entry of signal and power cable.

Water Reservoirs

The Flyte pump was set into an upstream reservoir that provided 3.8 m^3 of storage. A second tank at the down-steam end of the line was used to accept the flow and to act as a means of receiving the pig. The distance from the pipe exit to the back wall was sufficient to allow the pig to decelerate into the water. The two reservoirs were connected by PVC pipe sections, which allowed water to be distributed from the up-stream to the receiver tank, when required.

The Pig

The pig, Figure 2, was run with either hard or soft polypropylene sealing. The mild steel central tube, with water tight end caps, was large enough to accommodate the insertion of the required instrumentation.

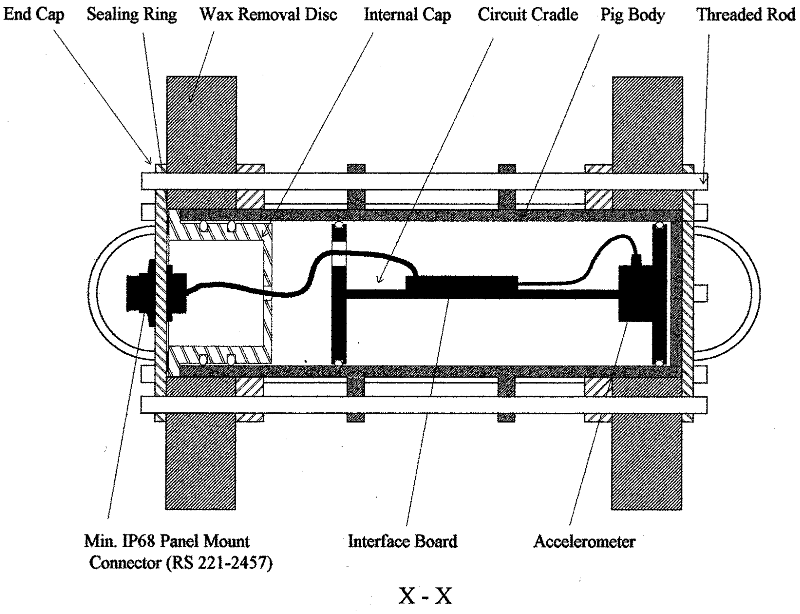


Figure 2: The Accelerometer Pig

The Hydrophone Set-Up for the Acoustic Tests

Two Bruel and Kjerr type 8103 hydrophones were mounted on the front of the pig. One used as an emitter was energised via a B&K type 2713 amplifier. The other received the signal, which was conditioned using a B&K 2658 charge amplifier. The initial tests, presented in this paper were carried out in lengths of coated and uncoated pipe section with the hydrophones placed statically at their end.

The Accelerometer

Two versions of a single axis ICS Euro Sensor 3145 were used. The majority of tests were carried out using an accelerometer with a range of +2 g to -2 g to investigate the lower intensity vibrations of the pig in the line. Further tests were undertaken using an accelerometer with a range of +10 g to 10 g to investigate the peak accelerations that occurred at a pipe flange or constriction. The axis of the device was set to measure in-line changes in acceleration.

Sensing of the Pig Position and Velocity

Initially a measure of the pig position, and velocity, was achieved by inserting fine conducting wires. across the inside of the pipe, at four positions along the pipe; three up-stream of the test section with the fourth just after. The wire, with a diameter of 0.25 mm, broke easily as the pig passed but was strong enough to resist the flow of water in the pipe. Each was inserted through a 5mm hole and held in position by a plastic bush, which also acted to insulate the wires from the steel pipe. As the pig passed, and broke, a wire the total resistance of an electrical circuit changed producing a step change in voltage developed over a known resistance. This voltage signal was recorded by an analogue to digital converter simultaneous to the digitising of the data from the pig instrumentation. The position of the pig corresponding to a particular point in the data was determined by noting the points at which there was a change in voltage on the appropriate channel of the digitised data. The velocity of the pig could be determined from the time taken to travel from one station to another.

Wax and Coating Methods

Hard wax was produced using pure paraffin wax. A soft internal coating was simulated through the use of Petroleum Jelly.

