Carbon steel pipelines transport billions of litres of fluids daily, from crude oil to natural gas. For obvious reasons, their safety is paramount, as failures can lead to incidents ranging from leaks to destructive explosions. Stress corrosion cracking (SCC) colonies and welding issues in pipelines are major causes of such failures and stringent regulations make it imperative to not only detect cracks, but also to precisely size them.

**Cracking in pipelines**

The efficiency and safety of pipes are matters of concern. Whatever their age, pipelines can suffer from a number of types of cracking.

**Cracking in welds**

There are many kinds of welds in pipelines: circumferential (girth), longitudinal and spiral welds. They are produced using
different welding processes, the most common being submerged arc welding (SAW), double submerged arc welding (DSAW) and electric resistance welding (ERW).

Welds are prone to several types of cracking mechanisms. Generally, cracking in carbon steel welds include:

1. **Longitudinal cracks**: breaks in the surface parallel to the weld axis, for example, along the centreline of the weld, close to the weld toes or in the HAZ.
2. **Transverse cracks**: breaks in the surface perpendicular to the weld axis, which may be completely within the weld metal or may extend from the weld metal into the base metal.
3. **Crater cracks**: breaks in the surface that occur at the crater of a weld because welding was improperly terminated. Crater cracks are also referred to as star cracks.
4. **Branching cracks**: clusters of connected cracks originating from a common crack.

**SCC**

SCC is an environmentally assisted mechanism that can induce rapid failure when initiated. SCC is the combination of a corrosive attack on metals subject to stress and a corrosive environment. As a rule, SCC induces failure at a stress level less than the ultimate tensile strength of materials, in environmental conditions where corrosion alone would not necessarily lead to failure.

SCC colonies are composed of many short and shallow surface breaking cracks, usually oriented along the flow axis, perpendicular to the hoop stress. The branched morphology of colonies makes SCC challenging to characterise with conventional nondestructive testing (NDT) methods. Further, to calculate the burst pressure in pipelines, it is essential to assess the deepest point in a colony.

**NDT techniques for pipeline integrity assessment**

Currently, the most widespread conventional in-ditch NDT techniques used to detect cracks in welds and SCC in pipelines are:

- Magnetic particle testing (MPI).
- Liquid penetrant testing (LPI).
- Ultrasonic testing (UT).
- Radiographic testing (RT).

More advanced inspection techniques include:

- Phased array ultrasonic testing (PAUT).
- Time-of-flight diffraction (TOFD).
- Automated ultrasonic testing (AUT).

**MPI**

As the most widely used non-UT technique, it is generally accepted that MPI is relatively simple, yields almost immediate indications of defects, is relatively inexpensive and is capable of inspecting large and small objects.

Some of the shortcomings of MPI are:

- Pre-inspection surface preparation.
- Weather dependent.
- No depth sizing.
- Post-cleaning and recoating.
- No digital records.
- User dependent.
- Long analysis process of high density colonies.

Under most in-ditch situations, once a crack colony is located and identified, a process of grinding and retesting is initiated until, through trial and error, the deepest point in the colony is assessed.

**UT**

In the oil and gas industry, UT is mostly used to find cracks in weld volumes and corrosion in thickness measurements.

Due to the nature of the technology, UT offers somewhat poor performance for shallow, surface breaking cracks and nonlongitudinal cracks. In tightly packed crack colonies, it also has a hard time isolating and sizing individual cracks. Spiral welds are another significant challenge because the UT transducer is difficult to deploy consistently along the scanned area.
MPI and UT are two widely different inspection techniques requiring different setups and skill sets from operators and analysts, making them time consuming and sometimes unreliable in various pipeline integrity assessment applications.

**Tangential eddy current array: integrated solution for pipeline integrity**

An eddy current array (ECA) consists of series of single eddy current elements arranged in the same probe to cover a larger area than conventional eddy current testing (ECT) probes. ECA probes effectively eliminate the need for raster scans (necessary with ECT pencil probes), which has a significant impact on inspection speeds and the quality of results. Carbon steel, however, is a challenge for ECA technology.

Tangential ECA (TECA™) technology improves on ECA with a better response to surface breaking cracks in carbon steel thanks to the tangential arrangement of coils. Eddy currents induced by TECA flow perpendicular to the direction of scans and, as they meet cracks, they must go under them or around their extremities.

