Technology Status Assessment for

Circumferential MFL for SCC

Magnetic flux leakage (MFL) is the most commonly used inspection technology for pipelines today, holding over 80 percent of the market. MFL tools detect and characterize metal-loss corrosion, one of the most common causes of pipeline failures. As currently used, though, MFL tools cannot detect all metal-loss corrosion, and they cannot detect other defects such as cracking.

Background

MFL technology has been successfully used on pipeline inspection tools since its introduction in the 1960s. This technology has been made sufficiently rugged to overcome the many rigors of pipeline environments. In MFL tools, defects are detected by the way they disrupt a magnetic field. In nearly all MFL tools, the magnetic field is oriented along the axis of the pipe. While most corrosion defects disrupt this axial magnetic field, the magnetic field passes by narrow axial defects with minimal disruption.

Narrow axial defects are particular important to pipeline operators because they can lead to ruptures. Ruptures are uncontrolled releases of product, caused by rapidly moving fractures (openings) that propagate from the ends of a through-wall defect. The axial length of a defect is one of the controlling parameters in determining whether a defect will leak or rupture.

Because long narrow defects do not significantly disrupt axial magnetic fields, they are not reliably detected by most current MFL tools. Many narrow axially oriented defects can go undetected, and those defects that are detected are often not conservatively sized. Of particular importance are axial cracks, such as stress corrosion cracking.

The inability of current tools to reliably detect long narrow defects is not so much a limit of MFL technology as a limit with the standard implementation. Circumferential MFL is a new implementation that has potential to detect and quantify axially oriented defects such as cracks, seam weld defects, mechanical damage and groove corrosion. This implementation works by orienting the magnetic field around the pipe rather that along the axis. By orienting the magnetic field around the pipe (the circumferential direction), the axial defects that were magnetically transparent now can disrupt more of the magnetic field and can be more easily detected. Recent advances in unrelated industries have enabled this new implementation of this proven technology.

Prior Circumferential MFL Developments

The earliest attempts at implementing a circumferential MFL system were made by Tuboscope in the 1970s. At that time, coil sensors were used on all MFL tools, including the Tuboscope circumferential tool. The Tuboscope coils required circumferential movement to produce a measurable signal. As a result, Tuboscope built the tool to rotate as it moved down the pipeline. The concept was sound, but it proved too difficult to implement, and Tuboscope eventually abandoned the idea.

The Pipeline Research Council International (PRCI) began investigating circumferential MFL in 1994[1]. This early work concentrated on the feasibility of using circumferential MFL to detect cracks using a laboratory-scale mockup. As discussed below, feasibility was demonstrated.

Another commercial inspection tool that used circumferential MFL was developed in the mid to late 1990s by PII (formerly Pipeline Integrity International, which was formerly British Gas). This tool used Hall-effect sensors, which do not require circumferential motion, simplifying the implementation. The tool was successfully used to detect narrow axially oriented corrosion in a pipeline where the spiral wrapped protective coating tented at the girth weld. The long narrow tent allowed moisture to collect and long narrow corrosion defects to form.

According to PII, the new circumferential MFL tool successfully detected narrow axially oriented corrosion and it sized them with sufficient accuracy. PII reports a second successful application of circumferential MFL, in which the tool detected hook cracks on the inside surface of an ERW pipe.

In 2000, Battelle began a program to evaluate the use of circumferential MFL to detect and size mechanical damage. This program includes fundamental studies of magnetization and leakage fields and the effects of inspection parameters such as tool velocity and defect location (inside our outside diameter). It also includes studies of many tool design issues, such as magnetization strength, pole length, and pole width.

Throughout all the work described above, the detection of cracks in the body of the pipe with circumferential MFL has remained elusive. Feasibility was demonstrated in the 1994 PRCI program, and basic studies on circumferential MFL fields are underway in a current Battelle program. In addition, practical experience is being gained by PII (and other vendors, who are now building circumferential MFL prototype tools).