The weight of wax was calculated to produce a given thickness over the inner surface of the pipe length. This was heated in a crucible to just above its melting point. A stopper was place in one end of the pipe length and the wax poured in. The other end was then closed. The pipe placed on a bottle-rolling machine and rolled until the wax had cooled and solidified. The final coatings were found to be uniform as long as the wax did not cool too quickly

Experimental Programme

Static Acoustic Measurements

Response of Pipe Sections to Sine Wave Signals

The transmitting hydrophone was energised by a sine wave of a known frequency and the output from the detecting hydrophone was monitored by a true reading Bruel and Kjaer RMS voltmeter. The frequency of the sine wave was varied from around 500 Hz to 2000Hz. This covered the lower range of mechanical natural frequencies of the pipe sections. Measurements were taken for;

i. Open water – the hydrophone assembly was suspended in the tank to determine the response of the system when unconfined.
ii. Clean pipe.
iii. 'Hard' wax: two coatings of approximately 1mm thick and 8 mm.
iv. 'Soft' wax: two coatings of approximately 1mm thick and 8 mm

Measurement of Accelerations Response to Pipeline Condition

The pig was fitted with two different disks. These differed in their stiffness and diameter. The tests carried out involved;:

i. Old neoprene discs. These tests were to confirm the correct operation of the instrumentation. The discs were heavily abraded from previous tests and had an oversize of less than 1% of the line ID. They were also significantly softer than the new disks used for majority of tests.
ii. New neoprene discs, with an 'oversize' of 5% was run through the test section in a nominally clean condition.
iii. New Discs. Sections S2 and S1were coated with hard wax, to a nominal thickness of 5 millimetres whilst section S1 was left bare.
iv. New Disks. The two downstream test sections were coated with soft wax (petroleum jelly), to a nominal thickness of 5 millimetres. The upstream test section was again left bare.

Root Mean Square (RMS) Accelerations

The data from the accelerometer was digitised at 3000 Hz. Measurements of the strength of the accelerations were calculated over different section within the pipeline.

i. The entire test rig, from initial acceleration until it reached the end of the line. This was used to indicate any significant difference between different runs. Data from the test sections could be scaled by this 'overall' measure to compare the results from each test run, should other factors change the general output.
ii. Traverse through the entire 'test-section'. This consisted of data taken between the flange F3 to F6.
iii. Traverse through the first part of the test section (S1)
iv. Traverse through the middle test section (S2)
v. Traverse through the third part of the test section (S 3)

The RMS acceleration for tests (iii)-(v) was calculated for the steady state and did not include the large, transient, response as the discs hit a flange at the beginning and end of each section.

Spectrum of Accelerations

The energy spectrum for the signal *generated in sections S1-S3* was calculated for each test. These were compared with a spectrum, *taken from the same length of data*, taken upstream, ending *just before* flange F3.

Results

Pig Speed

The original wire arrangement was used to determine that the initial behaviour of the pig within the required window. It was found, however, that the transient response from the accelerometer, as the pig disk passed over a flange, was often sufficient to measure its position and speed. The speed was derived from a measurement of the time taken to travel between two different flanges on the rig. The first was between the flange F3 and F7 (see Figure 1) with a second derived from the time taken for the pig to transit from F6 to F7.

[In many cases it was found that an estimate of the pig speed could be gained using the 'double ping' as each of the two discs passed an *individual* flange. This effect was used to determine the pig speed at each of the four flanges in the test section (F3 to F6) and at the end of the test line (F7). This was a relatively inaccurate estimate, since the distances between the discs (170mm) was around one tenth of the distance between the flanges used in the first method. This technique provided a method of determining the transient pig speed at each flange.]

The pig velocity was found to vary consistently with the valve setting. Figure 3 illustrates that the relationship was linear when the new (hard) discs were used. A valve setting of 2 gave a pig speed of around 1.3 ms^{-1} which varied by around 2% for different runs. The pig when run on the soft discs behaved quite differently. At low flow rates it tended to 'stick'; when the valve was opened further, to four, the speed was around 2.4 ms^{-1}. This behaviour indicated that the older disks were allowing much greater 'by-pass' flow due to their poorer sealing characteristics.

