Real-Time Active Pipeline Integrity Detection (RAPID) System for Corrosion Detection and Quantification

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REAL-TIME ACTIVE PIPELINE INTEGRITY DETECTION (RAPID) SYSTEM FOR CORROSION DETECTION AND QUANTIFICATION

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ABSTRACT

Structural Health Monitoring (SHM) technologies offer a paradigm shift from schedule driven inspection and maintenance to on-demand inspection and Condition Based Maintenance (CBM). Utilizing SMART Layer technology and lamb-wave based damage detection Acellent has developed a Real-time Active Pipeline Integrity Detection (RAPID) system. The RAPID system utilizes a sensor network permanently bonded to the pipeline structure along with in-situ networked hardware and remote access and damage detection programs to provide both scheduled and on-demand monitoring of pipeline structures. Advantages of the RAPID system include: 1) Automated and on-demand inspection of critical areas; 2) Damage localization and quantification; 3) Easy to use interface requiring minimal training. To verify the capabilities of the system a series of tests were performed by Acellent in partnership with Chevron utilizing sections of 8in diameter steel pipes. During the tests a number of different sizes and depths of defects were introduced into the pipeline sections. These tests verified that the RAPID system was effective in detecting the occurrence of corrosion in the pipeline and monitoring its growth over time.

KEYWORDS : *pipeline, corrosion, guided wave, piezoelectric,damage quantification*

INTRODUCTION

Energy refining and distribution is a key component of modern infrastructure. In the United States alone there are over 2 million miles of natural gas transmission and distribution pipeline providing 24% of the total energy consumed [1]. As such, the continued safe operation of these pipelines is a major concern of pipeline operators. In 2012 there were over 500 pipeline incidents causing an estimated $200 million in economic losses [2]. While there are many different forms of damage seen in pipeline systems, corrosion/erosion is one of the primary concerns of pipeline operators due to heavy use of steel in modern pipeline systems. Steel pipelines are vulnerable to both internal and external corrosion damage which can quickly result in deterioration of the piping system; as a result, there is a need for regular inspection of steel pipelines for corrosion/erosion damage on both the external and internal diameters.

In order to ensure the continued operation of pipeline systems, pipeline operators must invest in regular inspection of their piping systems by a variety of methods including visual inspection, inline inspection (ILI), and traditional NDI based techniques. This results in intermittent inspection of the pipeline and increased operating costs. The utilization of Structural Health Monitoring (SHM) systems will allow pipeline operators to monitor pipelines on a continuous rather than intermittent basis, and drive toward more cost effective Condition-Based Maintenance (CBM) of their systems. In response to this need, Acellent has introduced the Real-Time Active Pipeline Integrity Detection (RAPID) system. This system allows for the detection, localization, and quantification of corrosion damage in pipeline systems including the calculation of the critical parameter of wall thickness loss. As a guided wave based detection system, RAPID, enables the inspection of an extended region of the pipe surface with significantly greater detection capabilities than current systems, which provide only a point measurement of wall thickness.

RAPID consists of Acellent Technologies SMART Layer® sensors, hardware and damage detection algorithms that provide a tailored solution for pipeline corrosion detection that has been shown to be successful in previous studies [3-4]. The basis of this system is ultrasonic guided wave based detection technology, which first detects the defect and then calculates damage location and surface area. By combining this detection technology with calibration curves, the RAPID system is capable of also quantifying the critical parameter of pipe wall thickness loss, which is critical for calculating such parameters as remaining useful life of the pipeline and determining when maintenance is necessary. By combining these algorithms with Acellent Technologies light-weight onboard systems, modern wireless communication, and a graphical user interface, RAPID provides a simple to use, easy to install pipeline monitoring system capable of fully detecting and quantifying damage over an extended region of pipeline as shown in Figure 1.

