The Benefits of Long Range Ultrasonic Sensors for the Efficient InLine Inspection and Corrosion Monitoring of Previously Non-piggable or Hard to Reach Pipelines

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Abstract

One third of all pipelines worldwide are considered un-piggable by the widely used existing Smart pigs. The vast majority of buried oil pipelines in Europe carry hazardous fluids at high pressure and temperature. While the most common type of InLine Inspection (ILI) pigs use magnetic flux leakage (MFL) techniques. Several limitations of this approach have been identified such as its effectiveness in distinguishing acceptable anomalies from defects, or determining whether the indication is on the external surface or internal as well as the signal reading when the pipe is encased by steel conduits, which is often the case through road and rail crossings. The other common technique used for the purpose is that of Ultrasonic inspection pigs. In this case the process of covering the whole pipeline length with Ultrasonic scan inspection would be both exhaustively time-consuming as well as impractical in sheer data volume to analyse and interpret even at the age of the IOT.

iPIM research program is bringing the idea of using Long Range Ultrasonic Guided Waves for a pigging system that is a permanent, reliable, manageable and energy efficient solution to pipeline monitoring.. A permanent network of novel low profile Long Range Ultrasonic (LRU) sensors will incorporate on-board signal processing capabilities.

Keywords: pipe thinning, corrosion, long range ultrasonic, pigging, structural health monitoring

1. INTRODUCTION

Around 0.5 million kilometres of buried oil pipelines in Europe carry hazardous fluids [1] often at high pressure and temperature. In Europe alone, up to 4 million gallons of oil are leaked into the environment per year due to corrosion and mechanical damage. Pipeline spills of hazardous fluids into the environment outnumber all other sources (e.g. tanker spills in oceans etc.) combined. The pipeline network in Europe is increasing at rate of about 1,000km per year [2].With this rapid expansion and the existing ageing pipeline (> 30yrs old), there is a growing challenge in maintaining its structural integrity. Finding and repairing pipe damage before catastrophic failure occurs, particularly as buildings encroach on pipeline sites is crucial. Existing inspection using ‘intelligent pigs’ to find potentially harmful damage and repair or replacement by digging trenches to expose the pipe is very difficult at river, rail and road crossings. Yet a typical 100km pipeline might cross 6 rivers, 4 railways and 3 motorways as well as numerous other road crossings [3].

Between 1990 and 2000, an average of 75 pipe leakage incidents released oil on land, in rivers and in underground water [4]. To address this issue, pressure is being put on pipeline operators to find new inspection technologies which provide an early warning about pipes in danger of failure [5]. In Brussels, European Union officials have urged 15 government members to begin applying new inspection, re-welding, and repair rules and technology to stem this pollution [6]. Oil and gas transmission lines are generally owned by specialist distribution companies, which have a small technical and engineering base. Most of their maintenance activities are therefore outsourced. This is particularly true in the areas of inspection, non-destructive testing (NDT), machining and welding [7]. Estimates put these markets as growing annually by 10% [8].

Most pipelines are buried in the ground and once buried, every effort is made to leave it there. Excavation is not only expensive, but the site conditions under which any repairs, re-welding or replacements are made are so poor that new defects might be introduced. Excavations are even more problematic when the pipeline is buried under rivers, railways and roads, where damage is more prevalent. Inspection and any repairs need to be conducted with the minimum of disruption. Disruption can be avoided by performing an internal inspection using inspection robots (pigs) although repairs necessarily require the pipeline to be excavated.

2. CURRENT METHODS AND “PIGGABILITY”

It is evident that there is a pressing need to increasingly inspect the full length of the aging pipelines as well as monitor the new ones for early detection of faults and optimise risk assessment and management.

The term “un-piggable”, as commonly as it is used, defines a pipeline that cannot be inspected with a free swimming inline inspection tool without a need to modify the tool or the inspected pipeline. This can be the case because of difficult access (launching and receiving facilities), restrictions due to valves, substantial changes in diameter along the length of the pipeline, small radius bends, dented or collapsed areas, excessive debris or scale build-up, impassable fittings, low operating pressure, low flow or absence of flow, and other configuration issues [9].

