SUMMARY DOCUMENT

Investigation into Ultrasonic Transducer Systems for Wall Thickness Measurements

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Prepared by:

Aparna Aravelli, Ph.D.

Florida International University Collaborators:

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

Brian Castillo, DOE Fellow

Submitted to:

Terry Sams, Washington River Protection Solutions, LLC

Gary Peterson, Department of Energy, Office of Waste Processing

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FIU | Applied Research Center
FLORIDA INTERNATIONAL UNIVERSITY

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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 high level waste (HLW) personnel and the contractor, Washington River Protection Solutions, LLC (WRPS), supporting 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 of the remaining useful life of the components and to incorporate those estimates into future design plans. Previous efforts at Hanford included the installation of sensors on a number of the POR 104 components, to provide real time pipe wall thickness measurements. Due to various limitations, alternative approaches for remote permanently mounted pipe wall ultrasonic thickness measurement systems are being investigated.

Currently, our efforts supporting this scope include investigating key options available in the market for remote permanently-mounted 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. FIU is assessing the use of various ultrasonic systems that are either commercially available or used previously at Hanford and selecting the most promising systems for further evaluation. This document provides the summary of the available options for obtaining thickness measurements for components similar to those in the POR 104 valve box. The options have been evaluated and a few were down selected for bench-scale testing.

Scope

The summary document provides information on previous efforts at Hanford regarding UT systems for pipe wall thickness measurements, as well as information on the present work at FIU, including market research for potential UT sensors. Advantages and limitations of each of the UT systems investigated are detailed and finally, two are down selected for further bench-scale testing on 2” and 3” diameter pipes.

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 can 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. The 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. Utilizing ultrasonic testing is completely nondestructive and safe, and it is a well-established test procedure in many basic manufacturing, processes, 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 material. 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.

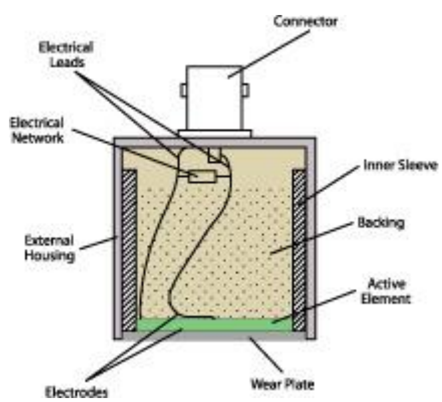


Figure 1. Cross section of a typical contact transducer [2].

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 (90^0 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.
- Be able to measure accurately to 0.001 inches.
- Will potentially be operating 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

Each of these systems is detailed below.

Previous Efforts

Previous efforts at Hanford, for pipe wall thickness measurements, included the use of a Pipe Wrap™ manufactured by Sigma transducers. Also, a conceptual solution had been modeled to demonstrate possible features of a custom made alternative. These are discussed in the next sections.

Sigma Transducers - Pipe Wrap System

The Pipe Wrap™ system consists of a linear flexible array of UT elements. Transducers are embedded in a silicon rubber substrate, which is then then wrapped around the pipe and secured with a hose clamp. To manufacture the system, a mold of silicon band is created and UT sensors are simultaneously embedded at various locations. An extra layer of silicon acts as a couplant to remove the air gap between the sensors and the pipe. Figure 2 shows the basic layout of the pipe wrap system.

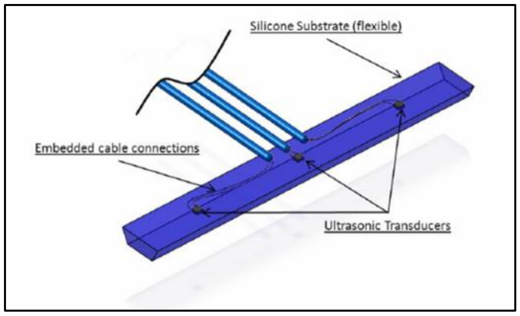


Figure 2. Typical layout of the Pipe Wrap system [1].