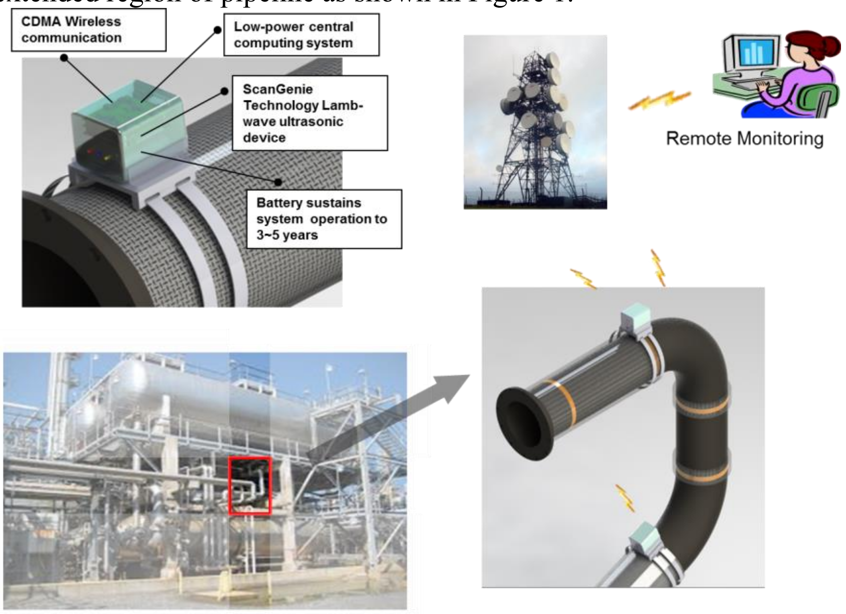


Figure 1: Schematic of proposed RAPID system for pipeline monitoring

Acellent in partnership with Chevron, studied the utilization of the RAPID system for in-situ monitoring of corrosion damage in a steel pipeline. The study was specifically focused on understanding the operating capabilities of the RAPID system for monitoring the growth and change of corrosion on a pipeline. This is a critical capability for the RAPID system as the ability to monitor and track change through time allows the inspectors to calculate corrosion rates and to ultimately determine the remaining useful life of the pipe.

1 System Principles

The function of RAPID is analogous to that of a built-in acousto-ultrasonic NDE system with a network of miniaturized peizoelectric sensors. A signal generator built into the hardware creates a short-burst, transient, sinusoidal signal that drives an actuator to propagate stress waves through the material. The stress waves are then collected and digitized by corresponding neighbouring sensors. When the stress wave encounters a discontinuity in geometric or material properties of the structure the wave is reflect or scattered resulting in changes in signal amplitude and phase as measured by the sensor. The approach used in the diagnostic process is based on comparing current sensor responses to historical baseline responses from the undamaged structure. By monitoring the differences between baseline and new signals it is possible to extract information on existing damage and other anomalies. The principle of operation for the RAPID system can be seen in Figure 2.

