SCC detection improvement using high resolution EMAT technology

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Introduction

Liquid filled pipelines can effectively accommodate mechanical piezoelectric transducers which couple to the pipe wall through the fluid being transported; a solution which would not work well for dry natural gas pipelines. An Electromagnetic Acoustic Transducer, EMAT, does not require mechanical / fluid coupling and can generate ultrasound waves in a wet or dry medium, a good solution for natural gas pipelines.

Inline inspection (ILI) tools available in the market today are primarily based on the magnetic flux leakage (MFL) principle. These tools have matured over the years to provide superior mapping of corrosion, but have not been very effective on axial cracking or stress corrosion cracking (SCC). Piezoelectric ultrasonics have been utilised for crack detection, specifically targeting SCC. However, the high frequencies required by the acoustics to achieve a detectable echo from SCC has proved to be overly sensitive to other intrinsic material anomalies manufactured into the pipe. In this case, the problem of too much sensitivity has reduced the commercial success of the piezoelectric tools.

The EMAT technique has been elusive in the past due to the inefficient nature of the electromagnetic transduction and the practical application of guided-wave techniques. Improvements in magnetisation capabilities and a more thorough understanding of guided-wave acoustics has changed this situation. The EMAT now has a distinct advantage over the piezoelectric transducer enabling the wave length and the frequency to be precisely controlled. Careful utilisation of particular guided-wave modes optimises the sensitivity to specific material features. For example, lower frequencies (<1 Mhz) with longer wave lengths can ignore most small features and provide the immunity to inclusions or other manufactured defects often prominent in older pipeline steel.

The proper selection of guided-wave modes can effectively highlight axial SCC within other crack orientations or other anomalous features.

SCC colonies from an inspection point of view

Although the mechanisms and causes for SCC in pipelines are still an ongoing research topic, the shape and appearance of SCC is well known. From an inspection point-of-view, the main characteristics are:

- cracks exist, with various lengths and depths, in colonies.
- there are numerous shallow cracks within one colony.
- depth growth by coalescing of initially shallow and short SCC within colonies.
- a distinct irregular surface, especially for the inter-granular crack types.
- typically open to the external pipe surface.
- typically occur on sections with disbonded coating.
- SCC occurs in gas and in liquid pipelines.
- in case of the test specimen discussed later, the SCC grew under a shallow angle of <45º from the pipe surface into the pipe wall.

SCC is difficult to image and size by any NDE technique due to the complicated structure and irregular nature of the cracking phenomena. SCC often occurs in groups or colonies. Within these colonies the larger cracks are of interest to be measured with an NDE tool while existing in a field of smaller cracks. Ultrasonic techniques based on reflection must overcome the poor reflectivity of these complicated irregular targets. Using conventional piezoelectric transducers, these problems can be solved with increased transducer frequency, and higher resolution transducers with higher sampling rates. Unfortunately, higher frequencies also cause increased sensitivity to other non-critical features in the pipe wall, increasing the number of false calls. Excessive false calls can easily destroy the practicality of a tool. Other limiting effects for piezoelectric transducers are the shallow angle of the cracks in this example and the obligatory liquid coupling of the sensor heads.

A guided-wave solution is well suited to the detection of SCC, because the SCC is a general degradation of the material, and the guided-wave is a mechanical elastic wave whose propagation depends on the dimensions and properties of the material itself. Guided-waves, as generated by an EMAT transducer, propagate within the external and the internal pipe surface as a boundary condition. The presence of SCC disturbs the guided-wave and a "significant" change in the dimensions of the wave guide, such as that from a crack, will reflect the wave and cause an echo, which may then be detected. SCC starts from a degradation of the material, as stress and corrosion team together to make the material fall apart on the microscopic scale. "Significant" SCC starts changing the material properties enough to enhance the reflection of particular guided-waves to enable favourable imaging of the SCC features. If the guided-wave modes are properly selected, an attractive signal can be obtained from the SCC location independent from the existing external surface coating.

