

The Smart Acquisition and Analysis Module (SAAM) for Pipeline Inspection.

Mr D Russell, R.S.T. Projects Ltd., Edinburgh, Scotland, Dr G H Smith, Heriot-Watt University, Edinburgh, Scotland, Mr R Snodgrass, R.S.T. Projects Ltd., Edinburgh, Scotland,

Abstract

This paper describes a low-cost -pipeline inspection tool developed by RST Projects, Scotland. The methodology underpinning the operation of the tool is fundamentally different from conventional in-line inspection systems. This emphasis of the present paper is placed on the basis for this approach and an explanation of the advantages in comparison with conventional intelligent pigging methods. A discussion of the necessary technical innovations is given. A brief example, from an offshore pipeline survey, showing how spool pieces can be identified by detection of the weld signature is presented. With the current volatility in the hydrocarbon market it is believed that this lower-cost approach will have considerable advantage particularly where pipelines are working with low profit margins or in extending the life of older lines.

Keywords: Pipelines, pigging, inspection, instrumentation

Introduction

Offshore and onshore infrastructure now accounts for more than 200000 kilometre's of pipeline in Europe. A significant proportion of the offshore lines are near to, or have passed, their design life and operators are required to demonstrate continued fitness for purpose to extend the use of these lines; much of the present infrastructure in the UK is now reaching its 20-25 year design life. The early identification of factors, such as corrosion or mechanical damage, which will compromise pipeline integrity, is of great concern.

The cost effectiveness of each line must also be maintained through the early identification of any condition, such as the build up of wax, which reduces production rate. This is particularly important for older lines that can rapidly become non-economic. These are often producing at low flow rates, where already low margins would be fatally compromised by extensive intelligent pigging programmes. However it is these lines which generate greatest concern.

Pigging Technology

The internal inspection of pipelines is undertaken by a combination of tools – so-called ‘intelligent’ pigs - which can provide information on a variety of pipeline parameters. (Pig is the general term for a wide variety of tools that are, usually, propelled down the line by the action of a differential pressure. Cordell and Vanzant (1999) provide a description of the range of pigging operations that can be undertaken.)

Many inspection devices have been designed to determine pipeline condition, with particular attention being given to the welds. Quantification of corrosion and identification of defects (cracking and pitting) are of primary importance in the determination of the line’s fitness for purpose. Two methods are pre-eminent in such surveys. The first is based on measuring the effect that the pipeline, and any material anomaly, has on a generated magnetic field (Magnetic Flux Leakage, MFL, or Eddy Currents). Complex analysis techniques can be used to relate these effects to the presence of corrosion, cracks or pitting. The second method uses an array of ultrasonic sensors to determine the presence of cracks and pitting by analysing the acoustic return from the wall reflections. Descriptions of these techniques are numerous, see for example Crouch, Anglisano and Jaarah (1996) or Willems and Barbian (1995).

A second class of inspection pig is used to determine the geometry of the line. Calliper pigs, using mechanical ‘fingers’ or ultrasonic sensors that measure the internal profile by time-of-flight, are used to determine the cross sectional profile down a line whilst Inertia pigs use on-board accelerometers and gyroscopes to define the pipeline geometry.

Such tools now provide a standard for the determination of pipeline condition. They tend to be specially designed pigs, which because of the large power and data storage requirements can be physically large and heavy. A typical MFL survey on a 100 mile line can generate as much as 4 gigabytes of data, Udpa and Porter (1995).

A major drawback inherent in the use of most intelligent pigs is the impact that their deployment can have on pipeline operations. The costs of the planning and preparatory work can be significant. This can include a pre-cleaning programme, modification to the pig traps and the need for special handling facilities.

Secondly, the tool is designed to give results from a *specific* internal parameter. For example, the magnetic flux tools relate the measured magnetic anomalies to differences in pipeline material properties. Finally,

there is, compared with a conventional utility cleaning pig, an increased chance of the pig becoming stuck in the line. All of these factors mean that an intelligent pigging survey is undertaken, in a producing pipeline, only after very careful consideration. This will limit the inspection frequency.

The final class of pig, of importance in the present context, is that used for the internal cleaning of the pipeline. 'Mandrel' pigs consist of a steel body supported in the line by stiff polyurethane discs, which also provide the sealing required to develop the differential pressure. These pigs perform a range of functions as required such as gauging, batching and cleaning. It is this type of pig that would be used to clean the internal surface of the pipeline before a conventional intelligent pig is run. The performance of these, commonly used, pigs was examined in an extensive project undertaken in the early 1990's, Short (1994) and McNulty and O'Donoghue (1995). These tests were undertaken to establish a better understanding of those factors that affect the ability of the pigs to complete their tasks, and improve design and selection criterion. It was, however apparent from these and other investigations that the pigs were strongly affected by pipeline condition.