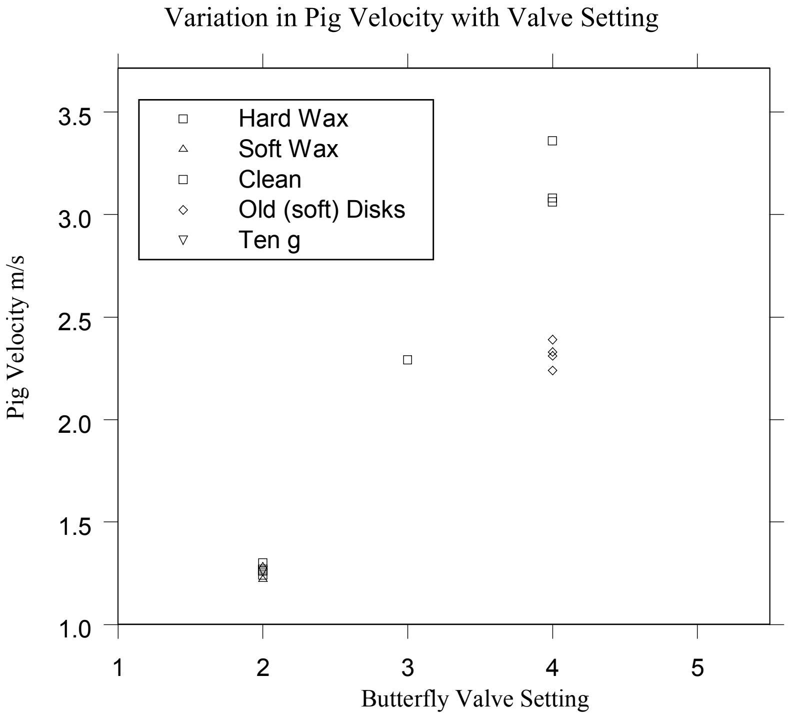
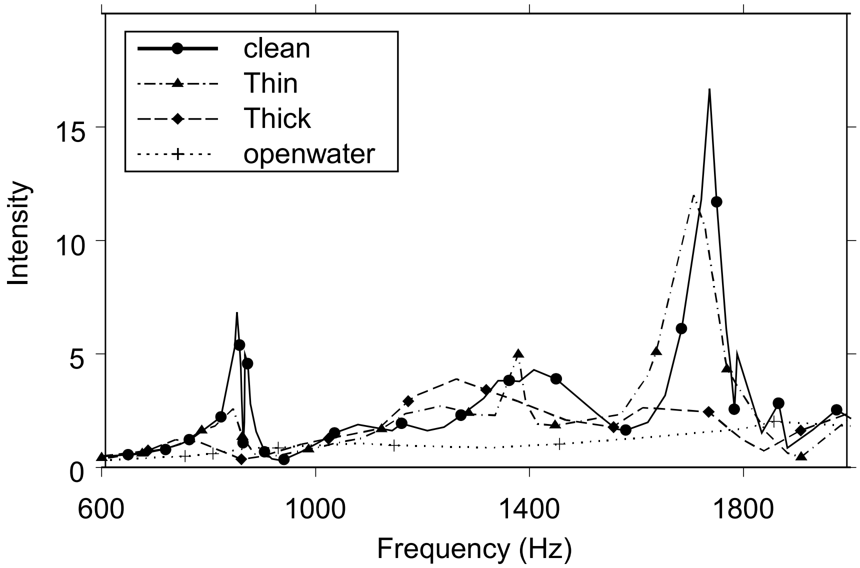


Figure 3 Variation in Pig Speed with Valve Setting

The Acoustic Response of the Pipeline

Figure 4 (a) shows the dependence of the frequency response of the pipeline on the degree of hard wax coating.. Also shown, for comparison, is the output from the hydrophone in 'open' water. Figure 4 (b) illustrates the response when the internal coating was soft wax.