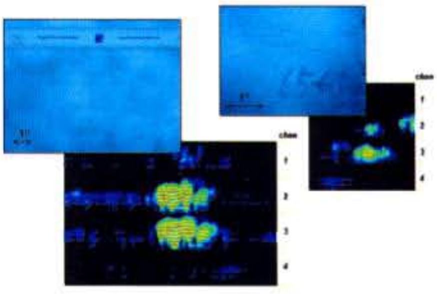

Figure 1: pictures of natural SCC colonies and data samples from these locations, taken with the high resolution EMAT prototype.

The concept of high resolution EMAT technology

Guided-wave acoustics are used for SCC detection. The selected shear wave mode is operated at a rather low UT-frequency (<1 Mhz), without compromising the SCC detection capabilities. The advantage is a lift-off tolerant performance and a reduced sensitivity to mid-wall and mill defects.

The high resolution EMAT sensors are sensitive in the clockwise and counter-clockwise direction of the perimeter of the pipe. This interrogates the inclined cracks from two different sides. The sampling rate and the circumferential separation of the EMAT sensors are determined by the physical size of the EMAT transducer itself, which in turn is a function of the pipeline diameter. The ILI prototype is designed for 48 EMAT channels, evenly distributed around the circumference. The pulse sequence and the receiver timing allows each sensor to cover a distinct, and overlapping, area of the pipeline.

Due to the appropriate selection of wave mode, the SCC measurement sensor is only marginally sensitive to coating changes. Nevertheless, by changing the timing of the receiver units, coating disbondment information can be obtained. SCC tends to occur in areas where there is a coating disbond. Detecting these areas of high SCC probability is an important additional feature of this inspection technique. Coating disbond has been shown to be a precursor to SCC, and if a line has a large population of disbonded areas, the susceptibility to SCC is greatly enhanced. Therefore, this failure must be detected as well in order to be an effective SCC inspection tool.

The magnetisation required for the EMAT technology is induced into the pipe wall mechanically, independent from the sensing devices. This prevents an unwanted "clotting" of ferromagnetic debris.

Test series on pipe specimens containing natural SCC colonies

The overall sensitivity of the high resolution EMAT prototype was determined on a set of EDM notches, simulated cracking introduced into a test pipe. Full-scale tests on a pull-rig showed excellent sensitivity. Notches of 0.6 in. in length and 10 per cent depth were clearly detected.

As part of a current commercial project, a test specimen was obtained from a large diameter, coal tar coated, natural gas pipeline. The specimen contains several locations with natural inter-granular SCC features. All areas were identified with MP-NDT and handheld UT measurements. The unusual orientation of the SCC was previously mentioned. The pipe sample was inspected and then re-coated along a short distance at an SCC location, to verify the independency of the selected SCC detection mode from coating and to determine the performance of the dedicated coating disbondment detection channel.

