Assessment of Guided Wave Ultrasonic Transducer Systems for Wall Thickness Measurements

Prepared by:

Aparna Aravelli, Ph.D.

Florida International University Collaborators:

Dwayne McDaniel, Ph.D., P.E.

Clarice Davila, DOE Fellow

Submitted to:

Terry Sams, Washington River Protection Solutions, LLC
Ruben Mendoza, Washington River Protection Solutions, LLC
Dennis Washenfelder, Washington River Protection Solutions, LLC
Jason Gunter, Washington River Protection Solutions, LLC
Gary Peterson, Department of Energy, Office of Waste Processing

FIU | **Applied Research Center**
FLORIDA INTERNATIONAL UNIVERSITY

Table of Content

Introduction

The United States Department of Energy Hanford Site Tank Farm has implemented a Fitness-for-Service (FFS) program for the Waste Transfer System. The FFS program, based on API-579-1/ASME FFS-1, examines structural parameters of the waste transfer systems in order to develop erosion/corrosion rates for relevant system components. The FFS information is acquired from opportunistic evaluations of pipelines that have been removed from service. FIU-ARC engineers work closely with key Hanford HLW personnel and the contractor, Washington River Protection Solutions, LLC (WRPS), on the FFS program, delivering solutions for sensor evaluations, conducting bench scale testing followed by data acquisition and analysis for corrosion and erosion assessment.

The objective is to assist DOE and WRPS in providing more realistic estimates to the remaining useful life of the components and incorporate those estimates into future design/testing plans. To aid to this objective, previous efforts at Hanford included the installation of sensors on some of the POR 104 components, to provide real time pipe wall thickness measurements. Due to certain limitations, alternative approaches for remote permanently mounted pipe wall ultrasonic thickness measurement systems are being investigated.

Present work is a supportive effort by FIU-ARC for DOE and WRPS, which investigates key options available in the market, for remote-permanently mount ultrasonic transducer (UT) systems for HLW pipe wall thickness measurements. Specific applications include straight sections, elbows and other fittings used in jumper pits, evaporators, and valve boxes. Previously, FIU investigated the use of various ultrasonic systems that are either commercially available or had been used at other sites and selected the most promising systems for further evaluation. This document provides an assessment of the down selected UT system as a replacement option for the existing prototype UT array for the POR 104 components and in other applications at various sites.

Scope

This summary document provides the verification and validation of the down selected UT system for pipe wall thickness measurements from the various options investigated previously. The chosen UT system is a guided wave transducer network system from Permasense [1]. Sensor system evaluation is conducted via bench scale testing using an in-house designed pipe section which includes 2-inch and 3-inch diameter pipe sections.

Method and Benefits

The proposed method will provide information that will assist engineers with understanding the failure potential of HLW transfer components due to corrosion and erosion. This information can assist in determining if and when lines need to be removed, saving time and resources on the unneeded excavation of transfer lines. This information will also assist engineers with designing new transfer systems by establishing more detailed/accurate guidelines governing the life expectancy of the transfer system and its components.

Ultrasonic Transducers (UT)

An ultrasonic transducer is a device that converts electrical energy into high frequency sound energy and vice versa. This feature of propagation of sound waves through solid materials has been used to detect hidden cracks, voids, porosity, and other internal discontinuities in metals, composites, plastics, and ceramics. High frequency sound waves reflect from flaws in predictable ways, producing distinctive echo patterns that can be displayed and recorded by portable instruments. This is conducted using ultrasonic testing which is completely nondestructive and safe, and it is a well-established test procedure in many basic manufacturing, process, and service industries. The frequency range of ultrasonic testing is generally between 500 KHz and 10 MHz.

