iPerm: A guided wave pipeline monitoring tool for Oil & Gas industry

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Abstract

Oil leaks are a major problem faced by Oil and Gas industry with over 30% of the pipeline accidents attributable to corrosion. According to the European Association of oil companies, there is over 15,900 km (46% of the total) of pipelines that are over 40 years old, while only 6% is 10 years old or less. The average annual corrosion-related cost for monitoring, maintenance, and replacement of pipeline stands at $7 billion. Failure of the aging pipeline is impacting negatively upon European society and its economy and needs to be addressed immediately.

This paper presents a structural health monitoring (SHM) system employing guided wave technology (GWT): iPerm; which has been developed to address this challenge. Until recently, the application of GWT was done periodically off-load with detachable transducers. The iPerm sensor is permanently mounted on the outside of pipelines in environmentally hostile, safety critical or difficult to access areas, and can monitor periodically in-service. iPerm enables a technology shift towards data enabled infrastructure whilst significantly reducing inspection costs by avoiding repeated access and providing enhanced damage monitoring capabilities to ensure the structural integrity of pipelines.

A rugged and robust ultrasonic sensor system has been developed for iPerm which utilizes piezoelectric transducers to generate consistent axisymmetric ultrasonic guided waves (UGW). This sensor system is used to excite UGW at low frequencies (typically under 200 kHz) which are transmitted along the pipe and can travel tens of meters providing 100% coverage of cross-section area of the pipe. Permanently installed sensor system improves the reliability of ultrasonic data by removing any transducer coupling variability. A portable data collection device is attached periodically to monitor pipe condition and can detect and locate both internal and external corrosion defects and quantifies the severity of damage for maintenance planning. This paper describes the system approach and results from initial performance evaluation.
1. Introduction

Oil leaks are a major problem faced by Oil and Gas industry with over 30% of the pipeline accidents attributable to corrosion \(^1\). According to the European Association of oil companies, there is over 15,900 km (46% of the total) of pipelines that are over 40 years old, while only 6% is 10 years old or less \(^2\). The average annual corrosion-related cost for monitoring, maintenance, and replacement of pipeline stands at $7 billion \(^3\). Failure of the ageing pipeline is impacting negatively upon European society and its economy and needs to be addressed immediately. With an increasing emphasis on safety and maintenance requirements, plant operators are applying several NDT tools and methods to ensure the structural integrity of their critical infrastructure. And this has stimulated numerous research and development activities to enhance and optimise this technology.

For inspection of pipelines, there are several inspection technologies available including corrosion coupons, pigging, acoustic emission, magnetostrictive, eddy current, microwave back-scattering and fibre optic sensing. But none of these solutions offer a completely non-invasive, autonomous real-time, energy efficient pipeline monitoring system that can provide 100% coverage. Guided wave testing (GWT) approach, on the other hand, has the capability to screen long distances of pipes from a single test point which is ideal for road crossings and buried pipes. GWT has been accepted by the Oil and Gas industry and until recently this approach was used periodically off-load for routine inspection with the detachable sensor system. However, repeated access to the pipe can be costly and time-consuming.

This paper presents a permanently installed system employing GWT for structural health monitoring (SHM) of pipelines. The system approach, components, installation procedure and potential applications are discussed here. This system is essential to monitor problem areas periodically during operation avoiding costs of repeated access such as stripping insulation and scaffolding. And more importantly, this system will improve the reliability of information and hence provide enhanced defect sensitivity by removing variability introduced by sensors and their coupling.

2. Guided wave technology for pipe inspection

In contrast to conventional ultrasonic, where high frequency ultrasound is used to measure wall thickness examining the volume of material directly under the test probe location (see Figure 1), in guided waves an axisymmetric ultrasonic pulse is transmitted along the pipe, this being generated by a ring of transducers clamped around it using mechanical or pneumatically applied dry-coupling force. The transducers are arranged in a distinct array to generate the desired wave modes and directionality. The generated waves are characterized by relatively low frequencies (typically under 200 kHz) and can propagate over a long distance in each direction (tens of meters) in bounded structural parts such as pipes. Changes in cross section reflect ultrasound back to the transducers. Such changes may be deliberate, e.g. welds or flanges or may be flaws, principally corrosion.
Pulse-echo techniques are used to detect features and defects for tens of meters at both directions (forward and backward directions) providing 100% coverage of cross section area of the pipe. It can detect and locate both internal and external defects without disrupting operation. The position of the weld or flaw along the pipe is determined by time of flight of the ultrasound. There are several commercial Non-Destructive Testing (NDT) inspection systems (4,5) utilising guided wave technology in a periodic fashion with detachable transducers. These systems have shown reliable defect detection capability for defects that remove around 9% of the pipe cross section area.

