Use of Nano/Microchip Sensor Technologies in the Oil and Gas Pipeline

a report by

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As climate change begins to manifest itself in the form of increased frequency and intensity of hazards such as floods, storms, heat waves and drought, the need for the oil and gas industry to address these risks, especially in the remote part of the world, is becoming urgent.[1] These unprecedented challenges makes task of providing the basic infrastructure required to support modern life. With the world's population set to reach nine billion people (a rise of 33 %) by 2025, innovative technology needs to be developed and integrated into the oil and gas sectors (built environment) in a way that can maximise its performance in use. Whilst the integration of innovative technology into new pipeline construction is daunting enough, when one considers that for the UK, the vast majority of the horizontal infrastructure that will be present in 2025 already exists; many of the innovative technological solutions will have to be retrospectively fitted to existing facilities. That in turn will demand a greater understanding of the operational and strategic characteristics of the horizontal infrastructure. Indeed, the UK Built Environment and Transport Foresight Panel identified the need for a greater understanding of the maintenance process and the use of innovative technology.[2] These needs support the link between pipeline system monitoring and its sustainable performance in-service and beyond. This research addressed this challenge by developing a new approach to maintenance planning for oil pipeline distribution systems. The solution monitors performance in use and identifies changes in performance as a result of deterioration of the pipeline infrastructure. This information is then fed into the maintenance model and action is taken to rectify the problem without the need for re-inspection. It reduces pipeline failures and the associated disruption to supply, damage to the environment and cost to the company.

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Monitoring Oil Pipeline Distribution Systems

About 65 % of the energy produced in the world today is derived from fossil fuel, much of which is drilled and produced in remote areas and transported through a vast pipeline network (over one million miles), which is ageing and prone to localised failures. The recent high profile oil pipeline leakages in Alaska; sabotage in Nigeria, Iraq and Russia; and the explosion at the Buncefield complex in North London have focused not only the industries attention but also alerted the world's news media to the problems associated with oil and gas pipeline integrity, and in particular with the inspection processes for pipeline distribution systems. Current inspection systems are either based on destructive or non-destructive approaches.

Destructive tests involve a section of pipeline being isolated, pressurised and monitored to ensure no leaks are present. However, as this approach disrupts the pipeline's normal operation it is generally only used for the initial inspection of pipelines and not once they have been commissioned and are in-service. Once a pipeline is in-service it is more normal to use a non-destructive testing (NDT) approach. The magnetic flux leakage method and the ultrasonic guided wave method are the two predominant non-destructive methods used for testing pipeline integrity.

Vibration and acoustic emissions are another non-destructive testing technique that are able to identify defects in structural (pipeline) systems at their initiation stage and characterise their vibration and acoustic emission activity as they progress into their critical stage.[3] The methodologies have been successfully[4–6] utilised for testing both composite and metal structures. Their global nature allows for the inspection of large and complicated infrastructures with few sensors without the need for manual scanning and access to the inside of the structure. However, the calculations underpinning these systems utilise long wavelength propagation theory, which is not really appropriate to the detection of internal cracking associated with pipeline distribution systems. What is needed is a monitoring system that continuously monitors pipeline integrity, without affecting the pipelines production capacity and that is no more expensive than the current NDTs being used by the industry. It was the development of such an approach, using vibration and acoustic monitoring of changes in the performance pattern of oil pipeline transmission system in such a way that progressive defects can be detected by surface mounted sensors without the need for third party intervention, which this research project sought to achieve.

Summarised Experimental Programme

A test programme was developed in which two flow mediums (water and diesel oil) were pumped through a model oil distribution pipeline in which the central section of a linear length of pipe (60 cm) was replaceable by alternate sections having different failure characteristics (see *Figure 1*). Drilling three sets of holes simulated the failure characteristics in test series II (0.5 mm diameter hole for test S2; 1.0 mm diameter for test S4; and a 2.0 mm diameter hole for tests S6 and S7).

The location of the nails/holes was taken as the reference point for each test. However, the nails were removed from the holes for the last test series, although the holes remained sealed. The acoustic emission signals associated with each test were recorded at five locations (-43 cm, 165 cm, 168 cm, 204 cm and 300 cm) relative to the reference point. The sensor locations and characteristics were calculated by considering[7] equations and the specific parameters associated with the test set-up. The sensors had an effective frequency range of 0.5–15,000.0 Hz at ±3 dB. The results were then converted to mean values and standard deviations using the enveloping method.

It became clear by implication that the characterisation of an oil steel pipeline system defect requires greater sensitivity from the vibration sensor than just detecting the presence of the crack.

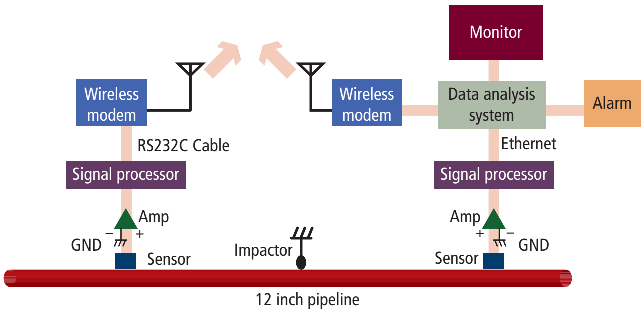
Test Series One and Two

The graphic representations compared sets of damage characteristics and also gave the output from the defective location routine for the three sets of damage. The graphical representations showed that the damage was located in each case within the constraints imposed by the irregularity of the pipe wall. It is assumed that, should there be any changes in the damaged area of the pipeline, it would result in a significant change in the graphical representations produced.