4 (a) Hard Wax Coating



4 (b) Soft Wax Coating

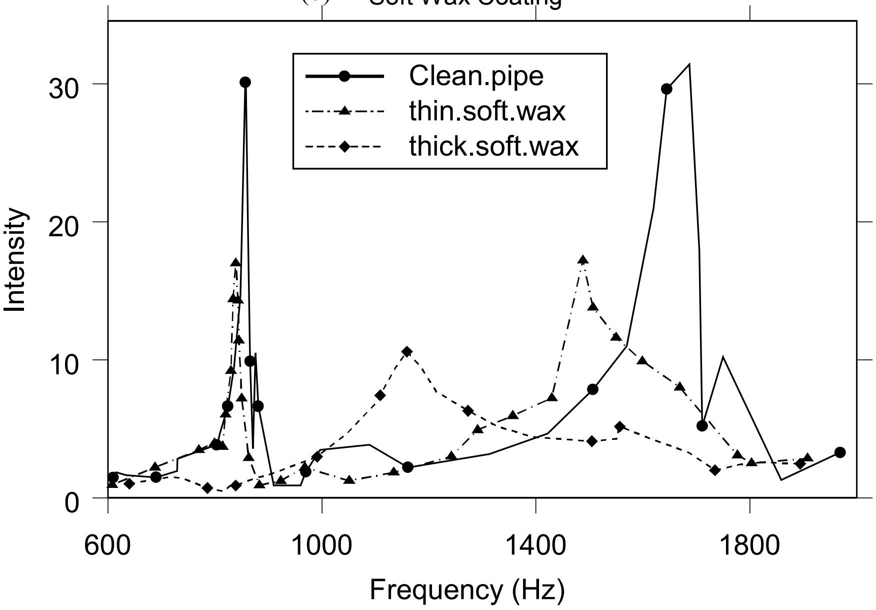


Figure 4: Variation in Acoustic Response of Test Section

Accelerations

Figure 5 shows a typical accelerometer output as the pig was propelled down the test line. The upper graph illustrates the accelerometer response for an entire pig run. The pig accelerated from rest as the pump is started and then decelerates as it is pushed into the converger, after which is accelerates for a brief time. The double ‘pings’ produced as the front and back disk of the pig passed a flange can be seen in most cases. The lower plot shows the section of the time series derived from passage through the three parts of the test section. Figure 6 shows the measured RMS accelerations calculated for each condition.

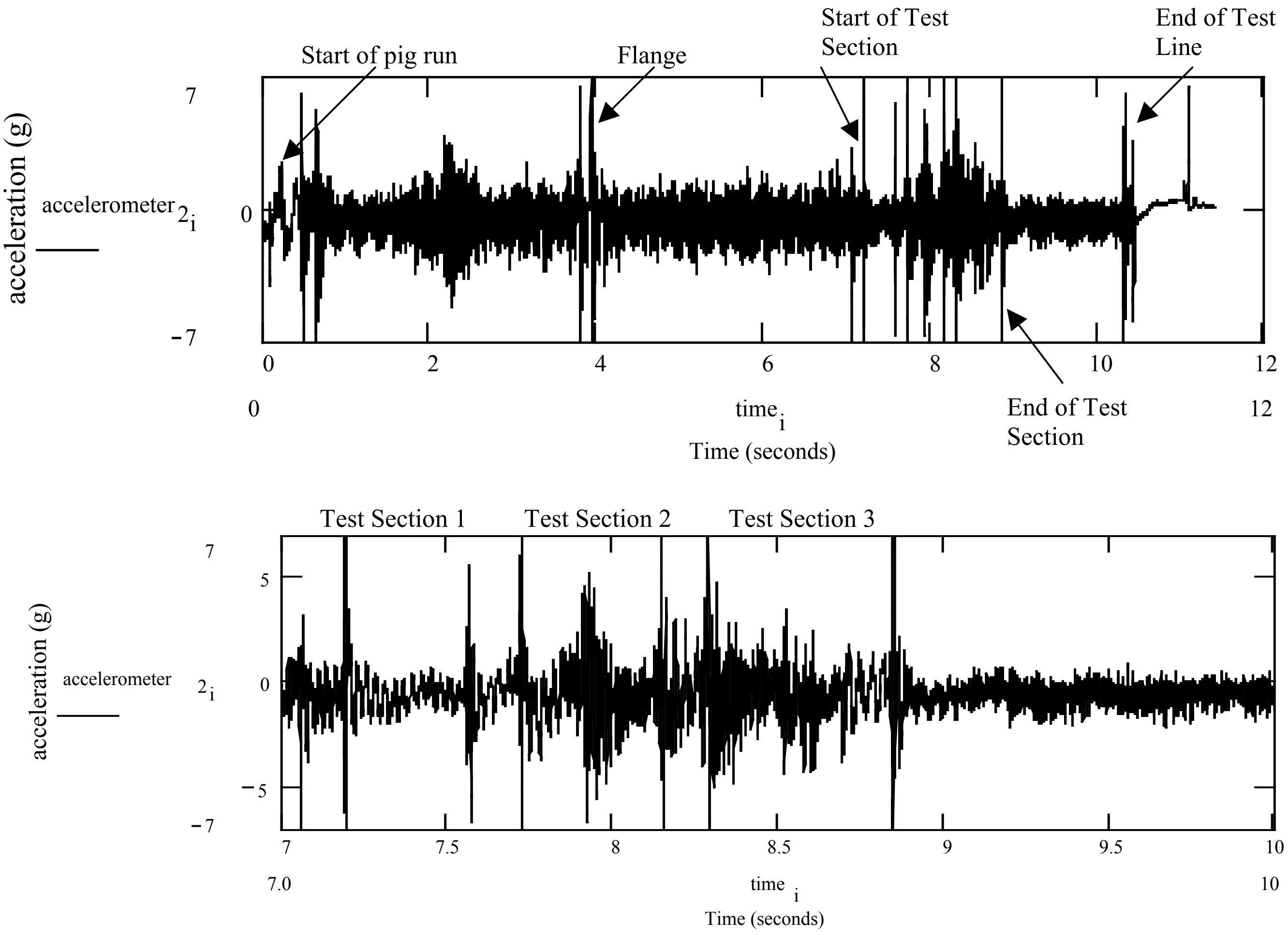
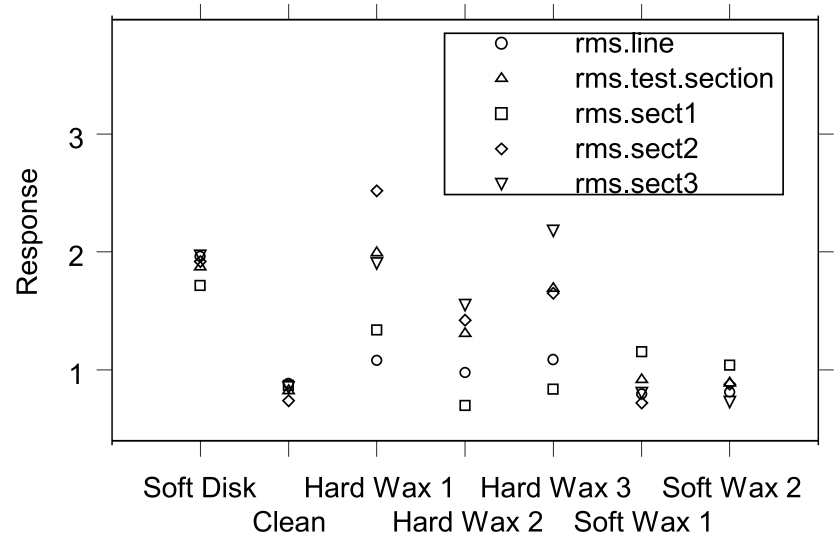


