

Effective SCC Inspection of In-Situ Oil Sands Pipelines Using Advanced Eddy Current Array Technology

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ABSTRACT

This paper presents the successful deployment of advanced eddy current array (ECA) probes for the inspection of intergranular stress corrosion cracking (IGSCC) present on the external surface of aboveground in-situ pipelines. During an inspection campaign carried out in 2020 and 2021 mainly on emulsion and produced gas pipelines, more than 20 indications were found over 20 kilometers of pipeline. These indications range from 5 mm to 400 mm long by 1 mm to 12 mm deep. The technology provided the pipeline operator a fast method for IGSCC detection leading to cost-effective inspection and maintenance planning, while preventing the risk of loss of product containment.

Key words: Stress Corrosion Cracking (SCC), Intergranular Stress Corrosion Cracking (IGSCC), Eddy Current Array (ECA), Non-Destructive Testing (NDT), In-Situ Pipeline Inspection, Emulsion Pipeline Inspection, Produced Gas Pipeline Inspection

INTRODUCTION

ECA technologies are not very well known in the oil and gas industry and are still undeservedly suffering from the bad reputation of traditional eddy current testing from twenty years ago. Eddy current techniques are often humorously compared to "black magic" in the sense that the results are difficult to understand, the probes are complicated to use, and only eddy current gurus can use it efficiently. However, ECA has evolved significantly over the past 15 years and is now much easier and more intuitive to use. It is in fact an extremely powerful technology when it comes to managing crack detection and depth sizing on critical assets like pipelines, pressure vessels, tanks, turbines, aircrafts, launch vehicles for the aerospace industry, and many others. ECA probes can be elaborate and precisely tailored for specific applications. Beyond that, the software capabilities are continuously evolving to bring this technology to another level. The ECA technology provides speed, high probability of detection (PoD), improved control over the human factor, impressive repeatability, and high accuracy on depth sizing. It is time for the industry to learn more about where this technology stands today.

The case study described in this paper showcases the use of ECA technologies for the inspection of in-situ aboveground pipelines for the oil sands industry. Following a few unfortunate surprises associated with

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IGSCC, the industry was desperately looking for an efficient solution to inspect oil emulsion (multiphase) and produced gas pipelines. Dry magnetic particles inspection (DMPI), which is the de facto method for pipeline direct assessment for cracks, was first considered for this work. However, this testing would have required an incredible amount of time to complete and extensive surface preparation (e.g., sandblasting, and careful painting as proper contrast is key with this technique). DMPI would also have been inevitably impacted by weather, environmental conditions, and outside temperature. Additionally, magnetic particle inspection is always subject to the human factor. Virtually all steps of an MPI inspection procedure relies heavily on the operator: surface preparation, magnetization, interpretation, and reporting. Although extremely useful in a wide variety of contexts and surface geometries, DMPI is intrinsically subject to human errors which heavily impacts repeatability and PoD during an inspection. Indeed, after having considered DMPI, it became obvious that this technique would require too much time, too many technicians, and offer limited confidence in the inspection results. Being able to collect data, map the results in an intuitive way, and archive digital records were also key features that only a digital inspection method could bring.

In parallel, the ECA technology was also considered and evaluated as a potential alternative to DMPI. During a blind trial performed on samples containing artificial flaws and real IGSCC, the ECA tool led to the discovery of a higher number of indications than DMPI, in less time, with no increase in false positives, while providing complete digital records of the inspection. After having demonstrated such an impressive and convincing performance, it was decided to opt for the digital way. Adding to its large coverage capabilities and high scan speed, ECA was the only logical choice for this challenging inspection scope.

This paper depicts the problems encountered with IGSCC on aboveground emulsion and produced gas pipelines, describes the basics behind the specific ECA solution being deployed in the field for crack detection and sizing, and finally, unveils results from multiple inspection campaigns ran by a few major Canadian oil sands operators over the past few years.

The problematic

In midstream oil and gas operations, SCC is a very well-known and well documented issue having historically been mainly associated with buried carbon steel pipelines. External SCC on buried pipelines occurs in two forms, high pH SCC and near-neutral pH SCC, with cracking morphologies being typically intergranular and transgranular, respectively.

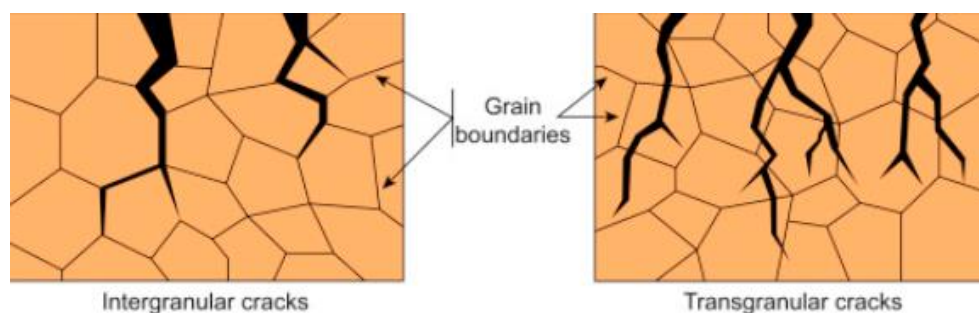


Figure 1. Schematic representation of intergranular and transgranular SCC¹.