One of the similarities noted in the signals recorded at each sensor location was the intermittent time shift, i.e. delay in the signal arrival time. Such intermittent time shifts could have been caused by the fluid flow through the damaged pipe, or the leak being periodically accessed (for example by fluid flowing into the uneven interior surface of the pipe), or bubbles being forced through the leak orifice. These intermittent time shifts in signal arrival time were detected using a threshold detection circuit on each sensor's output and then by measuring the time difference between the intermittent time shift at sensor location one and its counterpart arriving at sensor locations two, three, four and five. The defect-and-leak location was clearly revealed as a peak in the frequency profile chart (sensor 1A–1B to sensor 5A–5B), showing the shift of time domains, which were detected with specific arrival time differences between the sensors. The cross-correlation function produced the difference between the arrival times of similar signals between two sensors. This gave information that can be used for locating the defect-and-leak position along the pipeline.

Figure 1: Third Party Damaged Pipeline

Figure 2: Third Party Damage Detecting and Reporting System



GND = ground.

Third party damage to pipeline and schematic diagram of how third party damage can be detected and reported using the system we have developed with our Industrial partners CorRelTech of South Korea. The product is ready to be deployed on field implementation; however, tests that will lead to miniaturisation of the systems are ongoing. Notwithstanding, more industrial partners are required in areas of miniaturisations technology (lab-on-a-chip) specialist technology companies and oil and gas pipeline operators from different locations of the world.

Pipeline System Fault Detection

The results of the research show the possibilities for further integrating and developing a miniaturised sensor solution capable of delivering continuous information about an in-service buried pipeline system's change in performance in realtime. The data is converted into information (the device logic is coded to execute rules that extract raw corrosion/defect characteristics and processes data *in situ*) before reporting the performance changes to remote locations without third party assistance. Therefore, monitoring and examining

Figure 3: Precise Diagnosis Systems and Tools for Underground Pipelines

the relationship between the vibration sound energy and the defect characteristics can help differentiate any changes in performance of the pipeline system. This approach is innovative and enhances the existing knowledge of the subject. Most importantly, when the sensors are well calibrated against steady flow, it should be possible to see a change in signal strength as the pipe deteriorates. Further, when the pipeline bursts, a very large signal is produced.[8] In other words, another innovation and contribution to existing knowledge is that at the point of failure, there are large gaps in the acoustic (waveform) that can be used to quantify pipeline failure. It was possible to examine the effect of the defect on the pipeline's natural frequencies and a distinction could be drawn between detection, characterisation and quantification of the defect and leaks. The location of the defect is shown graphically in *Figures 1 and 2*.

It became clear by implication that the characterisation of an oil steel pipeline system defect (e.g. a crack) requires greater sensitivity from the vibration sensor than just detecting the presence of the crack. It would also be necessary that the defect location be accurately identified and estimated along the pipeline. It can be assumed that there is a linear dependence between the vibration signals and the induced damage on the pipeline system.[9]

Within this study, technical indicators were shown to provide a unique perspective on the condition and performance characteristics of the underlying pipeline system's maintenance prediction.

Figures 3 and 4 show precise diagnosis systems and tools for underground pipelines ready to deploy to; inspect the soundness of cathodic protection system and coating quality, with integrated geographic information systems (GIS)/global positioning system (GPS) mapping rules result and rules engine classifiers anomalies. Preventative approaches that would translate into savings of many billions of pounds each year as well as limiting disruption to users and social costs.

Implications for Industry

It is evident that the experimental pipeline system's condition deteriorated progressively. The pipeline system failure in the laboratory did not occur all at once but in phases. This raises two issues: performance and early detection. Firstly, the ability of the pipe to transport oil is diminished since some content is lost on failure. Secondly,