In general, pigs occupy the entire cross section of a pipe. Due to the size of the sensor collar, assembly is needed to provide 100% volume coverage. Pigs can cope with moderate changes in diameter and moderate bends in the pipeline but there is a large variation in pipe sizes e.g. standard welded steel pipelines for gas/crude/oil-product have internal diameter between 150-350mm while larger pipes have internal diameter 500-1,380mm. Therefore, a matching pig is required for each pipe size and for larger diameters, the pigs tend to be very large in bulk.

More common than other types, the magnetic flux leakage (MFL) technique is used [7]. These techniques are sensitive to changes in the flux of a strong magnetic field that is induced in the pipe-wall as the ‘pig’ passes through. Sensors detect leakage of the flux from the pipe-wall due to changes in the volume of the pipe-wall caused by corrosion, cracks, welds, bends and many other geometric effects. MFL ‘pigs’ cannot distinguish acceptable anomalies from defects, or determine whether the indication is on the external or internal surface. It also cannot determine the location of the discontinuity around the pipe circumference.

The second most commonly used method is that of the ultrasonic NDT inspection. To achieve full coverage, conventional ultrasonic probes would need to be positioned along the length of the pipeline. For example, compression or electromagnetic transducers (EMAT) probes would have to be adjusted every few millimetres to keep them in contact or close proximity with the walls. In practice, this is extremely difficult to achieve with a small robot.

Furthermore, the identification of defects remains difficult and misinterpretation of indications can have disastrous consequence. For example, misinterpretation of a dent in a 16” gasoline line as an innocuous weld manufacturing flaw led to the release of 237,000 gallons of fuel into Whatcom Falls Park, Washington State [10], which subsequently ignited killing three young boys and landing BP-Amoco with a $3million penalty [11]. To guarantee proper evaluation of all indications detected with the ‘Intelligent pig’, the pipe must be “dug out,” exposed and tested from the outside with more sensitive NDT techniques such as ultrasonics. This is applied manually and results are not accurate enough for Fitness for Service (FFS) assessment. The damaged section of the pipe is therefore replaced with a new section or ‘pup-piece’, which is welded into the pipeline at either end with butt welds. Of course, the excavated pipeline needs to be inspected again before being buried.

3. THE LONG RANGE ULTRASONIC GUIDED WAVES METHOD

The advantage of Long Range Ultrasonic Testing (LRUT) is that unlike conventional ultrasonic methods, when using LRUT, the sensors would only need to be adjusted every 50-150 metres, the typical attainable propagation range of guided waves (GW) in pipelines, thus making the mechanical adaptation more feasible and the data collection quicker and smaller[7]. Data is highly reduced compared with conventional ultrasound means (see Figure 1). LRUT can also be deployed internally for pipeline inspection [7]. Results can potentially be processed quicker with less labour after the pigging operation. This advantage is achieved at the expense of loss in sensitivity, with minimum detectable defect sizes being much larger than achievable with conventional ultrasound. However LRUT would allow serious defects that need immediate attention to be detected far more rapidly.

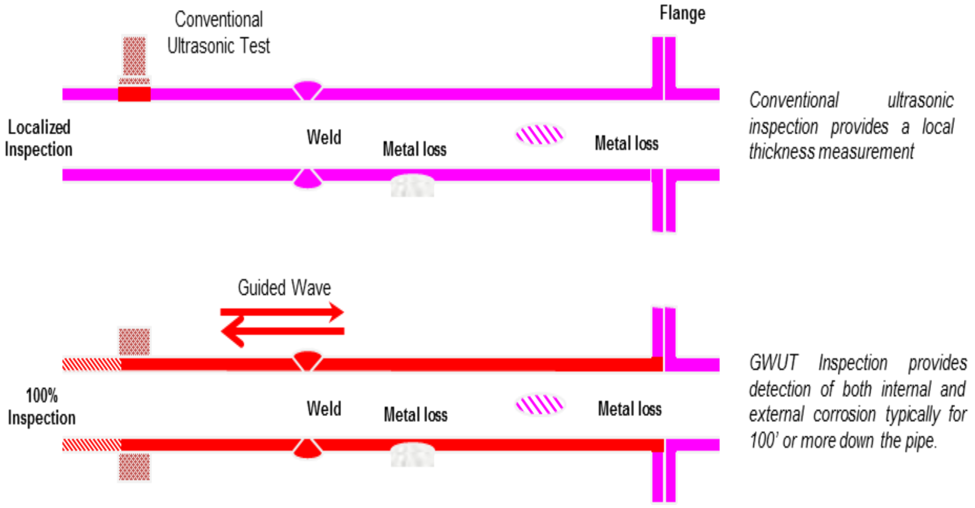

Figure 1: Conventional ultrasonic inspection vs GWUT inspection.