Typical transducers for ultrasonic flaw detection utilize an active element made of a piezoelectric ceramic, composite, or polymer. When this element is excited by a high voltage electrical pulse, it vibrates across a specific spectrum of frequencies and generates a burst of sound waves. When it is vibrated by an incoming sound wave, it generates an electrical pulse. The front surface of the element is usually covered by a wear plate that protects it from damage, and the back surface is bonded to backing material that mechanically dampens vibrations once the sound generation process is complete. Because sound energy at ultrasonic frequencies does not travel efficiently through gasses, a thin layer of coupling liquid or gel is normally used between the transducer and the test piece. Figure 1 shows a typical ultrasonic transducer.
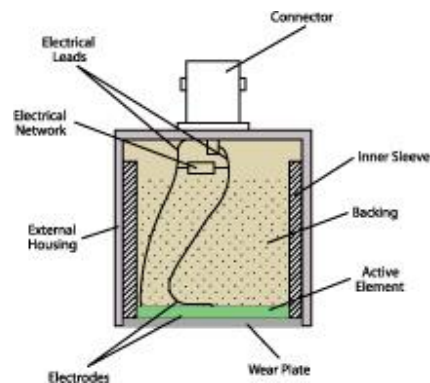

Figure 1. Cross section of typical contact transducers [2].

There are five types of ultrasonic transducers commonly used in flaw detection applications:

Contact Transducers - As the name implies, contact transducers are used in direct contact with the test piece. They introduce sound energy perpendicular to the surface, and are typically used for locating voids, porosity, and cracks or delamination parallel to the outside surface of a part, as well as for measuring thickness.

Angle Beam Transducers - Angle beam transducers are used in conjunction with plastic or epoxy wedges (angle beams) to introduce shear waves or longitudinal waves into a test piece at a designated angle with respect to the surface. They are commonly used in weld inspection.

Delay Line Transducers - Delay line transducers incorporate a short plastic waveguide or delay line between the active element and the test piece. They are used to improve near surface resolution and also in high temperature testing, where the delay line protects the active element from thermal damage.

Immersion Transducers - Immersion transducers are designed to couple sound energy into the test piece through a water column or water bath. They are used in automated scanning applications and also in situations where a sharply focused beam is needed to improve flaw resolution. _Dual Element Transducers_ - Dual element transducers utilize separate transmitter and receiver elements in a single assembly. They are often used in applications involving rough surfaces, coarse grained materials, detection of pitting or porosity, and they offer good high temperature tolerance as well.

UT Systems Investigated

Many commercially available UT sensor systems were investigated based on the following performance criteria.

- Permanent mounting capability to 2 inch schedule 40 pipe (90 elbow as well as straight).
- 100% duty cycle in a 200°F environment is ideal. The maximum temperature allowed for the waste transfer process is 200°F. Average transfer temperatures are closer to 130°F.
- Ability to measure accurately to 0.001 inches.
- Operate in a 50 to 250 rad/hour environment.
- A dry couplant solution preferred.

Sensor systems investigated are:

- Sigma Transducers - Pipe Wrap System
- Olympus Dual Element Sensors
- Acellent Technologies Smart Sensors
- Permasense Guided Wave Sensors
- Ultran Couplant-free Sensors
- Innerspec EMAT and DCUT Sensors

The details of each of the above sensor systems were documented in a previous summary document (FIU-ARC-2016-800006470-04c-242) and based on the pros and cons of each, the Permasense guided wave sensors were down selected for further testing.

Permasense Guided Wave Sensors

This system is developed by a UK based manufacturer – Permasense [1] and is as shown in Figure 2. The Permasense UT system is an integrated wireless system (Figure 2b) and uses a novel guided wave technology for the acoustic wave propagation. The most advantageous feature with this UT sensor system is that it meets the goal of proving the actual thickness measurement in pipes, is capable for 2 inch pipes and elbows, and is customized for mounting with a mechanical clamping system (Figure 2c).
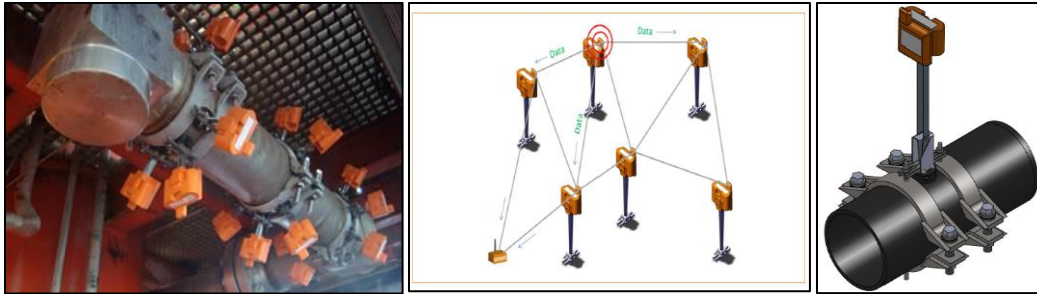
Figure 2. a) UT sensors [1], b)   Wireless network [1], c) Mounting system [1].

