**Final Report**

Contract DTPH56-06-T-0009

# Enhancing Direct Assessment and Inspection with Remote Inspection Through Coatings and Buried Regions of Non-Piggable Pipelines

Prepared for:
US Department of Transportation
Pipeline and Hazardous Materials Safety Administration

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# **Enhancing Direct Assessment and Inspection with Remote Inspection Through Coatings and Buried Regions of Non-Piggable Pipelines**

## **Background:**

Direct assessment of gas pipelines for their integrity is now a requirement for operating such lines in high consequence areas like those found near heavily populated regions of the country. Although pigging is the most reliable method of assessing the integrity of an installed pipeline, many lines are not piggable because they were built before inspection pigs were readily available. This program is directed at development of a new inspection technique suitable for direct assessment of non-piggable pipelines for external corrosion (ECDA) and internal corrosion (ICDA). For buried pipelines, this technique will require a minimum amount of excavation to expose a small sector of the top of the pipe. The coating will not have to be removed because the sensor can launch and detect ultrasonic waves in the steel *through the epoxy or tar coating.* It performs an ultrasonic inspection of a circumferential belt in a fraction of a second and achieves 100% coverage of the pipeline by scanning the sensor along the length of the pipeline.

## **Current State-of the Art;**

Ultrasonic inspection of pipes and pipelines is a well established technique in which an array of small piezoelectric sensors monitors the local wall thickness as the array is translated along the length dimension of the pipe by a carriage. A critical requirement of this technique is the need for intimate mechanical contact between the steel and the piezoelectric sensor. Thus, the presence of an irregular tar coating or a rusty, dry interface can render this ultrasonic method inoperable. Recently, transducers that rely on electromagnetic induction (EMATs) to excite and detect ultrasonic waves in steel *across a small air gap* have been introduced and used successfully to detect stress corrosion cracking in piggable gas pipelines. They also enable the use of guided ultrasonic wave techniques to reduce the number of sensors needed to achieve 100% coverage and, thus, reduce the complexity and increase the speed of inspection.

## **Objective of This Direct Assessment Program:**

The objective of this program is to advance the state-of-the-art of EMAT technology to demonstrate the ability to perform an ultrasonic inspection of steel pipes with sensors separated from the pipe wall by a large distance which may be filled with an irregular layer of tar or other corrosion preventing coating. Thus, a direct assessment of a pipeline's integrity can be achieved from a single ultrasonic sensor placed on top of a partially excavated pipeline while it is still covered with a thick tar coating.

## **Accomplishments To Date:**

*Operation at large air gaps.* The main disadvantage of most pipeline inspection techniques (UT, EC and MFL) is the fact that the sensor most be held close to the steel. EMATs share this restriction but because the sound is generated and detected at the surface of the steel, the sensor probe itself can be some distance away. EMAT theory states that the signal strength decreases with the size of the air gap between an idealized sensor and the steel at a rate of -55 db/in for a probe that excites and detects ultrasonic waves. As a part of this program, the idealized EMAT configuration was optimized for large lift-off operation by changing the permanent magnet arrangement and by a redesign of the coil shape. The results are shown in Fig. 1

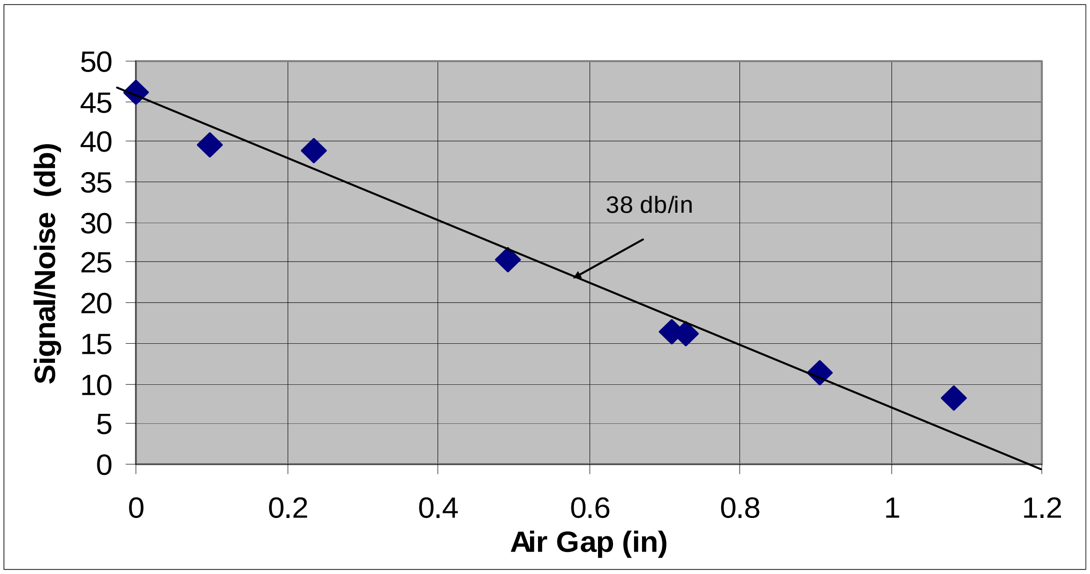


Fig. 1. Change in signal-to-noise ratio when the air gap between an EMAT probe and the steel surface was increased.