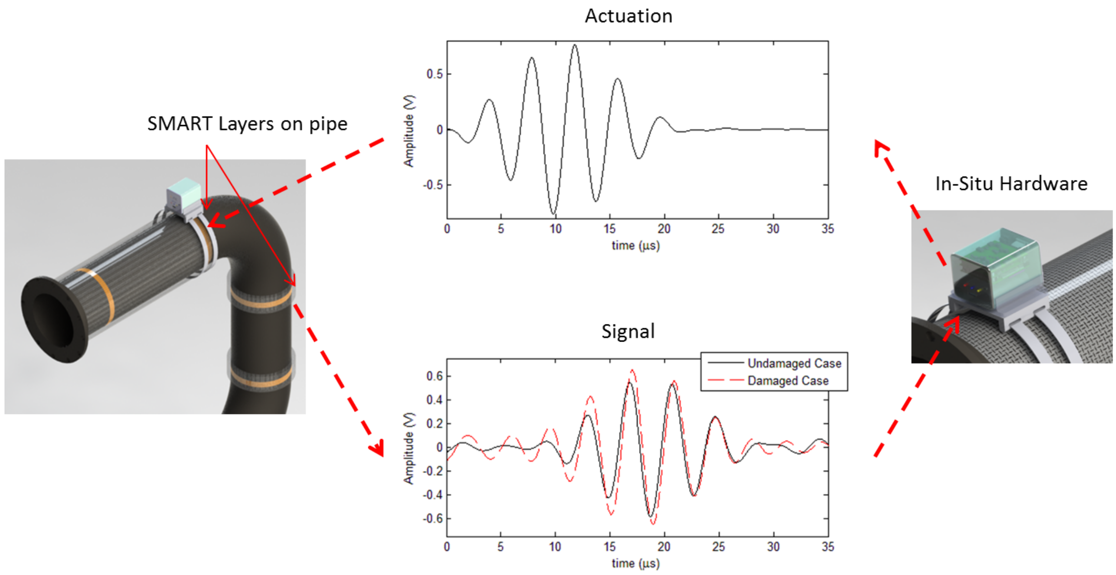


Figure 2: Principle of RAPID system

1.1 SMART Layer

The SMART Layer sensor network is well established in the field of structural health monitoring and is noted for its unique ability to cover a wide structural area with its network of embedded actuators and sensors [5-6]. The design eliminates the need to install sensors individually and is easily conformable to even complex structural geometries.

1.2 In-situ Hardware

The small, lightweight and low-powered diagnostic hardware contains multiple sensor/actuator (I/O) channels designed to interface with the sensors and contains a built-in ability to drive the piezoelectric actuators embedded in the SMART Layer and record the response at nearby sensors. The system can, furthermore, store the sensor data and provide real-time analysis before uploading the information over a wireless connection for storage on a remote server and use by the pipeline inspectors.

1.3 Corrosion Detection Algorithm

Damage detection in the pipe sections utilized a baseline dependent method for calculating the damage state. This method uses a comparison of newly generated waveforms with baseline waveforms generated and stored before damage is incurred. By comparing the new and historical waveforms, it is possible to determine the presence or absence of changes in the structure due to corrosion. By tracking the degree of change in the waveform through time, it is also possible to monitor the growth of the damage area through time. This is illustrated with different waveforms in Figure 3.

The damage detection algorithms are based on the calculation of a damage index (DI) for the waveforms in each sensor actuator path. This damage index serves as a measure of change in the waveforms resulting from damage and is used for two purposes: 1) to determine which paths have been affected by the presence of damage, 2) to provide a reference for estimating damage depth. Once the DI has been calculated for each path those paths with DI values above a predetermined threshold are found and denoted as affected paths. The combination of affected paths is then used in combination with a reasoning code to determine the size and location of any damage area. Finally, the DI's for the affected paths in each damage area are compared with known damage states from previous tests to provide an estimate of damage depth. Continuous monitoring of the damage over time allows the diameter and depth estimates provided by the software to be used to monitor the damage growth through time.

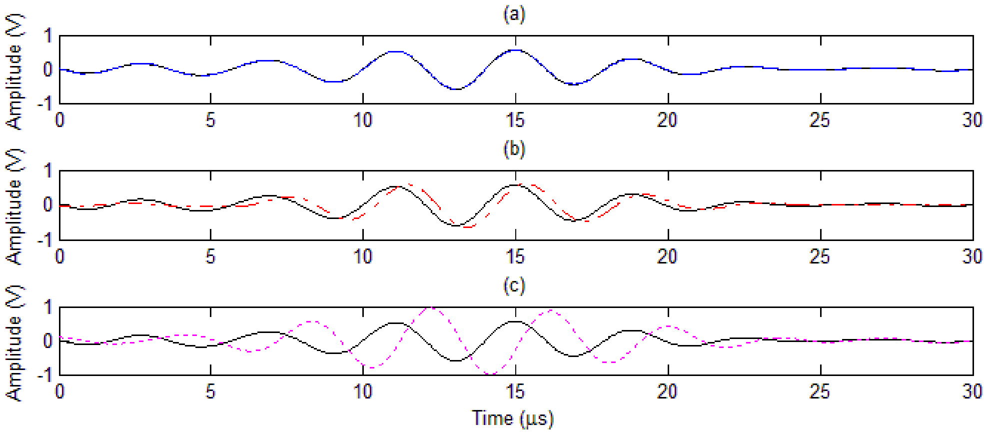


Figure 3: (a) Comparison of baseline(solid), and a second undamaged state waveform (dashed) (b) Comparison of baseline(solid), and waveform at 10% of wall thickness damage (dashed) (c) Comparison of baseline(solid), and waveform at 30% of wall thickness damage (dashed)

2 TESTING METHODOLOGY

The focus of this study was on demonstrating the capabilities of the RAPID system for long term growth monitoring of corrosion occurrence and growth in steel pipelines. As such this study looked at the growth in corrosion surface area and depth as the two critical parameters which must be measured.