An Alternative Approach to Inspection

Basic Criterion

The initial approach to the development of the technology was based on the requirement to provide extensive general information regarding the internal condition of a line, whilst ensuring that the cost from deploying the tool was minimised. This led to two fundamental design criterion.

1. Ease of deployment. Use of the tool should have a minimal impact on the normal pipeline management programme.
2. Flexibility: The tool was required to be able to provide information on a variety of line conditions and characteristics. This necessitated the use of a number of suitable instruments.

A solution to the first point was suggested from a consideration of the work, described above, which was aimed at improving pig design. *The pig itself could be used as an instrument.*

The behaviour of a conventional cleaning pig would be monitored as an indication of the condition of the line through which the pig was travelling. If this were possible, then little specialised preparatory work would be required by the pipeline operator as these pigs are used as part of a normal pipeline maintenance

programme. Also, since the package can be deployed within a conventional pig, data on line condition can be acquired as often as this pig is run. The frequency of inspection can be greatly increased and the time variation in pipeline condition determined with greater resolution. This led to the development of the Smart Acquisition and Analysis Module (SAAM™).

This tool will not replace the conventional intelligent pig, but will add significantly to the knowledge of line condition at lower cost. This information will lead to a more cost-effective deployment of the most appropriate inspection system.

The second criterion can be met by using several instruments, sensitive to different pipeline conditions. It is necessary to define the characteristics which must be quantified and identify the most appropriate instrument. A major problem is that the response of an generic instrument, to some simple property will often depend on a number of different pipeline or pig characteristics. This makes it difficult to relate the instrument response to a particular 'input' characteristic. An example of this is the measurement of the differential pressure between the front and rear of the pig, which can change as the result of several different factors. Thus the differential pressure is seen to rise if the pig meets an obstruction. This may be due to a change in line geometry (a dent for example, or passage through a valve), from the presence of debris (wax, sand) in front of the pig or as the pig runs into a region of liquid 'hold-up'. It may also be related to a change in pig characteristics such as wear of the sealing disks

Two conclusions arising from the above were made;

1. An instrument with a clear response to a single condition would be preferable, but it was very likely that the generic measurements being considered would be affected by a variety of factors.
2. Any realistic determination of line condition will be founded on the data analysis procedure. This would, ideally, relate not only to the individual instrument responses but would also cross-correlate results to determine a particular line condition

The instrumentation and software must be able, as far as possible, to de-convolve the effect of several inputs.

Technical Developments

Instrument Container

Figure 1 illustrates the way in which the instrument package is inserted into a standard pig. This approach is

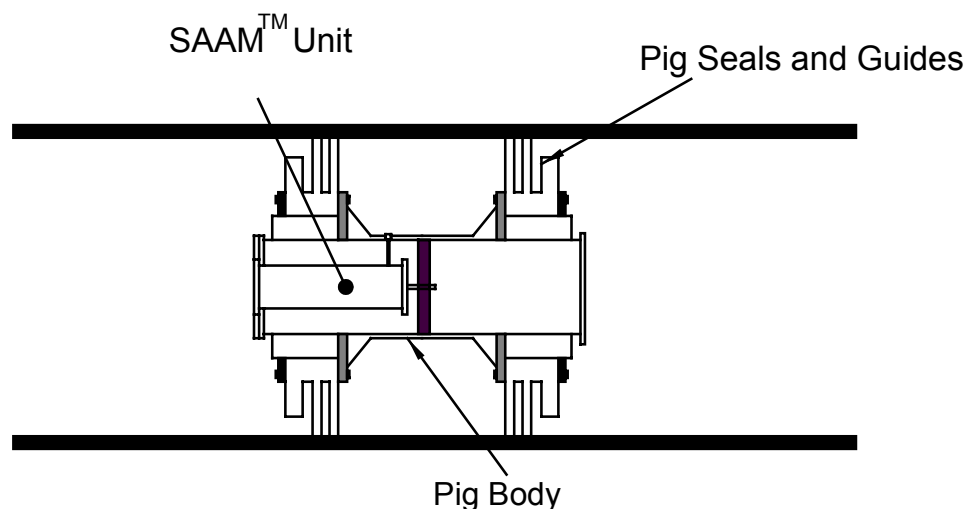


Figure 1: Typical Deployment of SAAM Tool in Cleaning Pig

different from that employed with a conventional intelligent pig, in which the pig body is designed to be large enough to contain the instrumentation, power and data storage. The primary problem with developing SAAM™ was to produce a package that had sufficient range to be of use to pipeline operators whilst meeting the requirements for deploying several instruments in a limited volume.