---

[1] Final Report on RESEARCH PROGRAM PR-3-9420 on "Evaluation of Circumferential Magnetic Flux Leakage for In-Line Detection of Stress Corrosion Cracks and Selective Seam Weld Corrosion" to NDT SUPERVISORY COMMITTEE PRC INTERNATIONAL, December 1999

Other Developments Aimed at Detection of Axial Cracks

In addition to the circumferential MFL developments described above, there have been a number of attempts to detect cracks using other inspection techniques. Previously developed nondestructive testing techniques (including angle beam ultrasonics, electromagnetic acoustic transducers, and remote field eddy current) have proven capable of detecting longitudinal cracks.

PII developed the first angle-beam ultrasonic tool in the 1970s, and the tool has seen some use in operating pipelines. The tool used liquid-filled wheels to allow ultrasonic energy to be coupled into the pipe wall of gas filled lines. The number of sensors is limited by the number of wheels, and sophisticated signal processing is needed to detect and characterize cracks. Generally, the tool has proven effective at detecting and sizing some cracks and crack colonies. Questions about its ability to discriminate between crack signals and non-crack signals remain. In addition, reliable estimates of probabilities of detection and sizing accuracies are not available.

Pipetronix (now part of PII) developed an angle-beam ultrasonic tool in the 1990s, and the tool has also seen use in operating pipelines. This tool operates only in liquid-filled lines. The liquid couples the ultrasonic energy into the pipe wall, negating the need for a wheel. The Pipetronix tool has many more sensors than the wheeled tool, and it is reported to have greater sizing and detection accuracies.

There have been several attempts to develop a commercial electromagnetic acoustic transducer (EMAT) inspection system for cracks. Early efforts directed at pipeline inspection included work by C.W. Pope in Australia and T.D. Williamson in the United States in the 1980s and 90s. These efforts were combined in the middle 1990s, then transferred to Tuboscope in the late 1990s. The tool is still under development.

Finally, work has also been done on the use of remote field eddy current and velocity induced eddy current techniques to detect and size cracks. The most successful of these efforts has been using remote field techniques. Significant restrictions exist on the velocity at which the techniques can be used. To date, they have not been used in operating pipelines.

None of the ultrasonic or eddy current techniques described above has proven widely successful. Each has limitations with applicability, such as a coupling media, minimum pipe diameter and maximum inspection speed. Furthermore, the complexity of the systems makes the cost of an inspection higher than a corresponding MFL corrosion inspection.

Prior Technology Summary

Table 1 summarizes some of the capabilities and deficiencies associated with various inspection methodologies with respect to axial crack detection. Ultrasonic techniques are most sensitive, but coupling the ultrasonic energy into some pipelines is difficult often making ultrasonic techniques impractical. Electromagnetic techniques are less sensitive, but coupling energy into the pipe is much easier to implement. This project is evaluating circumferential magnetic flux leakage, an electromagnetic technique.

Table 1. Capabilities and Limitations of Inspection Methodologies for Axial Cracks

Technology	Best Attributes	Worst Deficiencies
Ultrasonic	Proven NDT method for detecting cracks	Getting the ultrasonic signals into and out of the pipe
• Liquid Filled Wheels	Works in natural gas pipelines.	Sensors and sensor spacing are large, so each sensor must interrogate a large area. Many signals from benign sources must be analyzed to find crack signals. Difficult to scale technology to small pipelines.
• Angle Beam Ultrasonics	When using a larger number of small sensors, has the best detection and sizing capability for crack inspection tools.	Must have clean liquid coupling. Speed limited since minimum detectable crack length is a function of tool speed and sensor firing rates.
• Electromagnetic Acoustic Transducer (EMAT)	Works in natural gas pipelines. Electromagnetic coupling of the ultrasonic energy into and out of the pipe has been alluring since the 1970s	Though many attempts have been made, no pipeline in-line inspection implementation has been successful. Another new tool should be introduced in 2002.
Electromagnetic	Provides a relatively simple method of getting the electromagnetic energy into and out of the pipe	Poor sensitivity to far-side cracks
• Circumferential Magnetic Flux Leakage (MFL)	Proven pipeline inspection technology for metal-loss defects.	While near-side cracks can be found, far surface cracks such as SCC are elusive.
• Remote Field Eddy Current (RFEC)	Sensitive to most pipeline defects including cracks and metal loss in any orientation.	Inspection speed so limited that only tethered systems have been commercialized.