2.1 Test Specimens

This study utilized a total of five carbon steel pipe specimens of two distinct types. The first type of specimen utilized was a 3ft section of carbon steel pipe. The pipe used was 8 in schedule 40 pipe with a true external diameter of 8.625 in and a wall thickness of 0.322 in. A SMART Layer sensor network was installed on the pipeline consisting of two rings of eight sensors installed around the circumference on the exterior pipe. Within each sensor ring the individual sensors were spaced 3 in apart with the sensor rings spaced 12 in apart. The second type of specimen used consisted of a section of the same carbon steel pipe utilized for the first specimen type split lengthwise to create a pair of 36 in by 13.5 in coupon specimens. The purpose of splitting the pipe in half was to facilitate testing on the interior surface of the pipe. For the split pipe sections the sensor layout consisted of a pair of four sensor SMART Layer networks installed 12 in apart in the longitudinal direction with the sensor to sensor distance within each layer being 3 in along the circumferential direction. In total 3 full pipe specimens and 2 half pipe specimens were used for this study. The sensor and testing layout utilized can be seen in Figure 4.

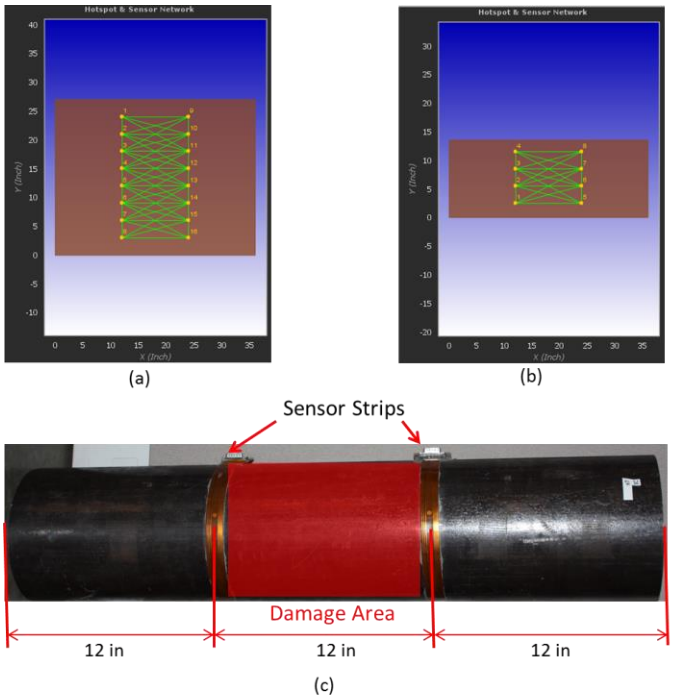


Figure 4: (a) Full pipe workspace with sensors in yellow and paths in green (b) Splitpipe workspace with sensors in yellow and paths in green (c) Layout on pipe with damage area in red

2.2 Damage Development

Testing was performed by using mechanical removal of the pipe wall to simulate thinning of the wall due to erosion/corrosion. The removal was performed using an angle grinder with an abrasive grinding wheel. Damage was modeled as a circular area with a parabolic depth. Damage was created on the exterior of the full pipe sections while damage was created on the interior of the split pipe sections. Examples of damage on the interior and exterior of the samples along with a schematic of the damage profile can be seen in Figure 5. In all cases the damage depth was taken to be the deepest point in the damage profile. Damage depth was measured using a dial caliper while damage diameter was measured using a measuring stick.