3.2 The importance of LRUT data interpretation

The use of LRUT or MFL approach determines and extracts damage-sensitive features from the signal using different signal-processing algorithms. A pattern recognition technique is then required to classify the damage and estimate its severity. It is important to note that GW Structural Health Monitoring (SHM) always involves the use of threshold values to decide on damage presence in the structure. The choice of the threshold is usually application-dependent and typically relies on some false-positive probability estimation.

There have been pointed out some limitations of the use of GW [12]:

- Complicated evaluation of data by highly trained operators is required because of the complex signals involved.
- Dimensions of corrosion (wall loss, longitudinal length, profile) are not directly determined.
- Significant corrosion can be missed, especially localized damage.
- The scattered signal is not directly equated to a specific area or volume of loss since there cannot be an absolute calibration standard.
- Many field conditions that limit the distances that can be effectively inspected and that cause artefacts which can complicate analysis exist.

It is assumed that a signal-to-noise ratio of 6dB is required for detection in order to reduce the amount of false indications. With this in mind, the required sensor detection performance can be evaluated [13]. However, it is not an objective assessment as the nature of the defects themselves requires a greater level of understanding. For this reason, the requirement of the implementation of GW SHM must involve the detailed characterization and understanding of the response from various types and sizes of defects.

In the paper: “A unified approach for the structural health monitoring of waveguides” [14] the authors assess the feasibility of a monitoring process on an aluminium plate and steel pipe, damage was simulated by changing the boundary conditions of each structure. It is also crucial to identify a formal classification routine that characterise flaw severity using GW. Damage could be incrementally introduced into the structure, and at each depth, multi-mode wave signals can relate the changes in received signals due to mode conversion and scattering from the flaw.

Lamb wave tomography reconstructions can be used by incorporating several different analysis techniques including wavelet-based feature extraction, and formal pattern classification to create a fully-automated analysis scheme designed to locate, size, and identify the severity of unknown flaws. Variations of Lamb wave propagation reflect changes in effective thickness and material properties caused by structural flaws as corrosion, fatigue cracks and voids that can then be mapped via a reconstructed tomographic image. [15]. In “Dispersion-based imaging for structural health monitoring using sparse and compact arrays” [16] an extension of classical imaging techniques that takes advantage of the chirplet-based matching pursuit algorithm was presented. For non-dispersive propagation, an accurate localization can be obtained. Even if specific low-dispersive modes are injected, mode conversion at discontinuities might generate dispersive modes which superimpose with the targeted modes. This effect significantly complicates the measurements and demonstrates the need for pattern recognition algorithms since they can be trained either through modelling or experimental data. The fundamental concept of class distribution within each feature space was discussed in “Ultrasonics Classification of flaw severity using pattern recognition for guided wave based structural health monitoring” [17]. Features were correctly identified with respect to their severity. Linear spread of classes would allow new data corresponding to an intermediate flaw depth to lie correctly between classes, in order to identify a feature space where the classes are most linearly distributed.

The approach using torsional ultrasonic GW has strong potential for prognostics-based structural health management due to the good correlation and relationship between damage size change and the signal deviation demonstrated using the error (erf) function. This process was effective in the monitoring of crack growth and shows an evaluation of the Probability of Detection (POD). The Euclidian distance, which is defined essentially as the signal-to-baseline ratio, was used.

4. THE IPIM SOLUTION

The iPIM is going to utilise the advantages of the LRUT in a robotic mechanism that is in the process of being developed out of a sophisticated prototype of an In-Line Inspection (ILI) PIG for NDT of pipelines (oil & gas). Overcoming the previously mentioned limitations, the iPIM is being built to:

- Detect of internal or external metal loss, wall thickness change;
- Identify metal loss down to 5% of pipe wall cross-section. Reliable detection of 9% metal loss flaws (equivalent to 5% amplitude reflection);
- Increase the POD to a 95% rate for corrosion-related defects at <9% Cross Sectional Area (CSA) loss over a 50m range either side of the transducers collar.