The Pipe Wrap™ system, although efficient, had a number of issues including: 1) excessive tightening of the pipe clamp causing damage to the UT array, 2) cabling issues, and 3) detachment due to excessive compressive force. Figure 3 shows the Pipe Wrap™ system installed on a 90^0 elbow of a 2” diameter pipe.

Figure 3. Installed Pipe Wrap™ system on a 2” diameter pipe [1].

Due to the limitations of the Pipe Wrap™ system, a conceptual solution has also been modeled to demonstrate possible features of a custom made alternative. A solid works drawing of the conceptual design, as shown in Figure 4, consists of a standalone framework to house the sensors. Although the concept has potential, it could be difficult to manufacture and implement.

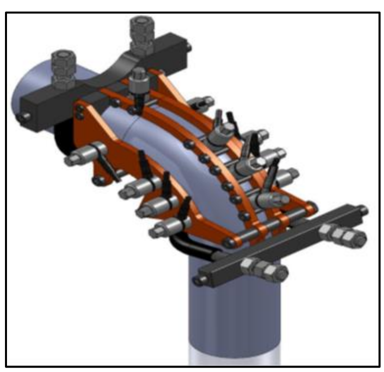


Figure 4. UT sensor system conceptual design [1].

Current Efforts

Limitations in the previous efforts have led to our current efforts which focus on the evaluation of alternative UT systems for pipe wall thickness measurements that are commercially available. These systems are detailed in the following sections.

Olympus UT Sensors

The first commercially available sensor investigated is the dual element UT sensor manufactured by Olympus [2]. The model is D790 SM and includes a 45MG digital ultrasonic thickness gage. The system comes with a gel couplant (glycerin), has a frequency of 5MHz and is a dual crystal transducer with a tip diameter of 0.434”. FIU acquired the Olympus system and took some preliminary measurements on carbon steel elbows as shown in Figure 5 (a).

Figure 5. (a) Measurements using the Olympus UT system (b) Vacuum tests [2].

Some of the advantages of the Olympus UT system include: 1) portable and easy to use (digital display of thickness), 2) provides accurate readings (accuracy of 0.001”), and 3) suitable for high temperatures. The system does, however, require a gel couplant and is quite large for 2’’ diameter pipes.

Initial bench-scale tests were conducted using the D790 SM system with the gel couplant and a dry elastomer couplant. Vacuum tests were also conducted to determine if the system could be used without any couplant. The gel couplant provided accurate readings while the vacuum tests and the dry couplant were very inconsistent. Table 1 lists the results obtained using the gel and the dry couplant and Figure 5(b) shows the vacuum test set up on a straight carbon steel pipe section of 3” diameter.

Table 1. Thickness Results Using Olympus UT sensor (D790 SM)

	Gel Couplant (Glycerin)		Dry Couplant (Aqualene)		Error (%)	
	Top	Extrados	Top	Extrados	Top	Extrados
90° Elbow (carbon steel)	0.239	0.210	0.312	0.310	30.5	44.7
90° Elbow (cast iron)	0.265	0.25	0.32	0.32	20.7	26.4
	Diameter (smaller)	Diameter (larger)	Diameter (smaller)	Diameter (larger)	Diameter (smaller)	Diameter (larger)
Reducer (carbon steel)	0.235	0.275	0.301	0.325	28.0	18.1

Acellent Smart Sensors

The Acellent smart layer sensor system consists of mini piezo sensors embedded in a flexible kapton tape. The circuits are embedded inside the tape and are available in single and multiple piezo options. The smart layer system is an integrated system which can be permanently mounted to the pipe and the readings/data can be recorded on a computer. A layout of the configuration for individual sensors is given in Figure 6. The figure also explains the features of each of the components.