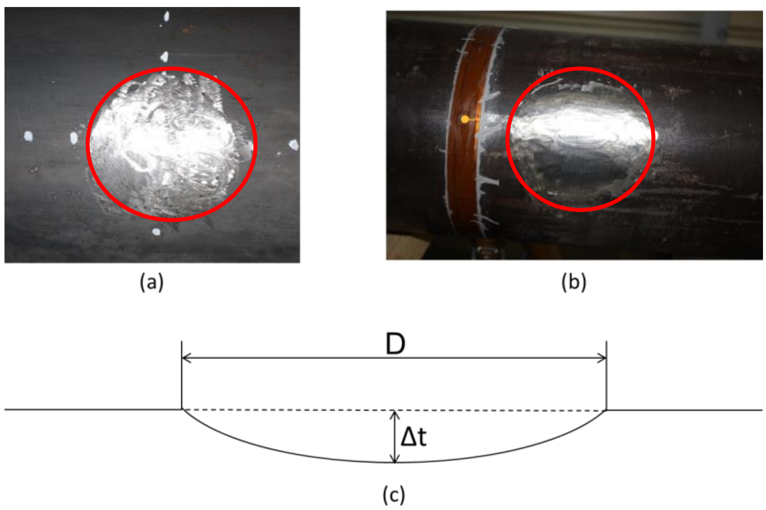


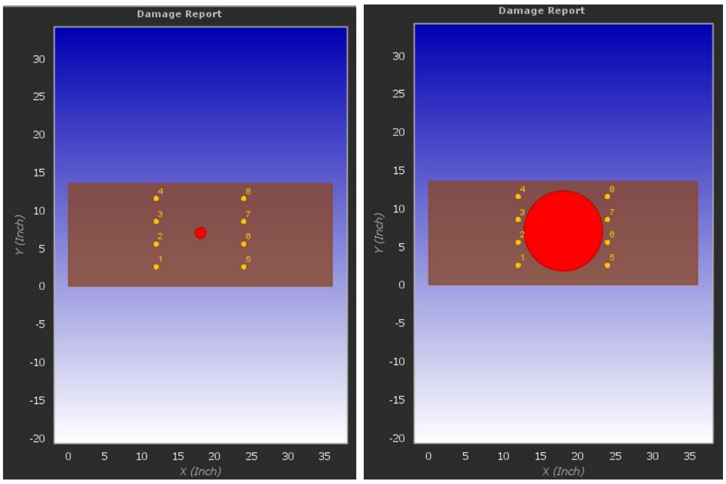
Figure 5: (a) Example of damage on interior of split pipe section (b) Example of damage on exterior of pipe (c) Schematic of damage profile

To demonstrate the damage growth monitoring capabilities of the system a series of tests were performed. These tests featured two types of corrosion growth monitoring: growth in corrosion surface area, and growth in corrosion depth. These two types of growth were tested in separate tests to isolate the effects of growth and depth. To test growth monitoring of corrosion surface area, a progressively growing damage area was created on the interior of a split pipe sample starting at 1 in in diameter and growing to cover the entire sensor region including the region directly underneath the sensors. Damage depth was held constant at 0.03" (9% or wall thickness) while a minimum of two damage detection tests were completed for each damage size.

Testing of depth growth monitoring was performed on several samples including both full pipe and split pipe section. Damage areas of both two and four inches diameter were tested with the depths being grown from 0.01 to 0.1 in deep (3.1% to 31% of wall thickness). Damage depth was grown in either 0.01 in or 0.02 in (3.1% or 6.1% of wall thickness) increments. The two inch damage was created on the interior of the split pipe while the four inch damage was created on the exterior of the full pipe. Furthermore, when calculating wall loss the two inch results were used as a reference for estimating the wall loss of the four inch damage. A minimum of two damage detection tests were completed for each damage size.

3 INCREASING AREA TEST RESULTS

For the increasing area tests the overlap between the estimated damage area and the actual damage area was very strong, demonstrating a good localization capability. Figure 6 gives a comparison of the detection results between the 1 in damage (Figure 6(a)) and the uniform damage (Figure 6(b)) results with the yellow dots representing the sensors. Finally a comparison between the true size and estimated size can be seen in Figure 7. This estimate was created using a running average of four damage detection measurements to calculate the damage size and comparing that to the estimated true size for those four measurements.