Figure 5: Pig Acceleration Signal Along the Test Line

Typical average RMS accelerations through the various parts of the rig are presented in Figure 6. Results for one run with the soft disks, one with hard disks into clean pipe, three with the hard disks in to hard wax and two with hard disks into soft wax are presented. Figure 6 (a) contains the ‘raw’ unscaled accelerations whilst the lower graph presents the values through the test section scaled by the RMS acceleration calculated over the entire test line.

(a) Unscaled Response



(b) Scaled Response

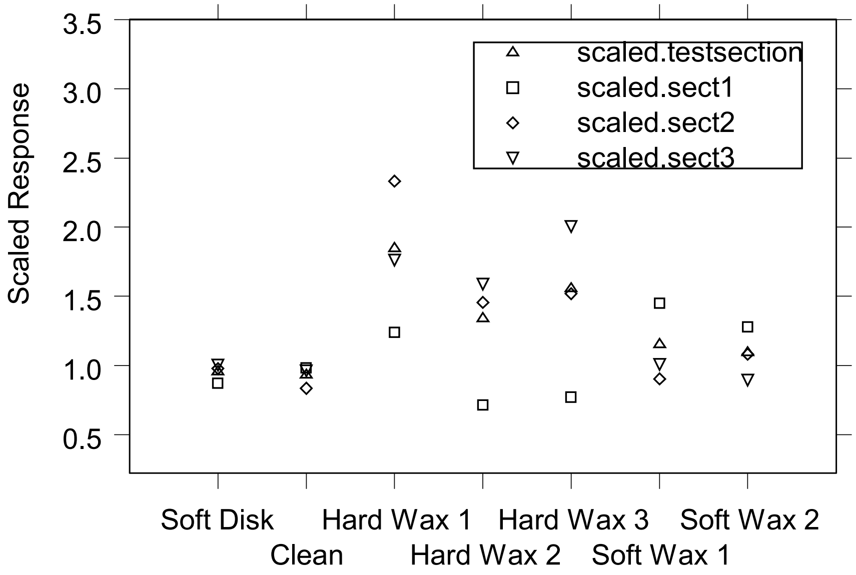


Figure 6: RMS Response of the Accelerometer for Selected Tests

Figure 7 shows the spectrum measured when the pig was run with the older, soft disks. This signal was very different from the new, hard, disk spectra shown in Figure 8 which shows the signal produced from a clean, hard and soft wax coated test section.

