Integrity Management of Axial Stress Corrosion Cracking and Selective Seam Weld Corrosion

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Abstract

The discovery of Axial Stress Corrosion Cracking (ASCC) in the 1960's motivated the development of inline inspection (ILI) technologies capable of identifying and sizing these features with sufficient accuracy to support integrity programs. Along with ASCC, the discovery of Selective Seam Weld Corrosion (SSWC) has emerged in the past decade as a threat that sometimes exhibits crack-like behaviour. In the case of both ASCC and SSWC, current ILI technologies continue to be challenged with the detection, characterization and accurate sizing of these features.

Novitech with its Micron ILI Technology® has designed and developed six primary sensor systems to detect and identify pipeline defects. These sensor systems include CMFL-MF℠ (Multi-field Circumferential Flux Leakage), AMFL-MCD℠ (Axial Magnetic Flux Leakage for detection of metal loss and cracking), IDD-SM℠ (Internal Depth Detection-Stress Measurement), HPG (Precision Geometry Measurement) and IMU.

The advanced flaw diagnostic approach with CMFL-MF℠ and its low drag force design is combined with the extensive experience detecting and sizing other threats (metal loss, circumferential and off-axis cracking), demonstrating the potential of the technology to detect, characterize and size both ASCC and SSWC threats in the same inspection campaign.

This paper explores the new multi-field CMFL sensor technology concept, which uses varying levels of magnetization. The mid-field system shows potential to differentiate signals derived from corrosion than those from cracking for better identification of axially oriented features.

Both the full-field and mid-field CMFL sensor systems have sampling densities of up to 1,000 readings per square inch. When combined with the AMFL-MCD℠ and other sensor systems the sampling density of complete detection system can exceed 3,000 readings per square inch.

Using the multifield CMFL approach along with the supporting data from AMFL-MCD℠, high precision geometry, IDD-SM℠, Residual Field, and IMU mapping greatly improves the probability of detection (POD) and probability of identification (POI) of ASCC, Selective Seam weld Corrosion (SSWC) and, achieving very high probability of identification.

Nomenclature

AMFL:	Axial Magnetic Flux Leakage
AMFL-MCD℠:	AMFL for axial metal loss and crack detection of
ASCC:	Axial Stress Corrosion Cracking
CMFL-LDF℠:	Circumferential Magnetic Flux Leakage with Low Drag Force Design
CMFL-MF℠:	Multi-Field CMFL
EDM:	Electrical Discharge Machining
HPG:	High Precision Geometry Measurement

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IDD-SM℠: Internal Depth Detection-Stress Measurement
IMU: Inertial Mapping Unit
Micron CD-360℠: Micron Technology for Crack Detection with 360° coverage for crack and critical flaw detection
SSWC: Selective Seam Weld Corrosion

Introduction

The detection and discrimination of axial stress corrosion cracking continues to be a significant industry challenge. Mainstream ILI technologies were not optimized to detect, characterize, and size with sufficient accuracy to manage ASCC and in recent years SSWC.

Following the success on detection and characterization of circumferentially and off-axis oriented cracks and crack like features including CSCC, the research team is developing a program to evaluate and improve the discrimination of axially oriented features.

This paper explores the testing and analysis results of the new CMFL-MF℠ sensor technology, which uses varying levels of magnetization to enhance axial flaw discrimination.

ASCC Discrimination Research

Further development of a more advanced inline inspection system to investigate ASCC and SSWC discrimination is required to improve probability of detection (POD), probability of identification (POI) and sizing to aid pipeline integrity programs that target these threats.

The focus of the research program is the development of technology that includes AMFL-MCD℠ and new multi-field CMFL-MF℠ modules. The multi-field CMFL sensor elements allow the separation of ASCC and SSWC signals from the shallower surface corrosion often present at these anomaly locations.

The first step of the testing began with NPS 20 pipe sample (half shell) containing a large ASCC colony that was nested in approx. 20% wall thickness (WT) corrosion (see Figure 1).

