Long Range Ultrasound Guided Waves for Pipelines Inspection

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INTRODUCTION

In-line inspection vehicles (Smart pigs) are used today to detect corrosion, cracks and dents in a pipeline by crawling or swimming through the pipe internally. These vehicles occupy the entire circumferential width of a pipeline in order to provide 100% inspection coverage of the pipeline wall using ultrasonic or magnetic sensors. They can cope with moderate changes in pipeline diameter and deflections in bends up to 180°. However, defects which are larger than this, and particularly those which are located very close to the external surface of the pipeline, can cause the pig to swing or ‘walk’ along the pipe wall thus reducing the effectiveness of the inspection. Pipeline operators are often not sure if the pig has properly inspected the pipeline and whether the inspection results can be relied upon.

PigWaves project - “In-Line Service for Internal Inspection of Undersea Burned Oil Pipelines Using Long Range Ultrasound Guided Waves in Fifty Metre Segments” is a European Research & Development Project funded under FP7-Capacities “Research for SME’s” Programmes. This project addresses the need to develop inspection tools for in-service Non Destructive testing (NDT) inspection of large diameter pipelines meeting the international standards such as the ISO (15156-1:2008-212-326) and EN 1412.

The use of latest technologies and new developments will allow performing also remote inspection for many pipes and complexity. Moreover the proposed project will enable pipelines with diameter reductions caused by obstructions or sharp bends. The technical objectives involve the development of an innovative, flexible Long Range Ultrasonic Testing (LRUT) collar adaptable to typical steel pipes used in the Oil & Gas pipeline and reduce ‘false-alarms’ from pigging by using LRUT to assess indications.

In a collar with LRUT for inspection has significant advantage over a similar collar using a more conventional, localised inspection techniques such as Ultrasonic Testing (UT) or Magnetic Particle Leakage (MFL). One major advantage is that data collection can happen every 50 metres whilst maintaining 100% coverage of the pipeline, whilst with conventional methods data collection is performed every few millimetres. This leads to reduced data gathering and faster inspection time.

The operation of LRUT inspection consists of generating ultrasonic waves to propagate within the pipelines in order to detect metal loss and other defects due to corrosion or other degradation processes. These waves are transmitted along the pipeline by physically attaching multiple rings with ultrasonic transducers on the internal or external circumference of the pipeline. Defects in the metal produce reflections of the ultrasonic waves which are picked up by the transducer, making it possible to identify defects.

A theoretical model is a key to understanding the fundamental mechanics, but also to outline the necessary behaviour such as the field pattern generated in the material and to aid the interpretation of received signals. COMSOL, Multiphysics® simulation software was used to study the behaviour of such guided waves in the PigWaves project. A transient regime model allowed to:

- Generate realistic PDA
- Couple Elastic-dynamics with electromagnetic
- Use FFT to extract the frequency content from the A-scans.
- Use 2D FFT to identify the content of the echo pattern (A-scans at different positions) with regards to frequency/space.
- Show how discontinuity (defects) affect the wave propagation.
- Show the effect of the remaining thickness on the mode conversion.

Piezo-electric transducers diffuse in steels mode along the test surface unlike the transducers used in conventional ultrasonic. If the transducers are arranged to operate in a circumferential direction, then a toroidal wave is produced.

A ring of oval oriented transducers generates an axi-symmetric longitudinal wave in both the forward and backward directions, which are also 100% reflected at the flange. This is due to the large difference in acoustic impedance between the pipe and the air. As with conventional ultrasonic, the rings fire a pulse and then wait a period to detect reflected echoes. Echoes from symmetrical features around the pipe, for example girth welds and flanges reflect symmetrical waves back to the transducers. Non-symmetrical features, however, do not reflect symmetrical waves but instead reflect facets modes.

RESULTS

In order to analyse the results, behaviour of Guided Waves (GW) have to be understood.

- GWs travel in both directions until it reaches the end of the pipe.
- GWs reflect and reflected echoes are sent back to the sensors.

Diagram 1. Oil and Gas pipeline

Diagram 2. 20% of thickness loss

Defect Characterisation

Evaluating the size and the nature of the defect are two of the most controversial topics in ultrasonic flaw detection. Defect sizing in particular can be a complex subject, with various uncertainties. Figures 5 and 7 illustrate the difficulty of quantifying a flaw. Being small, or very large, flaws being isolated or covered by many facets in the field. The simulation is used to interpret and process the obtained signals.

Diagram 5. 20% of thickness loss

Diagram 6. 100% of thickness loss

Diagram 7. 20% of thickness loss

As for conventional ultrasonic testing, signal amplitude can be a mean of defect sizing. Figure 8 shows several A-Scans of different scenarios of wall thickness loss. The non-defected 90% thickness loss/100% wall thickness loss present significant differences in terms of wave amplitude. The time of arrival indicates the position of the defect.

The amplitude can provide information about the material loss estimation and its severity, classifying the defect in different categories.

Figure 5. 100% of thickness loss

Figure 6. Defect location 1m

Figure 7. Defect location 1m

Figure 8. A Scans at 75% from transducers 6, 26, 35 and 50% of wall thickness loss

Figure 9. A Scans at 75% from transducers 6, 26, 35 and 50% of wall thickness loss

Probability of Detection (POD)

The probability of detecting a defect is defined by the error function assuming that Gaussian statistics apply i.e.

\[ P(D|A) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} e^{-\frac{a^2}{2\sigma^2}} du \]

Where A is the voltage amplitude.

As expected, for a defect representative of 50% wall thickness loss, the POD in ideal environmental conditions is very high. Under practical conditions a POD is a more complete function that used additional parameters such as:

\[ POD_{i} = \frac{1}{2} \cdot \text{erf} \left( \frac{A_{i}}{\sigma} \right) \]

Where: 
1. A the expected value of smallest detectable damage
2. σ the quality factor.

CONCLUSIONS

Feature classification is based on signal amplitude and recommendation for follow-up priority from the screening operation can be obtained. The outcome of this inspection is a decision on to whether the follow up inspection is in oil high, medium or low priority.

The degree of defect severity needs to be assessed, and this is done by looking at the signal amplitude for a specific level of metal loss. A deep study is required to characterise the defects. Large amplitude responses will be from a large cross-sectional area defect. Small defects cannot produce large amplitude reflections. 15% of thickness loss of cross sectional area (CSA) is the lowest reliable detection threshold that can be assessed. Smaller levels of metal loss have been detected using this technique; however a lower target level can result in an increase in false calls.

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