The power and memory requirements are dependent on the instrumentation (power consumption and number), data acquisition rate, length of line to be surveyed and the pig (flow) velocity. The last two combine to determine the duration of the survey. Thus a long line with a low production flow rate will consume more power and require greater data storage capacity than a short, normal flow rate, line.

- i. Requirements for offshore deployment. The tool meets the approval and hazard risk criteria of all the major oil companies. The instrument package is powered up, only after it is in the pipeline, by a sensor activated by the increase of pressure used to drive the pig.
- ii. Size: This is the primary limitation on the tooling that can be deployed and is determined by the pipeline diameter and carrier pig design. The minimum standard unit has a casing with a diameter of 100mm and a length of 381mm, which can be fitted into an 8" line.

- iii. Power: Extensive development has been required to minimise the power requirements of the tool. Typical instrumentation requires 100 mA of current at a voltage of 7.2 volts. The present system uses Nickel Hydride batteries, which supplies 3.6 Amp hrs supply giving a total duration of around 36 hours. The duration of the tool has also been increased with the development of low power, single chip processors for control and some on-board pre-processing of the data.
- iv. Storage capacity: At present up to 8 channels of data are acquired. At a sample rate of 13 Hz this constitutes 11 Mbytes over a possible run time of 30 hours (typical for a North Sea inspection). Although storage capacity originally constituted a major limitation of the tool this is no longer the case. The use of digital camera, solid state memory gives a current total memory capacity of 440 Mbytes. This extra memory will be required should further instrument channels be added or if longer duration inspections are undertaken.

Instrument Development

Three years of development have defined a combination of suitable instruments with several identified for possible further investigation. This process required that each proposed instrument be considered in terms of its ability to respond to the pig dynamics and pipeline characteristics and the practicality of fitting within the instrument package. The initial identification was followed by extensive testing and, if found to be suitable, deployment in the field.

Baseline testing, under closely controlled laboratory simulations, is of fundamental importance. It is only by performing tests on each instrument under known conditions that its response to each factor can be evaluated. Extensive test loop and laboratory work must be undertaken to validate the response of an instrument to each conditions considered to be of importance.

Present deployment of the SAAM unit incorporates 4 sensors.

- i. Differential pressure gauge. This can be related to the presence of debris, the state of line components and the state of the pig sealing disks.
- ii. High sensitivity, $\pm 2g$ accelerometer, which measures the linear acceleration and inclination of the pig. This can be related to the presence of debris and geometry of the line.
- iii. Low sensitivity, $\pm 10g$ accelerometer, which records the pig vibration signal. The vibration signal can be related to the state of the internal surface of the line. The signal from this sensor is analysed in five

frequency bands centred at 178, 405, 766, 1483 and 3151 Hz. This is achieved by analogue filtering of the signal into five separate channels. This approach was used, as there is insufficient storage to achieve the necessary data rates for a full digital analysis over the required frequency range.

- iv. Temperature sensor to provide details of the process fluid. This can be used as an indicator for the possible presence of wax.

These measurements allow determination of;

Dents and buckles

Vertical profiling (consecutive measurements can indicate subsidence)

Status of in-line components

Zones of wax deposition

Analysis of Data

The quantity of data acquired over a survey, although of two orders of magnitude less than a conventional intelligent pig run is large and, as has been stated previously each instrument can be affected by different inputs.

The use of conventional deterministic and statistical (mechanistic) analysis techniques can be limited. For this reason development has concentrated on the use of artificial intelligence algorithms. Particular use has been made of self-organising maps (SOM's) a type of neural network which is useful in the classification of complex multi-dimensional data, Hertz (1991). This algorithm is unsupervised, requiring no user intervention. Representative parts of each of the instrument time series are used as an input to the algorithm, which then produces a multi-dimensional map showing areas of high correlation between each. The areas of high correlation are identified with a particular pipeline characteristic, and the algorithm then goes on to analyse the complete data set to identify the same characteristic by means of the self-organising map.

An example is provided, by the considering the application of each approach to determine the position of pipeline welds and identify each spool piece in the line. The vibration signals recorded can be effective in indicating the presence of each weld. As the pig sealing discs pass the weld a slight double 'kick' is experienced by the pig. Data from a survey of a 24" North Sea oil export line was used to determine the effectiveness of the neural net technique in comparison with a mechanistic 'thresholding' algorithm.