SCC is a type of environmentally assisted cracking: it takes its source with the combination of corrosion and tensile stress. Corrosion is related to the susceptibility of the material to the environment, while stresses may be residual, external, or operational.

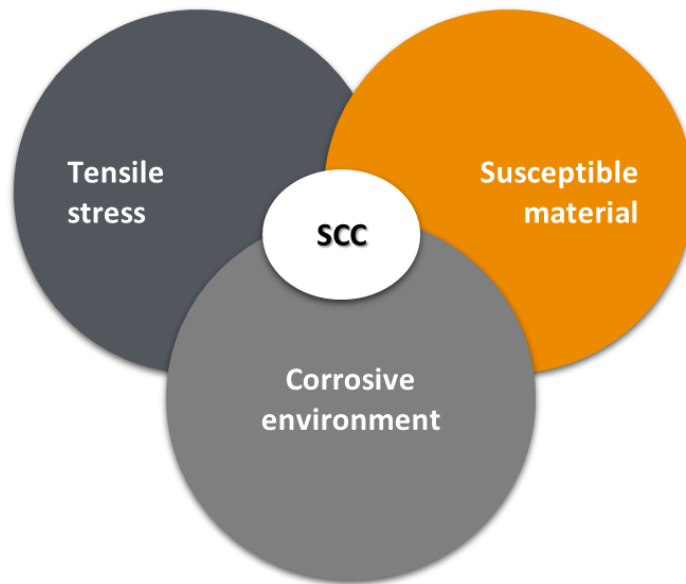


Figure 2. SCC occurs from the combination of three conditions: a material susceptible to corrosion, sufficient tensile stress in the material, and a corrosive surrounding environment.

In aboveground pipelines, no SCC of any form had been observed until recently. However, over the past ten years, multiple oil sands producers have experienced externally initiated in-service leaks on aboveground oil emulsion pipelines, and lab investigations have confirmed that the cracks were initiated by IGSCC². The investigations also revealed that the pipe material and stress contributed to crack growth, but that the main factor was more likely originating from the environment. Considering that the coating type, level of cathodic protection and soil environment could not have played a role in the SCC formation on those aboveground pipelines, it had to be something else pointing in that same direction. It was later found that the environment created by a specific type of insulation, after water intrusion and around high residual stress areas, was the perfect combination of factors for triggering SCC^{3, 4}. Furthermore, given the fact that many incidents tended to point towards a specific type of insulation widely used in pipeline construction post 2005, an important inspection campaign on emulsion and produced gas pipelines was launched in 2018 by a few major Canadian operators.

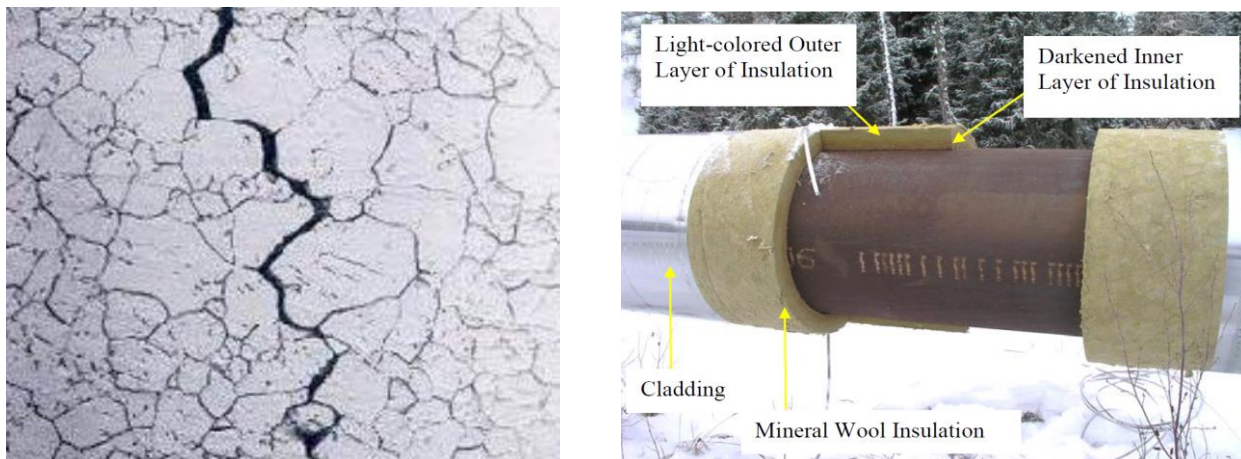


Figure 3. Left: Close-up view of IGSCC developing in aboveground pipelines; Right: Emulsion pipeline with insulation creating an environment prone to the development of IGSCC.