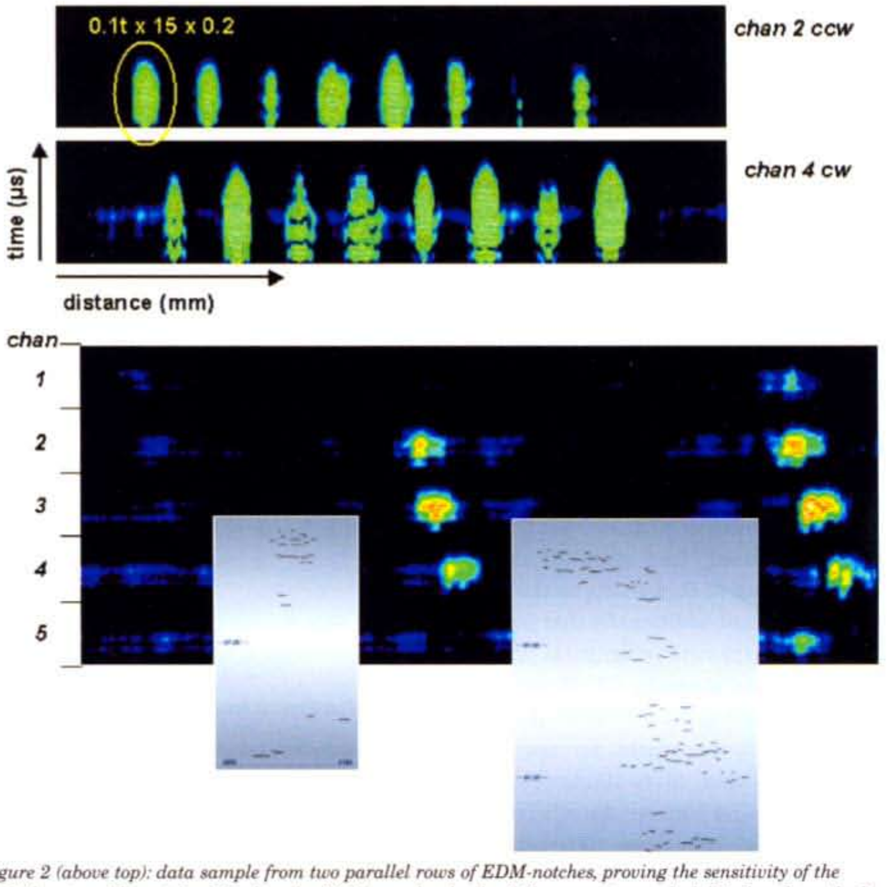

Figure 2 (above top): data sample from two parallel rows of EDM-notches, proving the sensitivity of the EMAT system. The notch with a length of 0.6 in. and a depth of 10 per cent is marked. Displayed are the B-scans of two adjacent channels. Figure 3 (above bottom): data sample from high resolution EMAT prototype. Two adjacent areas containing SCC were clearly detected. Displayed are B-scans from 5 adjacent channels.

The full-scale tests performed on this pipe sample can be summarised as follows:

- All areas with SCC were detected. The dimensions of an SCC colony can be analysed from the measured data. Individual cracks cannot be distinguished from the detection signal.
- The signal amplitude is a function of the lateral size of the colony and the depth of the most prominent cracks.
- Due to the oblique orientation of SCC, the signals obtained in the clockwise direction were clearly stronger than the signals obtained in counter-clockwise direction.
- The reflection from the SCC was only marginally attenuated within the re-coated area.

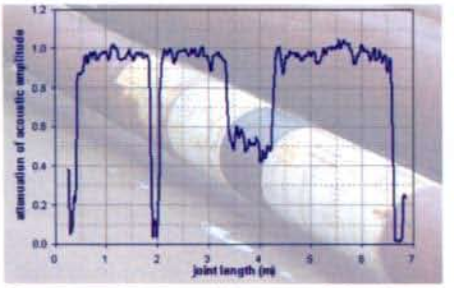

Figure 4: performance of the coating disbondment channel. Coating is damping the reference amplitude by 50 per cent. The other sharp reductions can be correlated with girthwelds.

- The basic principle of coating disbondment detection was verified. A quantitative evaluation of the exact bonding quality will need further investigation.

Conclusion

A novel high resolution EMAT ILI tool was presented. The tool has an improved detection capability for SCC defects due to an appropriate selection of ultrasonic guided-waves and a two-directional circumferential pulse sequence.

By additional measurements of the guided-waves, independent of the SCC measurement, information about the integrity of the coating bond can be obtained. A moderate lift-off performance was achieved by choosing a rather low frequency ultrasound.

The detection capabilities on natural SCC specimen were demonstrated. Tests on artificial notches showed an excellent sensitivity on shallow and short defects (depth 10 per cent of wall thickness and a length of 0.6 in.).