It was found that the accuracy of both methods was comparable, around 95 –98% being identified. However the conventional thresholding method required that the adjustable parameters, defining the peak be optimised on a case-by-case basis leading to an increased requirement for operator intervention.

The neural net technique was easier to optimise. The net was trained using the first 20 to 30 welds that had been identified previously. An example of the maps that were obtained for four vibration channels (labelled V0 to V3) is given in Figure 2. These indicate that the weld feature is strongly correlated with three of the vibration channels and that this feature is indicated by a high response in the bottom left hand corner of the SOM. The higher frequency channel, V3, does not have a high correlation in this region and so is not strongly related to the effect of the weld. Figure 3 shows the resulting weld ‘tags’.

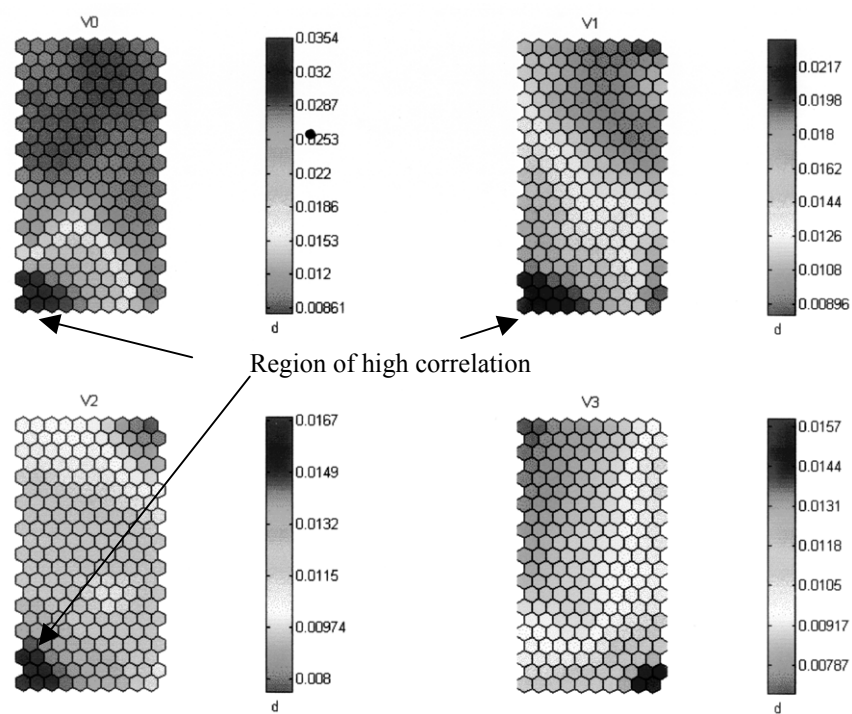


Figure 2: A Self-Organising Map (SOM) Obtained from the Vibration Channels

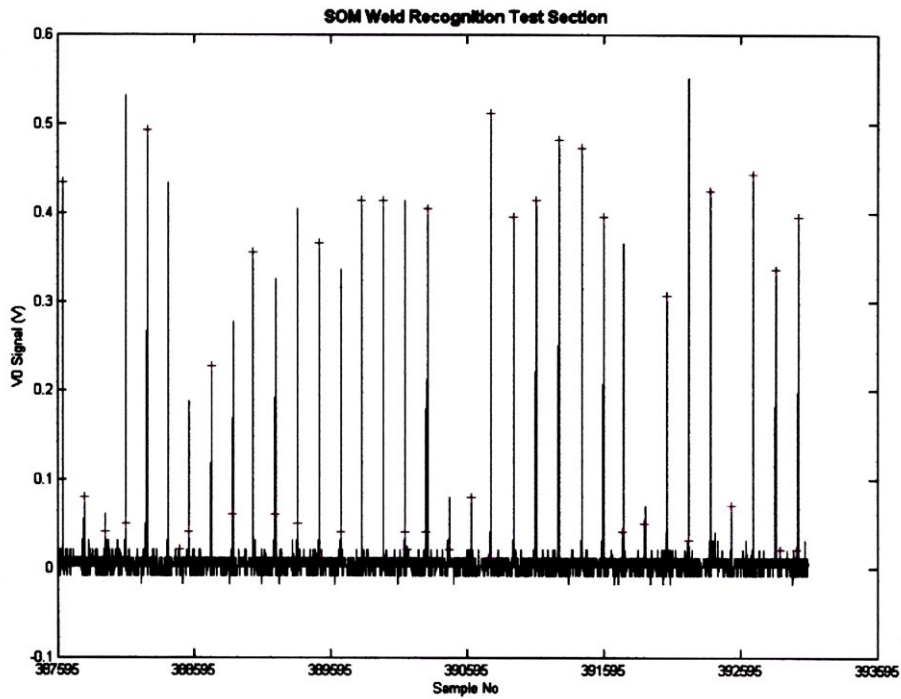


Figure 3: Example of the Detection of Weld Signatures

Summary and Conclusions

Simple instruments contained within a conventional cleaning pig can give important information on the internal condition of a pipeline. This has several advantages over conventional intelligent pigging surveys. Table 1 illustrates the perceived operational advantages of using the SAAM tool, in comparison with a typical intelligent pig inspection.

Task	Intelligent Pigging	SAAM TM
Project Planning	Extensive	Minimal
Pre-Inspection Pigging	Required	No
Modification of pig traps	Often	No
Adjustment of production rates	Often	Rare
Risk of deployment	Significant	Negligible
Typical cost	\$ 000's /km of line	\$ 00's/km of line

Table 1: Comparison of Operational Requirements

The effectiveness of this tool is dependent on an adequate understanding of the response of the pig and instrumentation to the variations that can be encountered within the line. This has been achieved through extensive laboratory and flow-loop testing. The present neural net techniques are particularly successful in identifying weld signatures and have also shown the ability to identify regions of wax build-up.

The current tool has now been deployed in around 2000 km of pipeline, 90% within the North Sea offshore market with further offshore surveys having been carried out in Nigeria and the Middle East. Around 200 km has involved onshore pipelines.

Future Developments

Several areas have been identified as being key to increasing the effectiveness of the tool.

Operational Improvements:

- i. There is an increasing need for inspections in lines at higher fluid temperatures. In the short to medium term, improvements to the tool to operate up to 100⁰ C are necessary with a longer term requirement for operation in temperatures up to 150⁰ C.