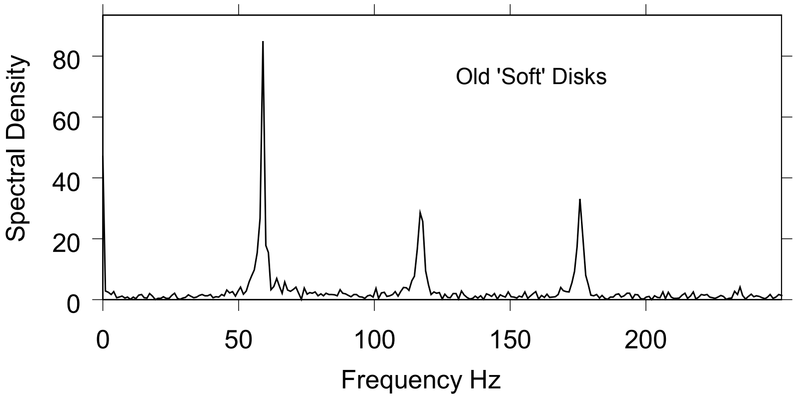
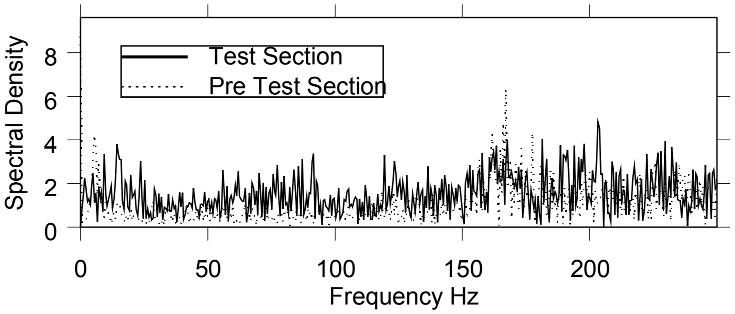
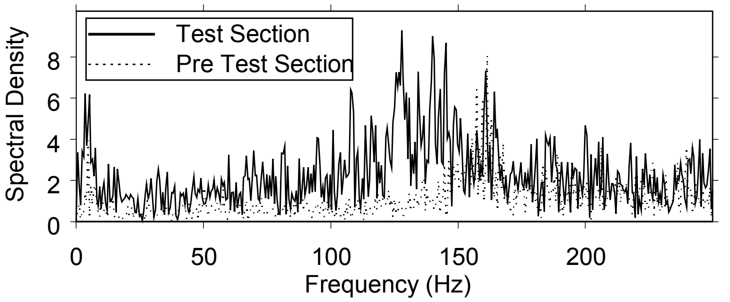


Figure 8: Measured Acceleration Energy Spectrum - Soft Disks Fitted to Pig

(a) Hard Disks - Clean Line



(b) Hard Disks - Hard Wax Coating



(c) Hard Disks - Soft Wax

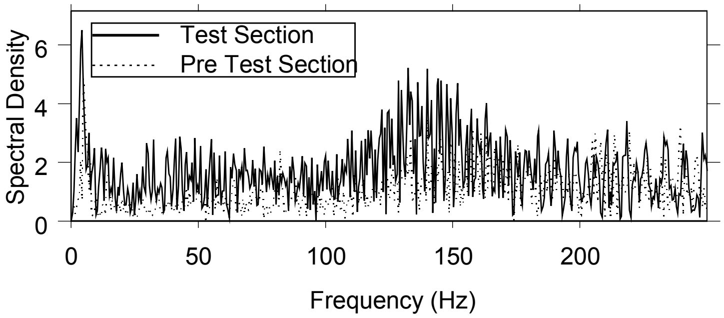


Figure 7: Measured Acceleration Energy Spectrum - Hard Disks Fitted to Pig

Discussion

The Acoustic Response of the Line

Typical results for the static response are given in Figure 4. In each case two resonance peaks can be seen. The lower is at a frequency of xxx Hz whilst a second appears at approximately double the first. In each case the intensity was reduced as the thickness of the coating increased. There was also evidence that the frequency of the peak reduced as the coating thickness was increased. This corresponds to a change in pipe resonance due to a change in diameter.