Detailed Circumferential MFL Results

SCC - Unstressed Conditions

The potential of circumferential MFL to detect longitudinal defects in the absence of stress was demonstrated by the PRCI program described above. In this program, an external magnetizer was used to apply a circumferential magnetic field to a pipe segment containing stress-corrosion cracks. Figure 1 shows the results of a magnetic particle inspection of the outer pipe surface of a pipe sample; cracks appear as horizontal lines colored red or yellow in the photograph.

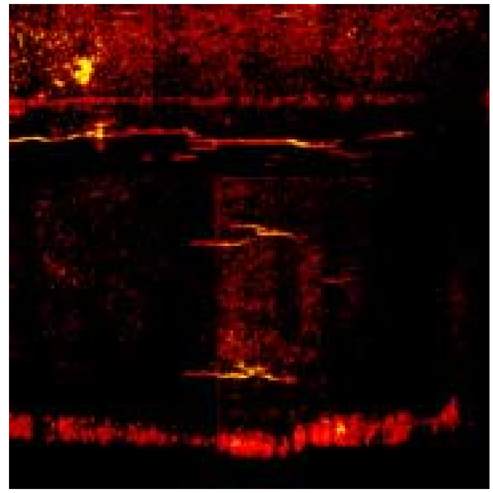

Figure 1. Magnetic Particle Indications

Figure 2 shows results from the circumferential MFL inspection. Flux leakage appears a dark regions in the center plot. Crack profiles through the thickness are shown in the call outs. The signals from one large crack near the top of the plot and two neighboring smaller cracks near the middle and bottom of the plot indicate that circumferential MFL could detect cracks. The signal from the middle crack is not strong, though, and it could easily have been missed in a field application.

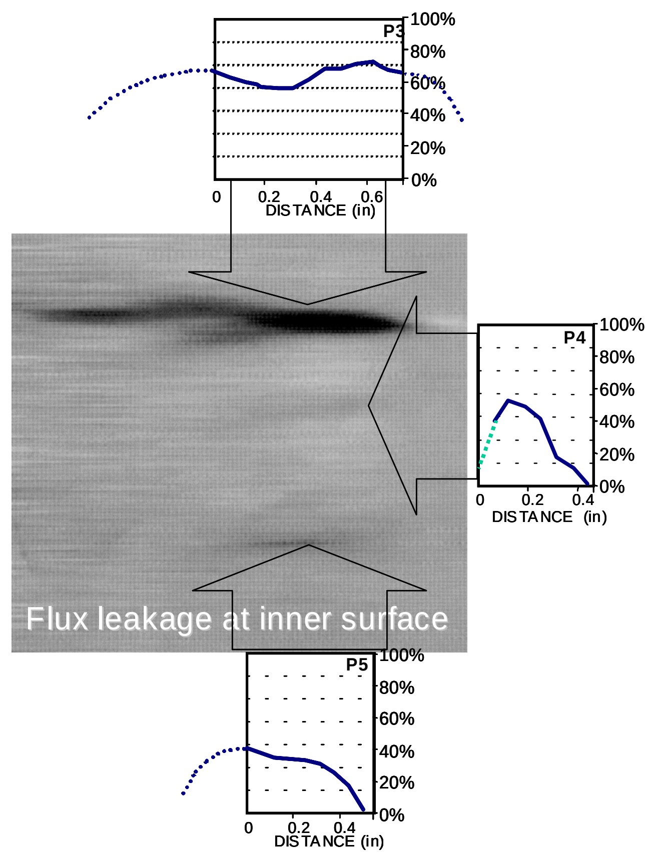

Figure 2. Circumferential MFL Results

SCC- Stressed Conditions

Stress is known to impact flux leakage levels, and so, the concept of stress enhanced magnetic flux leakage signal was also examined in the PRCI program. Circumferential flux leakage signals were acquired on a pipe sample while internal pressure with applied. Images of stress corrosion cracks were acquired at 0, 250 and 500 psi internal pressure in a 30 inch diameter, X52 pipe with a wall thickness of 0.375 inches. Conservative calculations showed that this defect could fail at pressures as low as 800 psi.