which plots the signal-to-noise ratio of a transmitter-receiver pair as a function of the size of the air gap between the EMAT sensor and the steel. These results show that the sensitivity to the air gap has been improved from -55 db/in to -39 db/in by the optimization procedures developed in this program. Furthermore, the data displayed in Fig. 1 shows that an acceptable signal-to-noise ratio of 10 db was obtained at an air gap size of nearly one inch.

*Detection and sizing of corrosion damage.* Because EMATs allow the acoustic wave mode to be specified by the design of the probe, it is possible to choose a wave mode whose velocity is sensitive to the wall thickness. By measuring the time for the wave mode to traverse one pipe circumference, the amount by which the transit time changes when a thin spot is encountered can be used to expose the presence of corrosion damage as well as to provide an estimate of the depth of that damage. Figure 2 shows a graph of the circumferential transit time as a function of the location of the EMAT probe along a pipe sample in which corrosion damage has been simulated by thin spots machined into the pipe wall at particular locations. The blue points are observations at locations where the circumferential belt of sound did not intersect a thin spot. The red points are observation locations at which the circumferential sound path included a machined-in thin spot whose depth is the indicated fraction of the wall thickness.

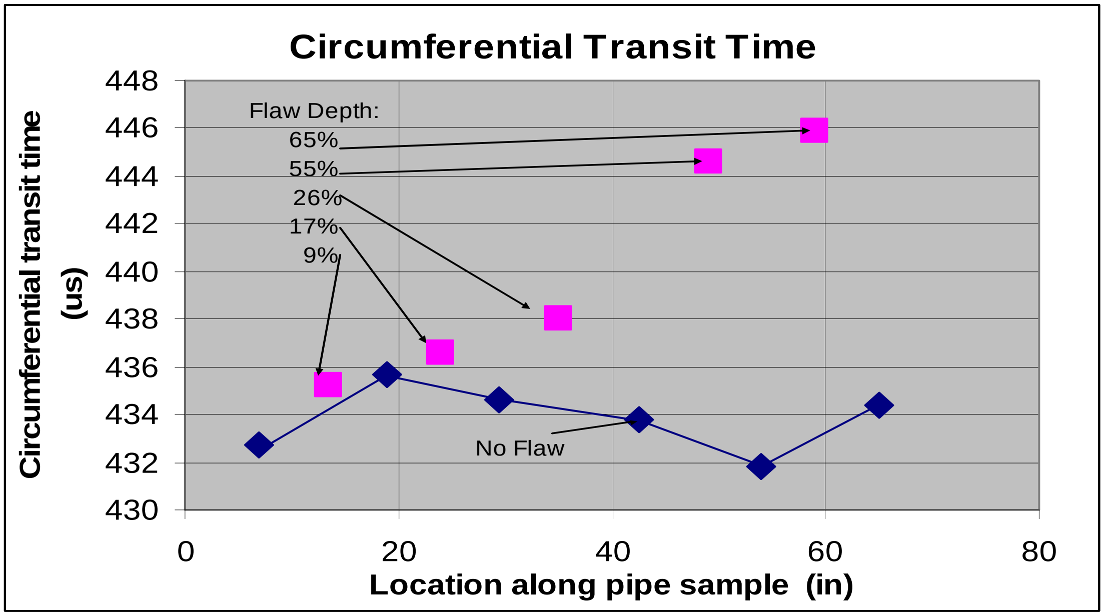


Fig. 2. Time require for the Ao guided wave mode to traverse the circumference of a 6.67” OD x 0.27” wall pipe sample into which patches of simulated corrosion had been machined to different depths.

*Achievement of large area coverage.* Figures 3 and 4 are photographs of two EMAT probes designed to excite and detect ultrasonic guided waves that propagate around the circumference of a pipe. The EMAT probes are mounted to an axial support bar that is equipped with wheels to allow the entire mechanism to roll along the length of a pipe. Thus, the circumferential guided wave path can be translated along a pipeline to produce 100% coverage of that pipeline. Because there is an air gap

Fig.3. An EMAT support carriage designed for both DAEC and DAIC on tar coated pipelines using circumferentially propagating ultrasonic guided waves.