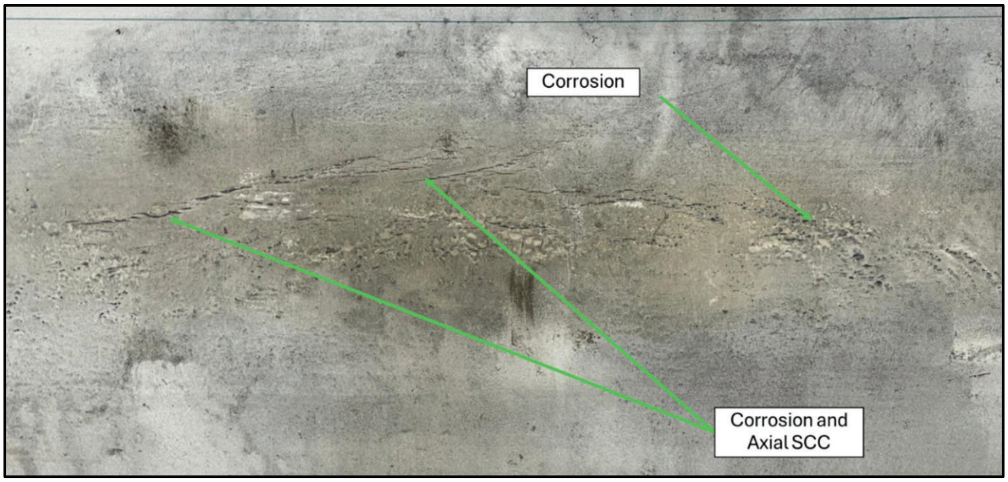

Figure 1. NPS 20 pipe sample containing a large ASCC colony.

Testing was conducted using the existing CMFL magnetizer and during the analysis corrosion signals were masking some of the signal responses related to deeper portions of the crack field. It was difficult to determine whether the detected feature contained only corrosion or corrosion and cracking combined. The setup had to be changed again to reduce this variability and gain clearer understanding of signal responses and a potential solution for sensor design.

The second step of experimentation utilized a small-scaled concept of an existing circumferential CMFL magnetizer for testing a mid-field crack detection solution. A 6-in pipe shell with both machined and EDM notches along with a prototype 6-in CMFL magnetizer were used for testing. The goal of this step was to determine a method to eliminate the effect of surface level corrosion features while improving the detection of deeper cracks.

An NPS 6, grade X42, 19.7” (0.5m) long, 0.222” (5.64mm) WT carbon steel pipe shell, was used for the testing (see Figure 2 and 3). Three rows of four straight axially oriented notches were machined into the pipe wall at varying depths to simulate in-field anomalies. Each row of notches was manufactured with depth verified using ultrasonic digital thickness gauge with a 7.5 MHz Dual crystal transducer and a digital depth gauge. The measurements showed approximately 23%, 40%, 70% and 90% WT depth (see Table 1). Each notch was 0.78” (20mm) long. Row 1 consisted of EDM notches where roughly 6-16% of the pipe surface was removed (by grinding) to simulate surface corrosion, while Row 2 consisted of the same EDM notches without surface grinding. Both Rows 1 and 2 notches had measured widths of 0.016-0.017” (0.4-0.43mm). Row 3 features were machined using a 3mm square end mill at the same specified depth and length as the EDM notches.

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Figure 2. NPS 6 test pipe notch layout

Figure 3. NPS 6 test pipe internal surface view with identified notch layout.

The intent of using the mid-field magnetizer system was to reduce magnetic pipe wall saturation to the limit where the signal response of external surface level anomalies such as corrosion were minimized, and deeper crack responses are captured. In conjunction with a high-field CMFL dataset, the mid-field dataset is designed to aid in distinguishing between external surface level corrosion and deeper cracking.

To reduce the pipe wall magnetic flux saturation, various methods can be used to manipulate the magnetic field. A combination of these methods was tested in this experimentation to develop this concept.