The limitations of the system include the cost and only 2 sensors can be installed in the 2 inch diameter pipe on the circumference to avoid cross-talks between the sensors in that limited space. These sensors have been proven successful in oil and gas industries and similar areas. As a recent example, erosion/corrosion monitoring using the permanent mount UT systems (from Permasense) in European refineries has been successfully implemented [2]. Thinning of pipes was determined based on real-time continuous monitoring. The sensors are capable of operating up to 600°C (1100°F). This is due to their patented waveguide technology that holds the sensor head (containing ultrasonic transducers, electronics, and battery) away from the hot metal. The sensor's measurements are transmitted wirelessly back to a gateway (wireless access point) mounted near the main unit. A schematic of the corrosion monitoring system is as shown in Figure 3.
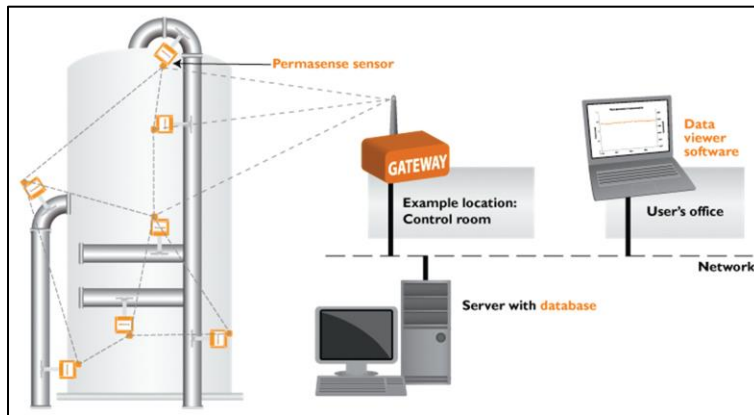

Figure 3. Permasense corrosion monitoring system [2].

Since there is no cost associated with measurement acquisition or measurement retrieval, the frequency of measurement can be configured to be as frequent as every 15 minutes. Connection of the gateway to the operator's existing information technology infrastructure allows the data to be viewed from personnel desks. Sensor battery life of up to 10 years allows continuous data delivery between turnarounds without access to a sensor's physical location.

The sensor model chosen for our testing and validation is the WT 210 series and is as shown in Figure 4. It consists of the 304 stainless steel wave guides, sensor head, antenna, battery and a stabilizer. In addition there is a built in thermocouple probe to monitor the pipe surface temperature which also allows the wall thickness measurement to be temperature compensated when required. The sensors communicate using

the WirelessHART [1] protocol, creating a self-forming and self-managing wireless mesh, which delivers continuous wall thickness measurements of the highest integrity and accuracy directly to the end user.
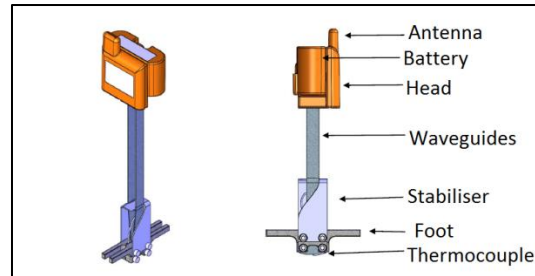

Figure 4. Permasense WT 210 series UT sensor [1].

A total of 4 sensors and the wireless gateway were procured for bench scale testing. The sensors are WT 210 series sensors and are accompanied by customized mechanical clamps for mounting on 2, 3 and 4 inch pipe sections and elbows. Figure 5a shows a typical sensor that was received and Figure 5b is the mechanical clamp. The sensors are connected via a wireless gateway system for data acquisition. The wireless system is termed WiHart and consists of an Emerson E1 420 Gateway and a few antennas and cables. The Emerson gateway is shown in Figure 5c.