The challenge

Inspecting a pipeline of large diameter over several kilometers is no small feat: the total area to inspect is gigantic. Nonetheless, there is no room for error (e.g., leaving a deep crack undetected) and the non-destructive testing examination must be reliable from start to finish while remaining safe for the technicians. Another challenging aspect of this inspection is that the pipeline's surface can reach past 160°C, while at the same time, the NDT technicians must endure Canada's harsh weather conditions.



Figure 4. Aboveground pipeline in winter.

As a summary, here is the list of specifications that had to be met for this inspection:

- Must be faster than DMPI
- Provides equivalent or higher PoD than DMPI
- Minimum crack size to be detected: 6 mm long X 1 mm deep
- Cracks in all orientations to be detected
- Operating temperature: 160°C
- Data acquisition must be encoded
- Fully digital records
- Depth sizing capabilities would be a plus

EXPERIMENTAL PROCEDURE

During the solution development phase, the requirements for crack detection were considered separately from those for depth sizing. This resulted in the development of two independent eddy current solutions: one large-coverage ECA probe for the rapid screening of the pipe and detection of SCC⁵, and a second smaller probe based on tangential eddy current array (TECA) tailored specifically for the depth sizing of cracks. This section presents the development process for both probes separately.

Probe #1 – ECA for crack detection

As a first step, the main objective was to provide a better tool for crack detection. The ECA probe design was oriented towards coverage and speed but also had to deliver high sensitivity and reliability. Due to the highly magnetic permeability of carbon steels, the detection was limited to surface-breaking cracks.

Essential ECA parameters

To meet the objectives described above, a list of essential ECA parameters needed to be determined:

- Coil topology (how the coils are used to create a channel)
- Operating frequency
- Coil diameter, array resolution, and coverage
- Array spatial resolution
- Scan speed

ECA coil topology

The selection of an ECA topology must consider all essential parameters listed above. For carbon steel, the selected topology is the long single driver (LSD), mainly for the optimum phase separation it provides between cracks and lift-off signals. In this topology, a single channel is constituted of two coils: one coil used as a transmitter (Tx), another as a receiver (Rx), separated from each other by a distance equal to one coil diameter, as shown in Figure 5A. The Tx induces eddy currents in the material while the Rx senses the eddy currents path disruption caused by the presence of cracks. This topology is directional, meaning it has a maximum sensitivity over cracks aligned with the line connecting the centers of both coils (Figure 5B). Alternatively, sensitivity is minimized for cracks perpendicular to this line (Figure 5C). Hence, the developed ECA probe uses two orientations of LSD channels, circumferential and axial, to ensure detecting cracks of all orientations during the scans (Figure 6).

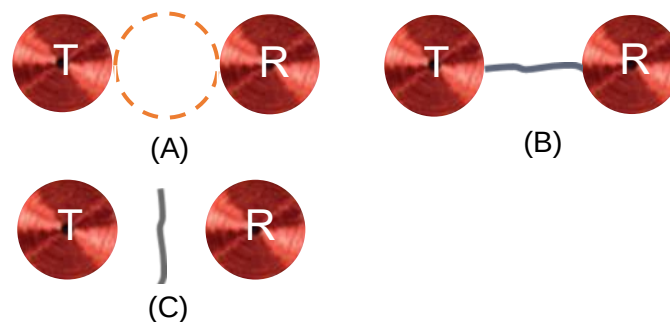


Figure 5. (A) Long single driver channel, (B) Crack orientation with maximum, and (C) minimum sensitivity.

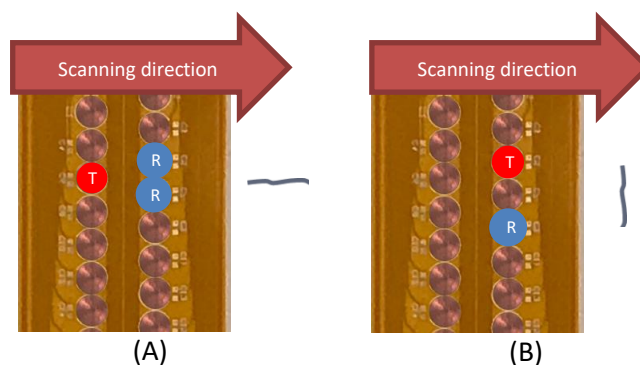


Figure 6. Demonstration of the long single driver channels: (A) axial channel and axial crack; (B) circumferential channel and circumferential crack.

ECA operating frequency

Because of the high magnetic permeability of carbon steel alloys, even at low frequency, the eddy currents