(a) (b)

Figure 6: (a) Detection of a 1 in damage (b) Detection of a 12 in damage

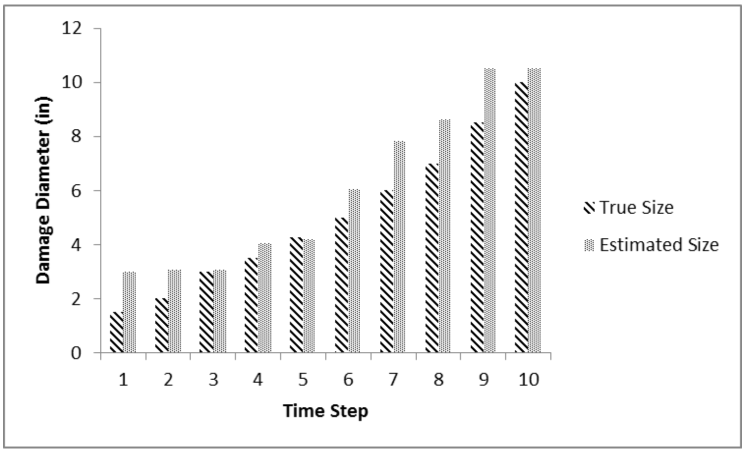


Figure 7: Monitoring of growth of damage size through time

4 INCREASING DEPTH TEST RESULTS

The 2 in and 4 in damage were both detected and localized with good accuracy. Once both damage detection tests were completed, the 2 in damage was used to provide a calibrated reference for calculating the percentage of wall loss for the 4 in damage. The results showed that by utilizing a reference damage for calibration, the system could accurately measure changes in wall thickness after the initial damage. However, the results did show that there was an initial offset in the results due to the use of different damage sizes in the comparison. A comparison of wall thickness change at first detection with the estimated change utilizing a four point moving average of the data can be seen in Figure 8.

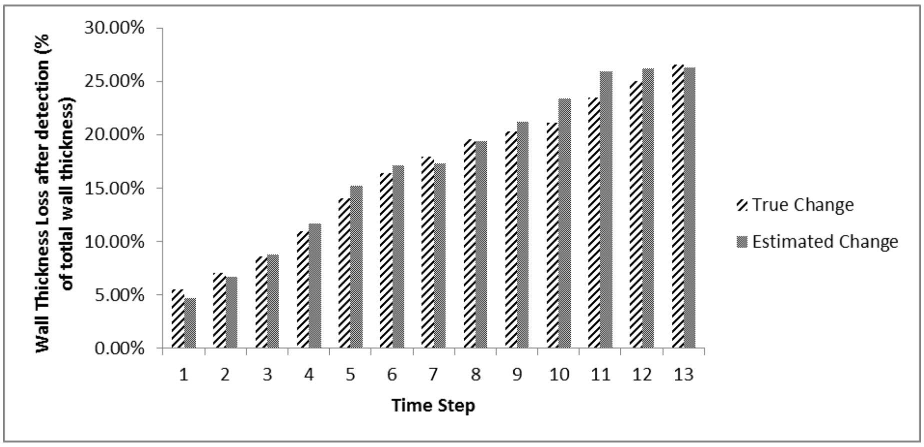


Figure 8: Estimation of change in depth after detection for 4 in damage through time

CONCLUSION

The results of the testing presented in this paper show that the RAPID system can be effectively utilized to monitor the growth and change of corrosion damage over time as the damage grows in depth and diameter. The advantages this system provides over traditional pipeline inspection methods include: 1) on-demand or schedule based inspection, 2) automated damage detection, 3) automated damage quantification and 4) monitoring of damage growth through time. The ability to monitor damage growth overtime is especially important as it allows for the calculation of corrosion growth rates and ultimately the determination of the remaining useful life of the pipe. As such the underlying capability of the RAPID system to provide this critical information has been demonstrated.

Future work on the RAPID system includes complete testing of the calibration curves, utilization of the system for blind damage detection testing and full field testing of the system on operational pipelines.

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