Figure 5. Permasense a) WT 210 series sensor b) Mechanical clamp c) Wireless Gateway (Emerson).

Bench-scale Testing

The bench scale test set up was established by designing a pipe section including 2 and 3 inch diameter straight and 90º elbow sections joined by a reducer. Figure 6 shows the CAD drawing along with the weld specifications at four sections. The material used was black/carbon steel. The welding of the sections was outsourced.
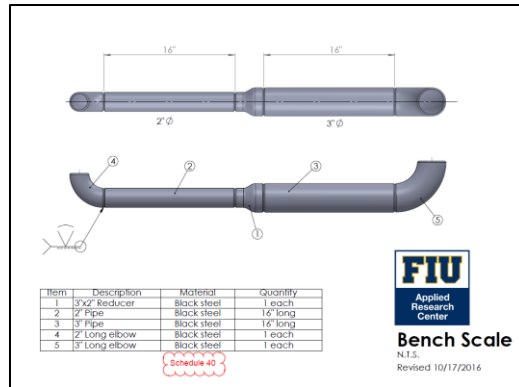
Figure 6. CAD drawing of the pipe layout.

Once the pipe sections were welded, the sensors were installed by the Permasense trained personnel as per the requirements. Figure 7 shows the installed sensors, one on the 2-inch elbow and the other on the 3-inch straight section. It is to be noted that the installation required a certain specified torque (30Nm/22 lbf.ft) to be applied on the clamps for completely eliminating the air gap between the sensor tip and the test surface. The clamps are custom designed for each section.
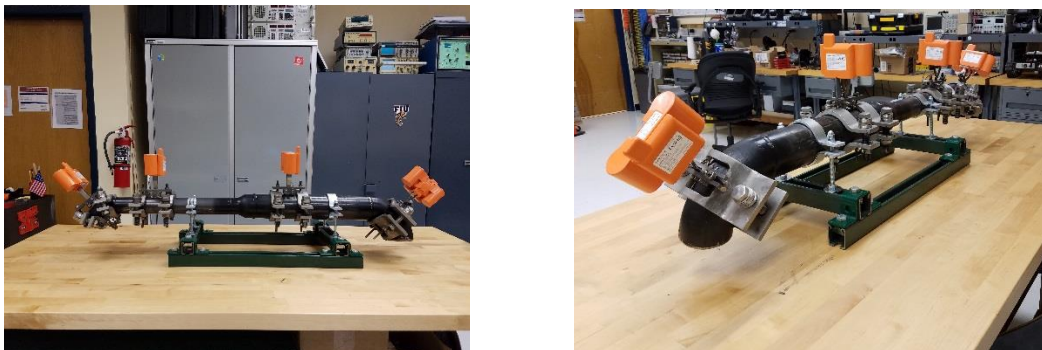

Figure 7. Permasense sensor system a) on pipe section   b) detailed view.

The test matrix for bench scale testing consisted of thickness data acquisition for a period of 4 months in order to verify the system's accuracy and robustness in measuring pipe thicknesses. Upon installation of the sensors, the system was integrated with a wireless Gateway and software (consisting of SQL server database) for data collection and analysis. The wireless gateway (from Emerson) has a range of 10-150 ft. from the sensors. The software has the capability to record real time data approximately every 15 minutes. It was configured to collect data every six hours. A typical waveform/signal response is as shown in Figure 8a. The peak to peak distance between the first and the second peaks of the waveform (A-scan) is used to calculate the thickness/distance travelled assuming known acoustic velocity in the material. The calculated real-time data (pipe thickness) is as shown in Figure 8b.
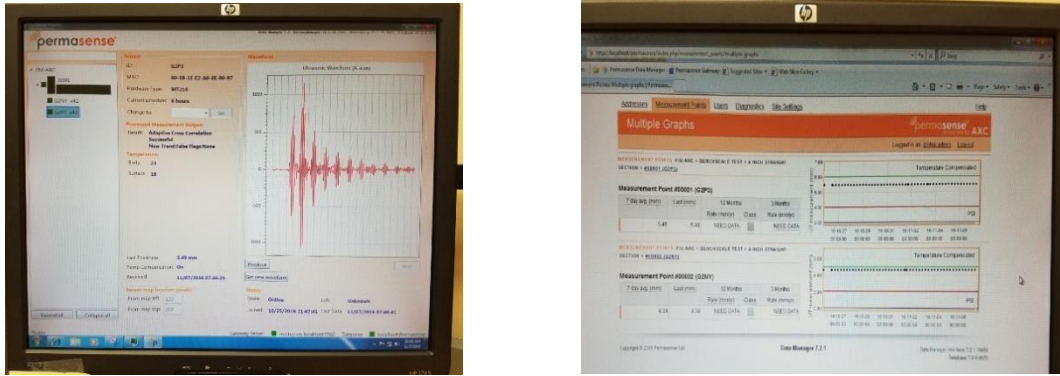
Figure 8. Sensor software: a) ultrasonic waveform b) thickness data/graphs.