The experiments showed that internal pressure greatly reduces the applied magnetic field levels. To enable crack signals to be compared at different pressures, field levels were adjusted using electromagnet augmentation to attain a 30 Oersted field level at each pressure. Figure 3 shows each show three images of signals from the stress corrosion crack region. The top image is the crack at pressure 500 psi, the middle image is the crack at no internal pressure, and the bottom image is the difference the signals at high pressure and no pressure. These plots are similar to the plot in Figure 1 except that the signals are shown in color rather than black and white. In the figures, the maximum signal in each case is shown in red, and the magnitude of the signal can be seen in the legends shown at the right.

Figure 3 shows that at high pressure the signal levels increase approximately 12 to 14 gauss or 20 percent. These results show that signals from stress-corrosion cracks can be augmented by internal pressure, provided that this pressure locally increases the stress in the pipe wall. The fact that significant stress effects would only be detected at pressures that begin to threaten integrity suggests an alternative concept for pipeline inspection.

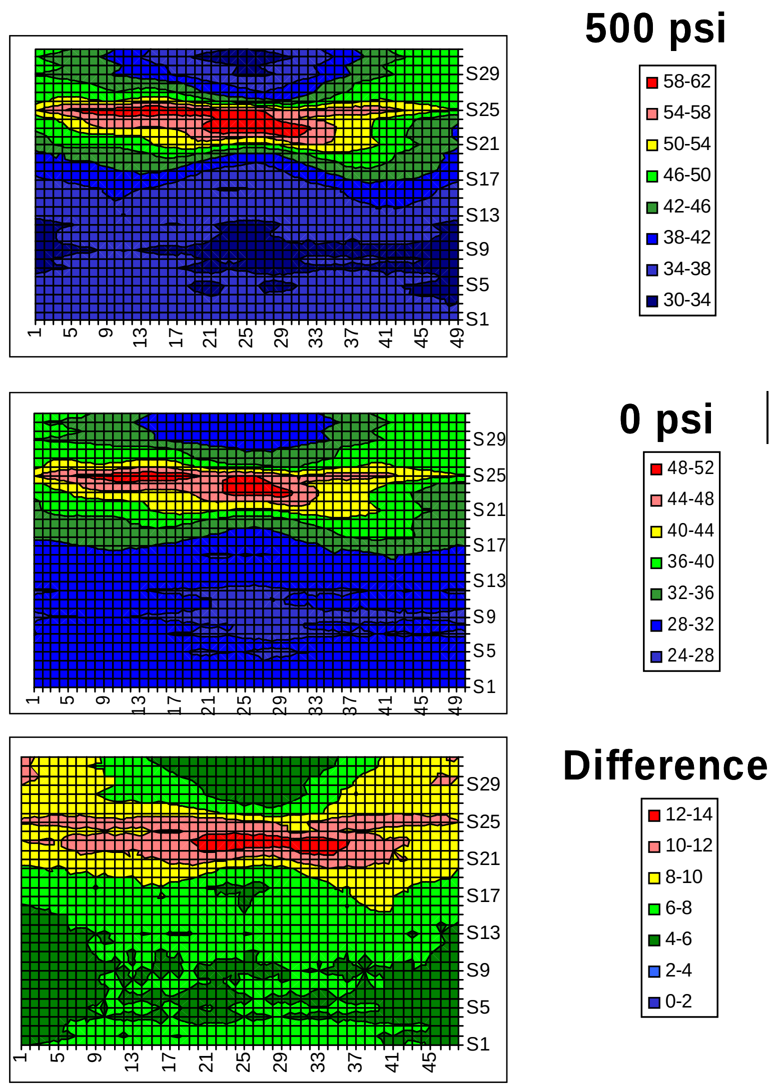

Figure 3. Circumferential MFL Signals Under Pressure

Seam Weld Corrosion

Circumferential MFL was also used to examine selective seam weld corrosion on an electric resistance welded (ERW) sample. With the seam weld examinations, the weld itself always gave a signal. So, changes in the signal were used to indicate where corrosion may exist. Signals from good welds, welds with general corrosion, and welds with selective seam weld corrosion are shown in Figure 4. In this figure, the signals are shown as a cross section of the circumferential leakage field.