By changing the dimensions of the magnets and magnetizer bar aspect ratio's, the field strength is theoretically reduced by a linear factor, as the field strength is proportional to magnetic strength and overall magnetic volume as detailed in the equations below [1].

$$B = \mu_0 * M$$

Where:

B = magnetic flux density near the surface (T)
μ_0 = permeability of free space $(4\pi * 10^7\ T\ m/A)$
M = magnetization of the material (A/m)

The N-value of the magnet represents the maximum density of magnetic energy stored in the magnet material (BH_{max}), remanence representing the magnetic field caused by hysteresis after the external magnetic source has been removed, while coercivity is the resistance to becoming demagnetized.

$$BH_{max} = B_r * H_c$$

Where:

- BH_{max} = maximum energy product
- B_r = remanence (T)
- H_c = coercivity (A/m)

Magnetic strength (or total magnetic moment) μ is based off the magnet volume and material properties. Described through:

$$\mu = M * V$$
$$V = length * width * height$$

Where:

- μ = magnetic moment $(A * m^2)$
- M = magnetization of the material (A/m)
- V = volume of the magnet (m^3)

The reduction of the volume of the magnet is proportional to the field strength, and the resulting saturation within the pipe wall decreases as well.

The experimental test was conducted by moving the assembly across each row of notches while their signal response was recorded. Summary of the results are as follows:

1. The most notable behaviour in the signals occurred at the location of the 23% WT depth notch. The signal response from the notch was reduced compared to the full field, while maintaining a strong and observable response from the deeper features despite amplitudes being diminished. This observation held true for both the EDM notches and wider machined notches and results were repeatable throughout multiple sample tests.
2. Due to reduced pipe wall saturation, the response of the surface grinding on Row 1 features was not captured on both signal channels in line with the notch and away from the notch. This validated the hypothesis that the simulated surface corrosion is ignored while deeper features are still being captured.
3. The number of channels affected by the features of interest along the axial region was also reduced with the experiment, as magnetic field propagation within the pipe wall along the

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> circumferential direction is lowered. Despite this inherent limitation, this approach in conjunction with a full field CMFL dataset should still provide a measurable discrimination between surface corrosion and cracking. Additional testing on real crack features is planned to further validate the concept.

While changing the overall shape and coverage of the magnetic field during testing of this concept, additional effects such as the shift of the field concentration rearwards during movement of the assembly due to eddy currents as highlighted by I. Mullin et. al. [2] needs to be further explored. Along with the limitation of adjustability of the tool to varying wall thicknesses, further testing with this method requires detailed investigation.

By using data synthesis or layering and comparing the magnetic responses of the multi-filed CMFL sensor to SSWC, the depth and severity of the flaw can be determined as follows: The medium field CMFL partially penetrates the pipe wall enabling detection of narrow axial metal loss that is deeper than 20% of the nominal wall thickness, and the multi-field CMFL is used to examine the entire wall thickness of the pipe. The data analysis will be combined with AMFL modules to support further discrimination of SSWC from coincidental corrosion and accurately map all corrosion feature in the vicinity of SSWC. Similarly, the same concept can be applied to ASCC.

Case Study – ASCC Detection

To demonstrate the potential of the new concepts, a pull test of an NPS 16 pipe sample containing ASCC features, provided by a pipeline operator (Figure 1) was conducted. Using the Novitech CMFL sensor, SCC features were successfully detected during the test. This finding had demonstrated the potential for discriminating axially oriented features and was used in the development of the multi-field CMFL module.