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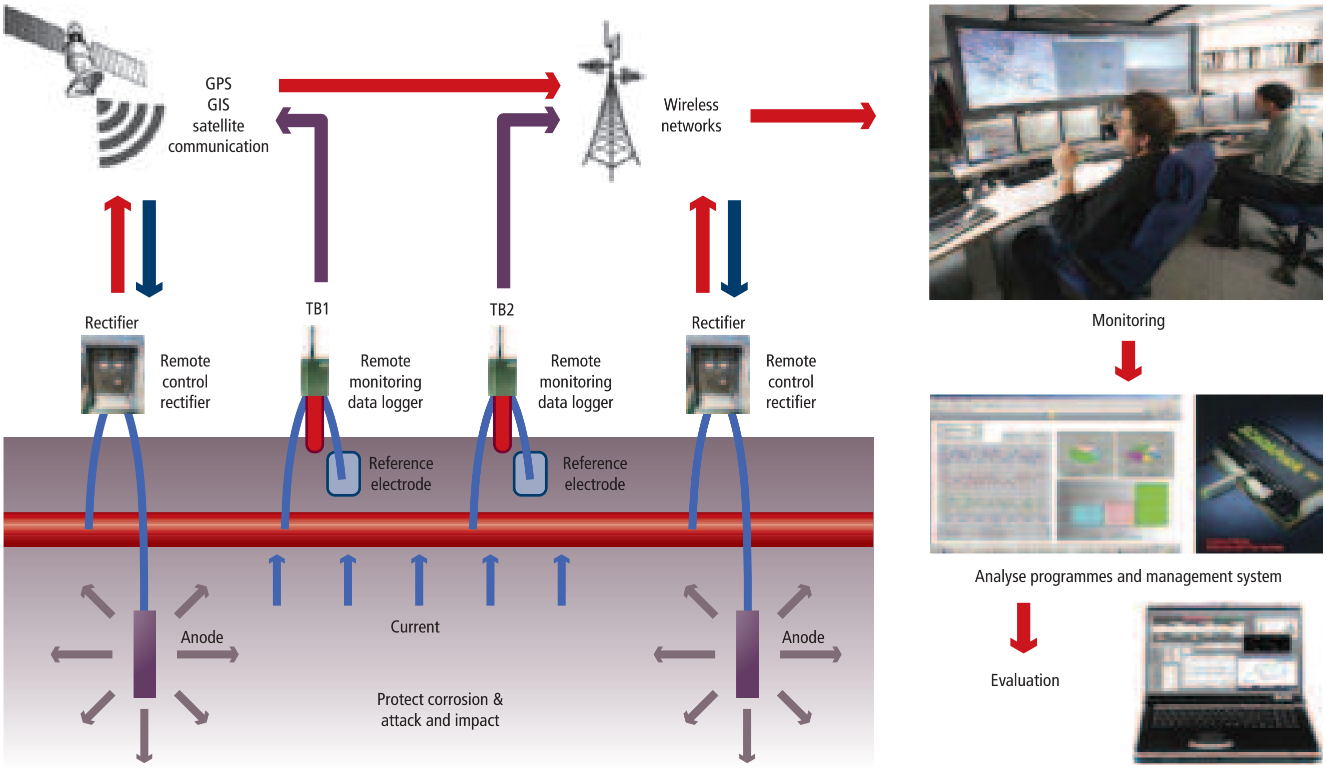
it is imperative to know the possibility of finding defective characteristics in an oil steel pipeline system before it fails completely. This knowledge would help to change the current reactive approach to maintenance to a proactive one that seeks to prevent the oil pipeline system failing.

It is also important to highlight some limitations that emerged from the analysis that are relevant to the thesis. The variation in defect profile values at first glance appears to represent the actual defect characteristics. However, the model of damage used did not take into account the length of the nails and steel material removed to form the hole, since this was negligible (and was not the main focus being addressed) in comparison with an analysis of the changes in condition.

Industrial Implications

The ability to carry out a basic inspection, analysis and report on a pipeline using an integrated sensor device offers many benefits.[2] The

Figure 4: NanoMind Investment and Development Company and Correltech Installation of Cathodic Protection Remote Monitoring and Controlling System



GIS = geographic information systems; GPS = global positioning system.

use of an integrated sensor device would provide valuable pipeline management information and the ability to detect and locate mechanical damage at an incipient stage, as well as providing an assessment of the overall pipeline operating condition and changes in performance profile.[10] This has been shown to be a feasible part of a pipeline maintenance and rehabilitation programme.

What does this mean for the pipeline maintenance manager in a situation where there is one kilometre sensor spacing for a pipeline that is 3,000 kilometres in length? Given an approximate current unit cost of integrated sensors of £100, this represents an initial outlay of £300,000. Ongoing costs of digging up the same pipeline stretch would amount to about £1.5 million and would need repeating zevery 6–12 months. So, considering existing monitoring costs, the integrated sensors would pay for themselves in three years. They pick up the point at which failure is about to occur and as a consequence reduce the impact of that failure, both economically and environmentally. Thus, in some parts of the world (the US in particular, where litigation is rife) this is of true significance.[10]

The major benefits include continuous monitoring to prevent expensive and potentially dangerous leaks. However, this outcome should not be taken as an end in itself but a means to an end. Furthermore the research results present the possibilities for an objective solution to the severe financial, environmental and safety liabilities posed by prosecution and compensation claims. Most importantly the miniaturised sensor solution offers the potential for industry to adopt fully. Nano/microchip sensor technologies in the oil and gas pipeline offer the industry many potential benefits that include the ability to carry out continuous inspection, analysis and report without third party intervention. The use of an integrated sensor device is expected to provide valuable pipeline management information without the deployment of heavy-duty equipment to site. Specifically the ability to detect and locate mechanical damage at the incipient stage and provide an assessment of the overall pipeline operating condition, including changes in performance profile and prediction of an estimated time to failure, has been shown to be feasible as part of a pipeline maintenance and rehabilitation programme. ■

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