Figure 4 shows strong signals are possible from selective seam corrosion in ERW pipe. In addition, nearby metal-loss corrosion is also visible. When both selective seam corrosion and metal-loss corrosion occur, the signals overlap, which confuses their interpretation. Based on these results, circumferential MFL has the potential for detecting selective seam weld and metal loss corrosion; however, many implementation and signal interpretation problems remain.

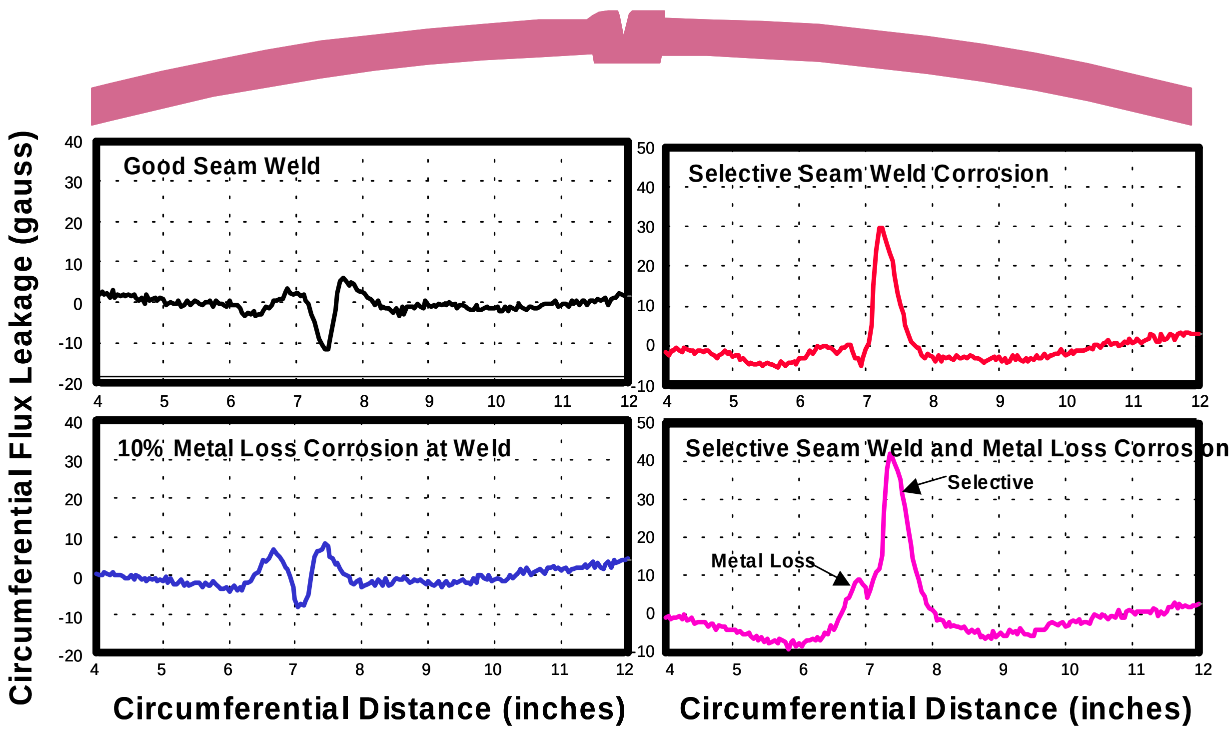

Figure 4. Circumferential MFL Signals from Selective Seam Corrosion

Conclusions

Prior work has been performed on circumferential MFL and other inspection methodologies to detect axial cracks in pipelines. These results demonstrate the feasibility of detecting stress-corrosion cracks and the practicality of developing a field-hardened circumferential MFL tool. Additional work is needed on signal processing to demonstrate reliable detection and sizing.