In-Line Acceleration Response for the Hard Disk Set

The RMS acceleration (Figure 4) was found to be quite sensitive to changes in line and pig condition. A comparison between the test using the soft and hard disks showed that the intensity of the response (in terms of RMS acceleration) were quite different for a pipe with the nominally same internal features. The responses measured for the hard and soft wax are particularly interesting.

Hard Wax

The intensity of response for hard wax was greater than that found for a clean test section. The response in each of the test sections, for the three tests show variations that indicated changes in the internal condition. For all three tests using hard wax the response in test section S1 was least – this section had left uncoated. The response for sections S2 and S3 were was a factor of two greater. It is interesting to note that the result for S2 reduced from the first test (Hard wax 1) to the third (Hard wax3). This was related, by visual observation of the internal condition of the line between test, to be due to the wax in section S2 being fractured and removed by the passage of the pig.

Soft Wax

The response from the soft wax was opposite to that described above. The largest response was seen in the passage of the pig through the first (clean) test section, S1. The response in the coated sections was below that found within the line in general. This was believed to be due to the lubricating affect of the wax between the disk and pipe wall. The response to the second section was smaller than that in section 3 for the first run (Soft Wax 1). This was reversed in the second run (Soft Wax 2) when the response in section S3 was smallest. Again this was due to the pig removing a majority of wax from the upstream section on its first pass.

The spectrum of the acceleration responses also demonstrated significant changes. Figure 7 illustrates a typical response from the soft disks. The signal very distinctly shows a narrow band response from the softer disks with a fundamental frequency of about 60 Hz.

Figure 8 (upper) shows the spectrum obtained when the pig was run into a clean test section. This is compared with a spectrum calculated from the data just before the test section. They are very similar indicating that the transient from the flange impulse has little affect. There appears to be a slight resonance at around 160 Hz.

The spectrum found when the pig was run through hard wax is shown in the figure 8 (b). That calculated from the data taken before the test section is comparable with the spectrum obtained for clean pipe, but varies significantly in its passage through the test section. The spectral density was around twice that found for a clean pipe. The spectral ‘peak’ has shifted down to around 130 Hz.

Finally Figure 8 (c) depicts the spectra from the soft wax tests. In this case, the signal was found to be of a more broad-banded nature. It is believed that this was due to the damping characteristics of the wax.

Conclusion and Further Work

Static tests have shown that the acoustic properties of the line are dependent on the internal coating of the line. The amplitude and frequency of the resonance peaks are dependent on the thickness of the internal coating and its mechanical properties (hardness and acoustic impedance). Initial measurements in a moving pig were disappointing. The whole body accelerations from the pig made it difficult to analyse the pure acoustic response. A further practical difficulty is the need to perform extensive signal processing (spectral analysis) in real time.

This technique provides an interesting alternative to other measurement principles and may be particularly sensitive to very thin coatings of soft wax, which have a particular affect on the acoustic damping within the pipe. Further consideration of the sound source and sensor are required if this is to be a practical approach. A redesign of the acoustic emitter/ sensor – using a single transducer as a ‘pinger’ for example would be more appropriate. The incorporation of such a system into an operating pig is not practicable at present.

The accelerometer signal was shown to relate closely to the type of wax that coated the line. Differences arising from the mechanical qualities of the debris (hard or soft wax) were found. The response will also depend to some extent on the degree of disc wear. Further detailed work is necessary to more fully quantify the accelerometer response to a greater variety of internal features to provide a set of fingerprints. These have to be correlated with data obtained offshore.

Although accelerometers have been deployed in pigs for some time this study has shown that considerable information can be garnered from a more detailed analysis of the signal time series, particularly the power spectral density. At present this is limited by the processing power required to perform real-time calculations but consideration is presently being given to this.

It should be emphasised that an individual instrument is not sufficient to definitely pin-point all internal features. It is the use of several, relatively simple instruments used on a more frequent basis, along with ‘smart’ software analysis which will reveal the internal condition of the line. This will be addressed in future paper.

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