This is achieved with the said methodology which incorporates signal-processing algorithms, pattern recognition technique to identify and classify damage. In addition, the algorithms used will be trained through modelling or experimental data overcomes to a large extend previous concerns.

The iPIM system advantages and characteristics are summarised in Table 1:

iPIM Advantages	**iPIM Characteristics**
Dual Sensor of both Acoustic Emission and Long Range Ultrasonic for constant monitoring as well as high resolution on detected fault.	Improved system sensitivity and monitoring capability. Discriminate between flaws and pipe features; welds bends, supports.
Ultrasonic Guided Waves for efficient inspections of even larger scale	Localised processing with on-board signal processing electronics and energy harvesting system
Longer runs: pipe-size-adjustable design covers a range of pipe widths to continue inspection uninterrupted.	Corrosion detection in-service pipes and pipelines and detection of corrosion under insulation.
Long term monitoring of the progression of cracks over time while gathering data for increased POD and higher CSA resolution	Graphic User Interface (GUI) and operational software. UGW focussing at the anomaly source to improve detection levels to greater than 5% cross sectional area CSA.

Table 1: iPIM system advantages and characteristics.

REFERENCES

[1] Lyons D, ‘Western European cross-country oil pipelines, 25yr performance statistics, CONCAWE oil pipelines management group.

[2] Financial Times comment ‘Growth in pipelines’, May 2002.

[3] Non-destructive Testing: An Expanding Market. 2002. Published by Business Communications Company. Web: www.buscom.com.

[4] Martin D E, European industry oil safety performance, statistical summary of reported incidents – 1999, prepared for the CONCAWE Safety Management Group.

[5] Davis P M, et al, ‘ Performance of cross-country oil pipelines in Western Europe, statistical summary of reported spillages – 2000, CONCAWE Oil pipelines Management Group special task force on pipeline spillages.

[6] Davis P M, et al, ‘ Performance of cross-country oil pipelines in Western Europe, statistical summary of reported spillages – 2000, CONCAWE Oil pipelines Management Group special task force on pipeline spillages.

[7] Fulop G ‘Future growth prospects for inspection and repair’, www.buscom.com.

[8] Lincoln Electric annual report 2001, www.lincolnelectric.com.

[9] Bukman F., Schmidt R. (1997)., ‘In-line inspection of hard-to-pig pipelines’, The Pipeline Pigging Conference, Amsterdam, The Netherlands, June 1997.

[10] ‘Pipeline rupture and subsequent fire in Bellingham, Washington June 1999’, Accident report NTSB/PAR-02/02.

[11] PR Newswire Aug 7th 2000.

[12] Assessment of the Capabilities of Long-Range Guided-Wave Ultrasonic Inspections, J. Galbraith, PPSA, February 2012.

[13] Strategies for Guided-Wave Structural Health Monitoring, A.J Croxford, P.D Wilcox, B.W Drinkwater, G Konstantinidis. 8 November 2007. DOI: 10.1098/rspa.2007.0048.

[14] A unified approach for the structural health monitoring of waveguides. Xuan Zhu, Piervincenzo Rizzo. Structural Health Monitoring November 2012 vol. 11 =no. 6 629-642.

[15] Ultrasonic Lamb wave tomography in structural health monitoring, Zhao X., Royer R., Owens S., Rose J. Smart Materials and Structures 2011, Volume 20, Issue 10, article id. 105002, 10 pp.

[16] Dispersion-based imaging for structural health monitoring using sparse and compact arrays, N Quaegebeur, P Masson, D Langlois-Demers and P Micheau. January 2011, Smart Materials and Structures, Volume 20, Number 2.

[17] Ultrasonics Classification of flaw severity using pattern recognition for guided wave based structural health monitoring, Corey A. Miller, Mark K. Hinders. Ultrasonics Volume 54, Issue 1, January 2014, Pages 247–258.

[18] An NDT guided wave technique for the identification of corrosion defects at support locations. NDT and E International 2015.