The sensors have collected data for over 4 months. A typical output of the excel spreadsheet generated by the software is given in Table 1. From the table, it is evident that the thickness readings are stable throughout up to two decimal places of accuracy. Temperature compensation adds to the measurement accuracy.

Table 1. Sample UT Sensor Measurements for 3 in Straight Section

ID	Name	Sent Time	UT measurement (mm)	Temperature (°C)	Temp. compensation Flag	
#00001	3 inch straight	10/25/2016 18:09	5.487	19.93	1	
#00001	3 inch straight	10/25/2016 18:13	5.483	19.87	1	
#00001	3 inch straight	10/26/2016 9:54	5.489	18.9	1	
#00001	3 inch straight	10/26/2016 9:57	5.483	19.49	1	
#00001	3 inch straight	10/26/2016 11:04	5.484	19.84	1	
#00001	3 inch straight	10/26/2016 11:17	5.483	19.93	1	
#00001	3 inch straight	10/26/2016 17:20	5.487	19.55	1	
#00001	3 inch straight	10/26/2016 23:24	5.488	19.22	1	
#00001	3 inch straight	10/27/2016 5:27	5.49	19.61	1	
#00001	3 inch straight	10/27/2016 11:31	5.489	19.17	1	
#00001	3 inch straight	10/27/2016 17:34	5.489	19.61	1	
#00001	3 inch straight	10/27/2016 23:37	5.488	19.25	1	
#00001	3 inch straight	10/28/2016 5:41	5.488	18.87	1	
#00001	3 inch straight	10/28/2016 11:44	5.489	18.9	1	
#00001	3 inch straight	10/28/2016 17:47	5.488	19.61	1	
#00001	3 inch straight	10/28/2016 23:50	5.489	19.55	1	
#00001	3 inch straight	10/29/2016 5:54	5.489	19.93	1	
#00001	3 inch straight	10/29/2016 11:58	5.485	19.93	1	
#00001	3 inch straight	10/29/2016 18:00	5.487	19.55	1	
#00001	3 inch straight	10/30/2016 0:03	5.488	19.61	1	
#00001	3 inch straight	10/30/2016 6:06	5.488	18.63	1	
#00001	3 inch straight	10/30/2016 12:09	5.489	19.61	1	