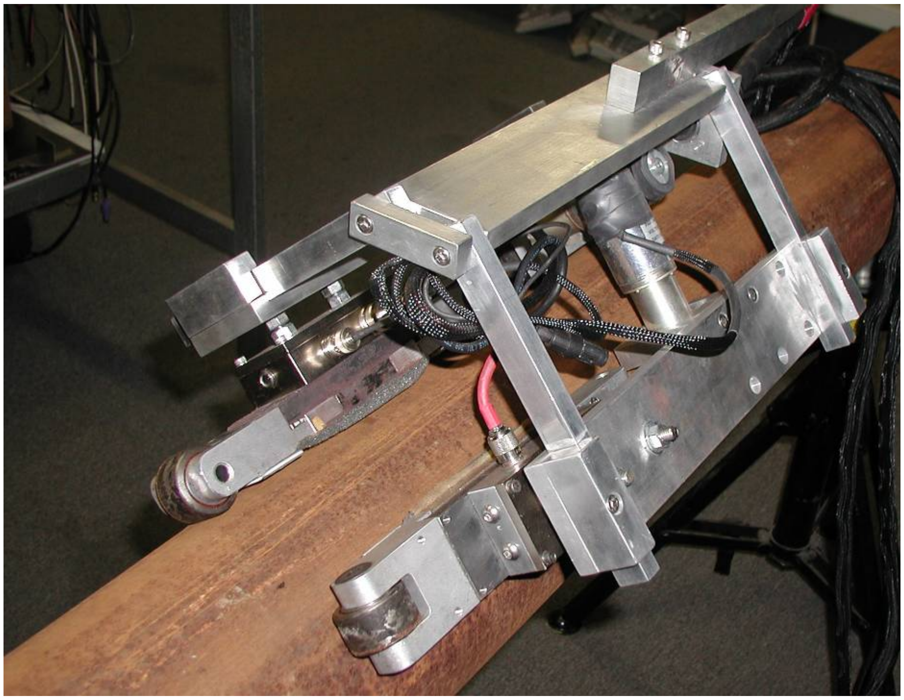

Fig. 4. A pair of EMAT probes on wheels for DAEC and DAIC of nonpiggable pipelines with thin coatings using ultrasonic guided waves that propagate in a circumferential direction.

under the EMATs, their performance as they move along the pipe is unaffected by tar or epoxy layers in part of the gap.

*Approach to commercialization.* As a result of the developments in this program, three opportunities to demonstrate direct assessment of non-piggable pipelines by ultrasonic techniques have presented themselves.

First was the use of the EMAT probe shown in Fig. 4 for measuring the corrosion damage in the Prudhoe Bay Pipeline in August of 2006. Here, many NDE techniques for locating the damaged areas on the bottom of the pipeline were investigated by the Department of Transportation and British Petroleum. Only the EMAT and an eddy current technique were found acceptable for the rapid inspection, over long distances and under arctic conditions *through the epoxy coating.*

Second was another use of the probe shown in Fig. 4 to inspect a short section of an operating gas pipeline being unearthed by the owner, PG&E, for its own Direct Assessment program. The excavation site was near San Luis Obispo so arrangements were made to demonstrate this program's EMAT technique to a group of industry representatives* as well as an Office of Pipeline Safety representative. Since this particular section of pipeline showed no corrosion damage, the demonstration consisted of showing that a guided wave inspection could be performed on a partially exposed, tar coated pipe when the EMATs were placed on a small tar-free area at the top of the pipe or when the transmitter EMAT operated through the 1/8" thick tar layer.

Third was a laboratory demonstration of the EMAT shown in Fig. 3 performing an inspection of an eight foot long sample of 6.6"ODx0.27" wall pipe covered with a 0.08" thick layer of Densotherm Tape. For this test, corrosion damage was simulated by a set of five dish shaped depressions machined into the pipe wall to depths ranging from 9 to 65 percent of the thickness. A graph of circumferential transit time versus location of the EMAT probe showed localized increases in transit time at the sites of the three largest depressions as expected from the data shown in Fig. 2.

**Conclusions:**

1. The performance of electromagnetic acoustic transducers (EMATs) was improved to the extent that an ECDA and ICDA ultrasonic inspection of a pipe sample could be accomplished with an air gap of ¾ inches between the sensor unit and the steel surface.

2. 100% coverage of the pipe was demonstrated by employing guided waves that propagated around the circumference while the sensor was translated along the length of the pipe.

3. Localized areas of corrosion damage were simulated by depressions machined into the wall at particular locations along the pipe's length. These were detected by observing corresponding changes in the time for the ultrasonic guided wave to traverse the circumference of the pipe.

4. Successful detection of corrosion damage by the rapid inspection technique used in this program was demonstrated on the Prudhoe Bay Oil Pipeline which was covered with a 0.02" thick epoxy coating.

5. Successful detection of simulated corrosion damage in a pipe covered with a 0.08" thick tar coating was demonstrated to a group of industry representatives.*

6. Successful operation of a circumferential guided wave EMAT probe was demonstrated in the field on an operating gas pipeline partially excavated by PG&E as part of their Direct Assessment program.

*The group of industry representatives was made up of persons from Southern California Gas, PG&E, Occidental Petroleum and two inspection service companies from Houston, Texas – Spectrum Sales Services and QPro Technical Services.