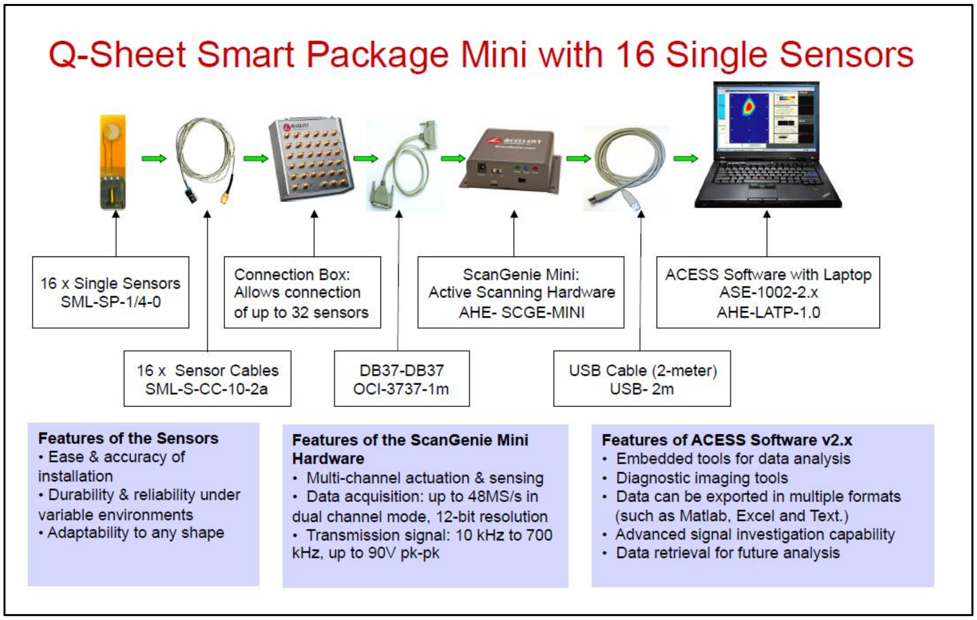


Figure 6. Acellent Smart sensor UT system [3].

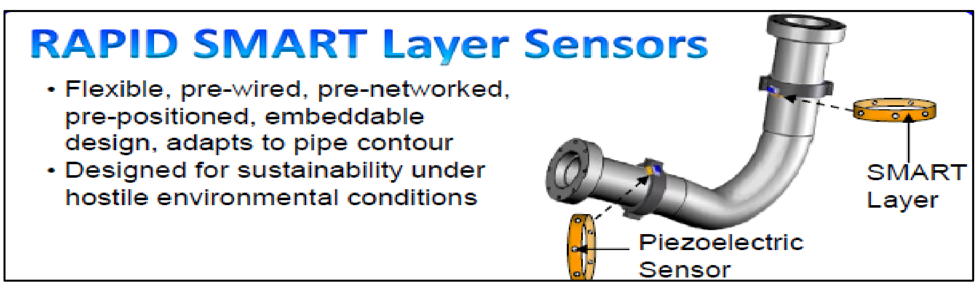
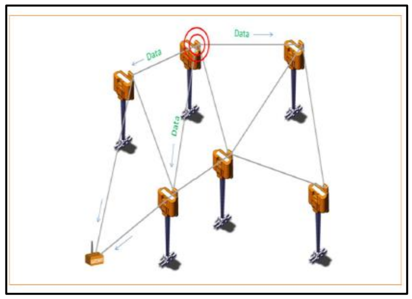


Figure 7. Smart Layer attached to a pipe [3].