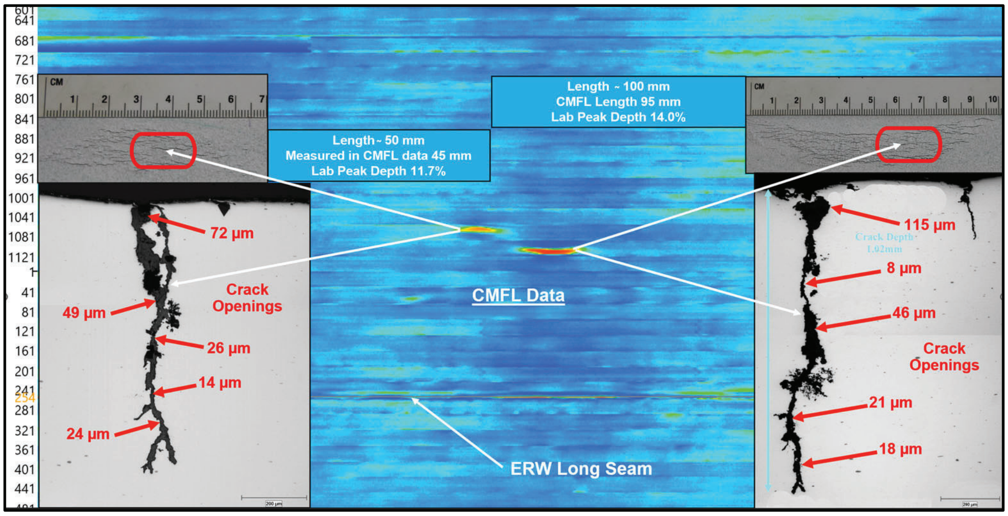

Figure 4. Result of NPS 16 pull tests of a pipe sample containing ASCC.

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Case Study - ERW Flaw Detection

The newly developed concepts of integrating multiple magnetic fields have resulted in more accurate characterization of ERW seam flaws. Figure 5 below is an example of an ERW seam flaw verification.