In addition, sample 2 inch elbow measurements from October 2016 till Jan 2017 are provided in the plot shown in Figure 9. The maximum thickness is measured to be 4.346 mm and the minimum value is 4.336 mm. The average for the sample data is as 4.340 mm and the standard deviation of the data is 0.0015.
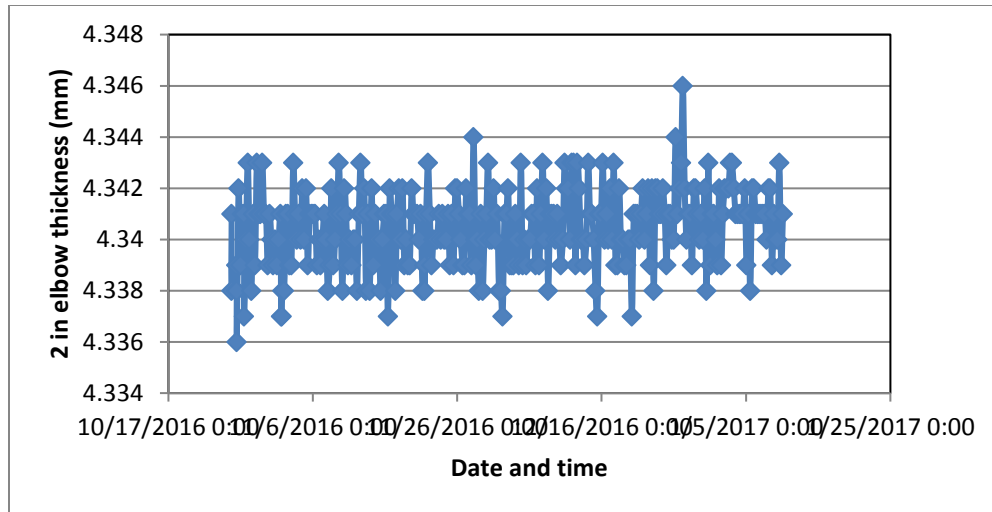
Figure 9. Sample thickness measurements for 2in elbow section from Oct 2016 to Jan 2017

Hence, during the testing period, there has been no significant changes in the average readings which is expected since the thickness remained the same. In addition, the thickness readings matched the manufacturer's specified thickness. Hence, the first phase of assessing the Permasense sensors for stable measurements for over a period of 4 months has been successful. The next stage would include measuring the actual wear rate of the pipes. One of the options is to circulate fluids such as NaCl solution, Na_2SO_4 solution, NaOH solution or other caustic solutions through a closed loop pipe section to record the thinning of the pipe using UT sensors. A preliminary design sketch of the loop is as shown in Figure 10 which includes 2 and 3 inch straight and bend sections.
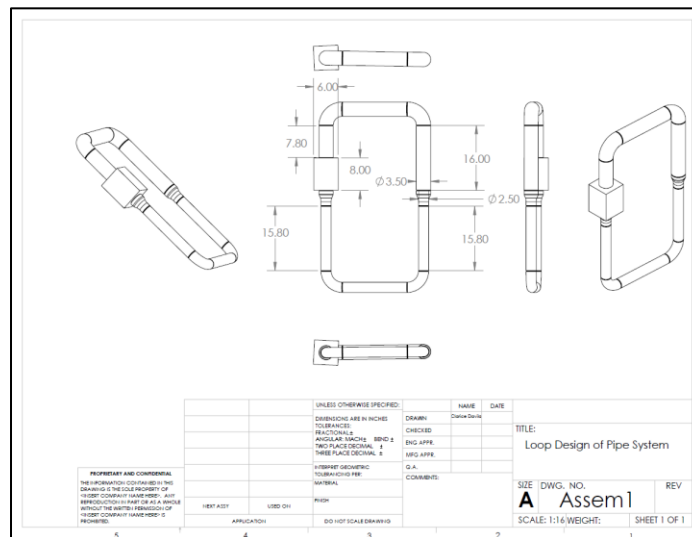

Figure 10. Pipe loop design for aging

Conclusions

The present work assessed the feasibility of use of the guided wave UT sensor system across DOE complex for pipeline and tank structural integrity analysis. The sensors from Permasense were down selected from a previous study. Initial bench scale testing for verification and validation of the UT thickness measurements was conducted successfully over a period of several months. The guided wave system including the sensors and the wireless network has proven to be accurate and robust for the period tested. Future work would include evaluating the sensors under real-time erosion on the pipe sections. This will be accomplished by circulating abrasive fluids to corrode the pipes resulting in uneven wear rates. Currently, FIU is investing the abrasive/caustic fluids, pumps and the design of the closed loop circulation system.

Works Cited

[1] http://www.permasense.com

[2] Philip T. and Jake D., "Monitoring and simulation resolves overhead corrosion – online corrosion monitoring in tandem with simulation modelling identified the root cause of corrosion in a crude unit overhead", www.eptq.com – PTQ Q1 2016.