The individual sensors can be integrated and embedded in a single layer called a smart layer strip which can be used in the pipeline (straight or elbow sections) as shown in Figure 7. One end of the sensor has a connector to attach it to an oscilloscope or signal generator. Initial oscilloscope tests were conducted using the single sensor. Although the smart layer technology "as-is" is a viable solution for the present task, certain limitations should be considered. The piezo-sensors (in the smart layer) are capable of providing the irregularities in the pipe line (i.e., the location and radius of a hole or anomaly due to pitting corrosion). They are, however, not capable of providing the actual thickness directly. FIU is working with the company to customize their system for our thickness measurement needs, but the system is expensive compared to the other options. Another issue is that the Smart layer is glued to the pipes using an aerospace grade epoxy. The elevated temperature and radiation levels could present problems for the adhesive.

Permasense Guided Wave Sensors

This system was developed by a UK based manufacturer, Permasense [4], and is as shown in Figure 8. The Permasense UT system is an integrated wireless system (Figure 9) and uses a novel guided wave technology for acoustic wave propagation. This UT sensor system does provide actual thickness measurements in pipes and can be used on 2-inch pipes and elbows. It can also be customized for mounting with a mechanical clamping system (Figure 10).



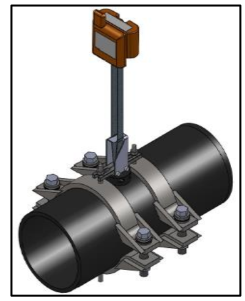


Figure 8. UT sensors [4]. **Figure 9. Wireless network [4].** **Figure 10. Mounting system [4].**

The system is fairly expensive and only 2 sensors can be installed on the circumference of a 2-inch diameter pipe. This is to avoid cross-talk between the sensors in the limited space.

Ultran Couplant Free Sensors

These are metallic UT sensors similar to the traditional sensors but require no couplant. It is a dry contact sensor developed by Ultran Group [5] and works by applying a suitable torque to the sensor when mounting. It comes with a polystyrene base and is available in 2MHz and 5MHz frequencies for our requirements. The typical Ultran sensors (WD 25-2) are shown in Figure 11. The mini sensors have a 6.4 mm active diameter and up to 8 sensors can be mounted on a 2” diameter pipe. These are also suitable for high temperatures.

Figure 11. Ultran couplant free contact sensors [5]

Innerspec EMAT

Electromagnetic Acoustic Transducers (EMATs) are available from Innerspec technologies [6] and are typically used on larger (> 8 inch) diameter pipes. Advantages of these systems include: 1) no couplant required, 2) can be customized for smaller diameter pipes, and 3) suitable for high temperatures. The EMAT Temate band includes an inbuilt mounting system for the pipes. The EMAT system is shown in Figure 12 and consists of the band in which sensors are embedded, a junction box and a power box. Although there are some advantages to EMAT sensors, they can only be used on carbon steel pipes. Additionally, the thickness measurements obtained are not as accurate as those obtained with UTs.

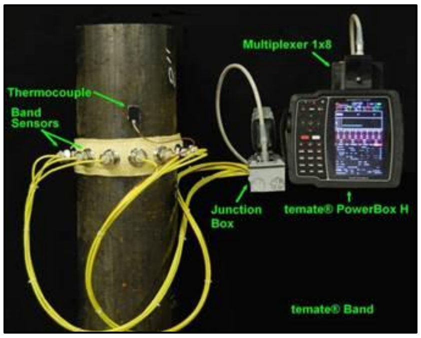


Figure 12. EMAT Temate band [6].

Conclusions and Future Work

Each of the UT sensor systems mentioned in the previous section have certain advantages and limitations. Based on discussions with the site engineers, two of the options have been down selected for further investigation. These include the Permasense guided wave technology and the Ultran couplant free sensors. Selections were based on applicability to various pipe sizes, ability to determine thicknesses accurately, and cost. One of the major challenges associated with a custom built remote permanently mounted UT system for pipe wall thickness measurements is the pricing of the systems. Currently, FIU is in the process of investigating alternative data acquisition methods for the UTs to minimize cost during this evaluation phase. An alternative approach that may be more cost effective would be to lease the UTs including the data acquisition system to demonstrate viability via simple bench-scale tests.

Works Cited

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