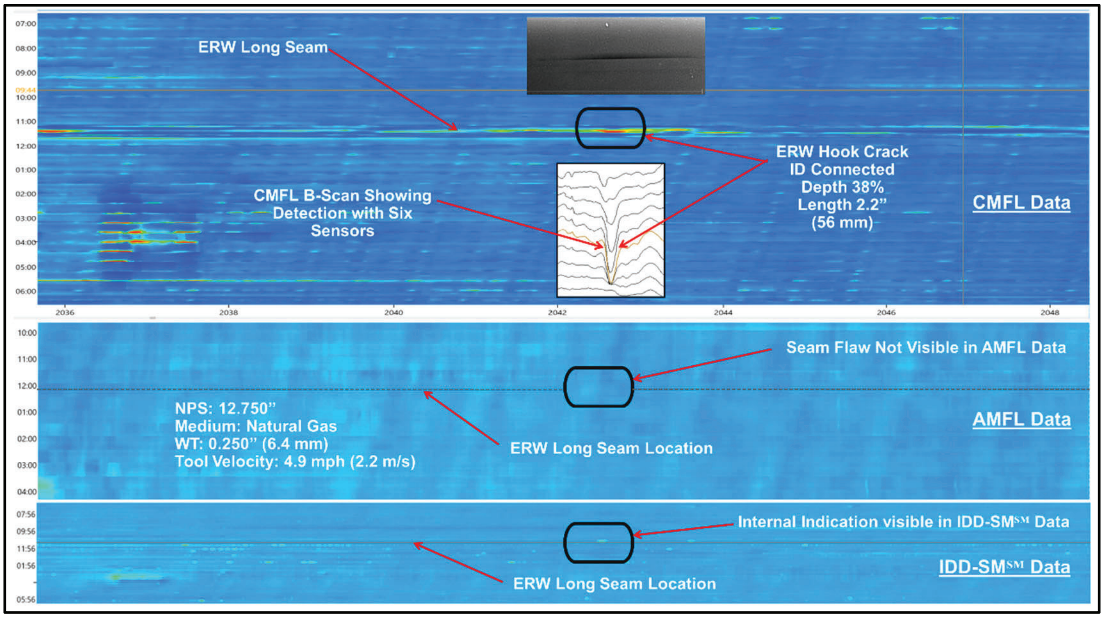

Figure 5. Example of ERW seam feature found by the multi-field CMFL technology

Case Study – SSWC Detection

SSWC can be characterized as narrow axial metal loss associated with the longitudinal weld seams. SSWC affects the bond line or heat affected zone (HAZ) selectively or preferentially to the base material up to four times faster than the adjacent parent material. These narrow groove or crevice-like features are not cracks but can create similar responses as axial cracks compromising the structural integrity of the pipe. The narrow axial profile of this type of metal loss, can elude conventional applications of ILI technologies, that were not designed to detect, characterize and size (with sufficient accuracy) to manage this type of integrity threat.

This type of feature has historically been sized shallower than the actual depth in most cases, however, more recent advancements in sizing have benefited from the multi-field and multi-dataset concept utilized on the Micron tools. By applying more recently developed data analytics and interpretation of the multiple magnetic fields has led to a better characterization of these features. Figure 6 below is an example of a feature that was reclassified as much more severe as a result of the new developments.

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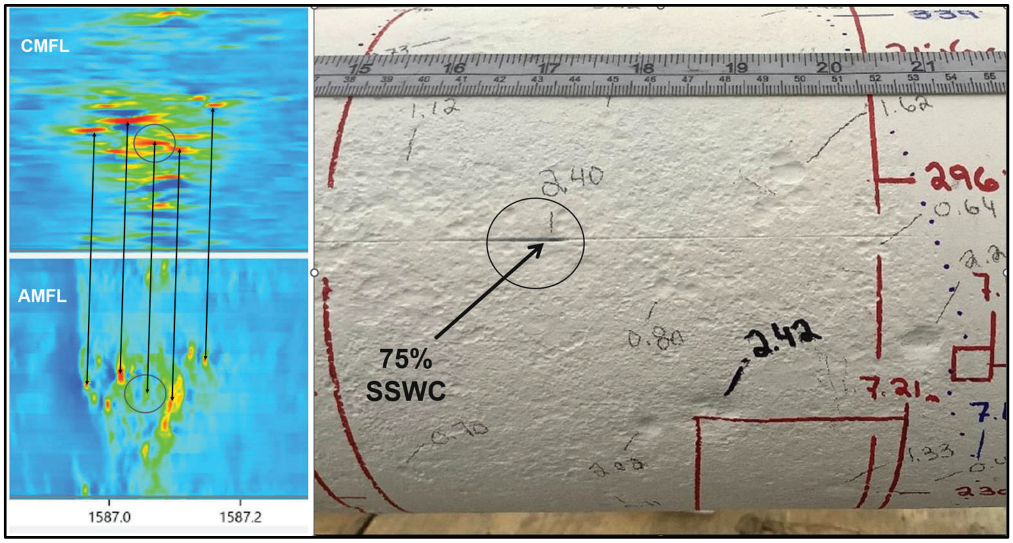

Figure 6. SSWC feature verified as severe by the multi-field CMFL technology.

Summary

The multi-field concept applied on the CMFL magnetizer systems provides an additional dataset to aid the analysis team in discriminating between surface level metal loss and other features and deeper axially oriented cracks, SSWC and crack like features. In conjunction with all data sets available on both AMFL and CMFL tools, this setup provides a much higher level of certainty for analysts when sizing, boxing, and discriminating axially oriented cracking features. This solution is a stepping stone for further development in the ASCC discrimination space. Scaling up this technology to the intended 12in system in addition to pull testing on real features will provide further validation of this concept.

With the new and advanced flaw detection approach and based on the extensive work on other threats (metal loss, circumferential and off-axis cracking), the ability to detect and size all major integrity threats in the same inspection campaign has been demonstrated. This combined inspection precision can substantially reduce false positives and unnecessary excavations.

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The evolution of inspection technology has always been a shared integrity partnership between the pipeline operators and the ILI companies, and we are very thankful for this continued collaboration.

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