- ii. Reduction in size to apply the tool to lines of 6” and below. This would extend application to smaller diameter flowlines.
- iii. Increase of range. Range is at present constrained by the ratio of required power to that stored by the batteries, since the number of batteries is limited by the small volume of the unit. Data storage is not a limiting factor, unless either greater survey duration or more instruments is required.

Instrument Improvements

- i. There have been indications that internal corrosion can be identified by the current instrumentation. Further work is required to establish if this is the case.
- ii. Measurement of angular velocity and horizontal pig motion to extend the geometry information. Vertical variations in geometry have already been achieved – see Russell and Ogunjimi (1999).
- iii. Further base-line measurements of instrument response. A new 10” test loop is currently under construction. An improved understanding of the way in which the tool responds to different inputs is a continuing concern.
- iv. More advanced ‘on-board’ signal processing would allow a greater range of digital analysis techniques to be used, without an undue increase in the requirements for data storage.

Software

One of the major innovations will be to apply the SOM techniques to a series of consecutive surveys. The variations in operating condition and disk wear make the direct application of these methods difficult at present.

Finally the premise upon which the tool was first designed is now being confirmed in the latest results, which demonstrate that the use of the SOM techniques with data derived from the vibration channels and the temperature sensor in combination will provide better identification of wax build-up. Further analysis is necessary to quantify this.

References

- Cordell J. and Vanzant H (1999). “*All About Pigging*”, Published by On-Stream Systems Ltd. UK.
- Crouch A, Anglisano R and Jaarah M (1996). “Quantitative Field Evaluation of Magnetic Flux Leakage and Ultrasonic In-line Inspection”, *Pipes and Pipeline Engineering*, Jul-Aug, pp23-32
- Hertz J, Krogh A and Palmer R (1991). “*Introduction to the Theory of Neural Computation*”, chapter 9, Addison and Wesley.
- Russell D and Ogunjimi P (1999). “Measurement of Pig Behaviour Provides Low-Cost Solution to Monitoring Pipeline Geometry”, accepted for publication in *The Oil and Gas Journal*.
- Short G (1994). “The Pigging Technology Project: The First Three Years”, *Pipes and Pipelines International*, July-Aug, pp 23-27.
- Udpa S and Porter PC (1995). “The Application of Artificial Intelligence to the Analysis of Magnetic-Flux Leakage Data”, *Pipeline Pigging Conference*, Houston.
- Willems H and Barbian OA (1995). “Ultrasonic Crack Detection in Pipelines by Advanced Intelligent Pigging”, *Pipeline Technology*, Volume 1, pp 223 –234, Elsevier Science.