3. SHM of pipes using guided waves

The requirement for continuously assessing the integrity of critical infrastructure and advancements in computation power has fostered research and development of SHM systems. These systems use permanently installed sensors that provide information regarding the condition of the structure, offering a paradigm shift from schedule driven maintenance to condition based maintenance. This facilitates prognosis of structural health for informed asset management decisions. Discovering and monitoring of damage state minimises in-service failures and associated maintenance costs, while maximising asset life and reliability. SHM using GWT has found a variety of practical applications on rail, ship hull, aircraft and containment structures (6).

The SHM technologies are progressively being developed and evaluated for pipelines in the industry to monitor critical lines continuously during operation rather than periodically off-load. This approach also avoids repeated access to pipe involving stripping insulation and scaffolding, which are costly and time consuming. SHM of pipes using GWT has been demonstrated using magnetostrictive sensors (7) and piezoelectric transducers (8,9) which are permanently installed. Permanently installed sensors remove variability introduced by sensors and their coupling and can therefore improve the reliability of information and enhance defect detection with baseline subtraction. But this is provided that the ultrasonic performance of the sensor system is not degraded over time and the system can reliably perform in extreme environmental and operational conditions.
4. iPerm: guided wave monitoring system

The main aim of iPerm was to provide a highly robust and stable permanently installed sensor system and a convenient way of collecting inspection data on a regular basis. With iPerm, a permanently installed sensor system employing GWT has been designed for environmentally hostile, safety critical or difficult to access areas on pipes. Access to pipelines is only required for system installation and data collection can be carried out from an accessible junction box. The inspection data is stored on a cloud platform and provides advanced information about the pipe structural integrity.

3.1 System hardware and installation

The sensor system is designed to be robust and weatherproof to provide reliable performance in extreme operational conditions during its operational lifetime. The hardware consists of guided wave transducers which are sealed by an encapsulation providing environmental protection. A tool lead connects the electronics of the collar to a connection box which can be placed at an easy-accessible area which can be several metres away from the pipeline. A pulser-receiver unit is used to transmit and receive the guided wave signals. The unit is lightweight and can be carried in a backpack. The portable pulser receiver has a wireless communication interface with a tablet for data collection. The system hardware components are shown in Figure 2. The system is designed to optimise installation procedure and full installation of up to 4 systems can be carried out in 1 day by 2 qualified people.
Figure 2 iPerm system hardware components for a 6” pipe. The portable guided wave controller (not visible) is carried in the inspector’s backpack

3.3 System software

The system software framework provides communication protocols between the hardware components and for reliable and secure data transfer between the hardware and the cloud infrastructure. The cloud platform stores recorded data and the test configurations of the pipeline to facilitate remote assessment. A graphical user interface (GUI) has been designed for the tablet with the operator’s ease of use in mind. The GUI follows a 2-layer approach: the first layer designed for non-expert users, while the second layer offers access to previously collected data and analysis for expert NDT inspectors. In this way, even inexperienced users, such as trainees, will be able to set the system up and carry out the inspection process. The data stored on cloud platform can then be analysed by experienced inspectors to evaluate the pipelines structural integrity. This information optimises maintenance operations of the pipelines and minimise the time they are out of service.
3.3 Applications

The system design is suitable for a wide range of pipe sizes (2”- 48” NPS) with operating temperatures of up to 100°C. The system is ideal for difficult to access buried and coated pipelines (e.g. road crossings), insulated pipelines, and critical lines which require frequent inspection.

4. System performance evaluation

4.1 System frequency response

To evaluate the ultrasonic performance of iPerm sensor system, a representative waveguide sample was used to carry out pulse-echo measurements for a range of excitation frequencies suitable for GWT of different pipe sizes. Figure 4 shows the pulse-echo response of the sensor system for 20-120 kHz whereby the peaks are the single mode end-reflections of the waveguide. The system demonstrates consistent performance in terms of signal quality (signal to noise ratio) for the entire frequency range.
4.2 System stability in operational environment

Following extensive laboratory testing, the system validation is currently being carried out at one of the refineries belonging to Tupras in Turkey. A number of iPerm systems were installed on different locations in the refinery on pipes experiencing different operating conditions. The systems have been installed for over a month and Figure 5 shows the first eight GWT measurements carried out over a period of 35 days from one of the systems. The first reflection around 3.5m is from a weld and the two succeeding reflection are from the pipe support. A consistent SNR of ~37dB and variability of less than 1dB confirms the stability of the sensor system over time. The stability of ultrasonic response is key to maintain enhanced defect sensitivity.

Figure 4 Frequency response of the iPerm sensor system

Figure 5 iPerm system stability in operational environment
5. Conclusions

A new permanently installed system employing GWT for SHM of pipelines has been developed to offer a cost-effective solution for in-service monitoring of critical lines in Oil and Gas and petrochemical industry. The system validation is currently being carried out in service environment on pipelines under different operating conditions. A number of systems have been installed for over a month and have shown stable and reliable performance. Further laboratory trials with representative defects are being carried out to evaluate the defect sensitivity of the system.

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