Recent inspections on the Canadian pipeline networks of major energy companies have highlighted the need for an integrated inspection solution to better assess fatigue cracks in welds and SCC colonies in pipelines. The butt weld and high resolution Sharck™ probes were selected, based on the premise that TECA could be a more efficient way of testing assets. Several advantages of the technology emerged:

- Sensitive to surface breaking cracks in various orientations.
- Capable of sizing depth and length with a depth sizing accuracy of 10 - 20%.
- Dynamic lift off and permeability compensation eliminate the need for stripping or sand blasting.
- Repeatable results within ±0.1 mm (0.004 in.).

Inspecting for cracks in welds

Sharck probes are used in the field since 2014, with nearly 200 units deployed in the oil and gas and power generation industries. Thousands of welds have been successfully and efficiently inspected on such components as bullet tanks, refinery piping, storage tanks and wind turbines with an excellent track record, notwithstanding the sometimes very hostile environments where they were deployed.

In 2016, it became clear that TECA technology could be used on pipeline networks, not only to address SCC colonies appearing on ageing lines, but also cracking on welds. With its individually spring-loaded fingers, the butt weld Sharck probe can easily conform to any kind of weld (girth, seam and spiral) and adequately cover the cap, toe area and HAZ (approximately 20 mm [0.79 in.] on each side) in a single pass. Being capable of 200 mm/sec. (8 in./sec.) scans, TECA proved the most efficient NDT technique, capable of accurately detecting and characterising surface breaking cracks in pipelines welds (down to 7 mm [0.28 in.]) – a game changer for the industry.

The technology was taken in-ditch for further testing in North America and Europe. The first series of tests mainly focused on girth and seam welds. Figure 3 shows a side by side comparison between LPI and TECA results taken on a 508 mm (20 in.) girth weld.

The similarities between LPI and the indications in the C-scans are impressive. All the cracks were easily detected by both techniques. The added value of TECA come from the fact that it not only detected the cracks, but they were immediately characterised and sized without the need for further measurement or grinding. The deepest fatigue cracks were also sized afterward on the same weld with UT to compare with TECA. The results were similar, with only a few tenths of millimetres of difference in depth sizing. On isolated cracks such as these, the reliability and accuracy of UT and TECA are comparable. However, when taking into account the time to get complete results (less than a minute with TECA), the TECA technology offers a clear advantage. Moreover, the smallest crack detected with TECA was 5 mm long and 1 mm deep (0.20 - 0.04 in.) – a very impressive result given its location in the weld toe.

**Probability of detection study**

This allows us to discuss a probability of detection (PoD) study commissioned to the Welding Institute (TWI) a few years ago, to compare the results obtained with MPI to those obtained with TECA technology, and to assess its capabilities on samples with known defects.

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![Figure 3. LPI compared to butt weld Sharck probe scan data.](image-url)
The following details some of the conclusions from the study:

1. TECA detects more. MPI detected eight indications of 13 present, whereas the Sharck probe detected all of them.
2. TECA generates fewer false calls. MPI detected five false indications, where TECA detected none.
3. Overall, the time necessary to perform inspections with each method is equivalent, but post-inspection cleaning is necessary with MPI.
4. The PoD curve in Figure 4, obtained after testing, demonstrates that 12 mm (0.47 in.) is the value where the PoD is 90%, which was deemed excellent because, with MPI, the same PoD is reached on defects longer than 12 mm (0.47 in.). As Sharck probe elements are 12 mm (0.47 in.) long, this makes perfect sense.

Even if, to some extent, false calls depend on operators, the data collected with TECA technology decreases uncertainties during analysis thanks to the data mapping display. The results of this two year old study were obtained with the first generation of TECA probes. TECA technology has continued to improve accuracy, repeatability and assisted analysis tools, making the technology less user dependent and yielding an even better PoD.

**Inspecting for crack colonies**

During recent in-ditch inspections, operators used the high resolution Sharck probe to look for SCC colonies. With much smaller TECA elements, this probe yields a much higher resolution than the butt weld model – a major advantage given the size and the density of cracks generally present in colonies. The probe can accurately size cracks up to 3 mm (0.12 in.) deep and provide crack profiles along their length. This is useful information for operators working on pipeline integrity assessment. The probe’s resolution is 1 mm (0.04 in.) axially and 3 mm (0.12 in.) circumferentially, enabling the high definition C-scan display of colonies at scan speeds that can reach 600 mm/sec. (24 in./sec.) on pipes as small as 254 mm (10 in.) dia.

Figure 5 demonstrates how the TECA technology was capable of displaying colonies with a very high resolution, which enabled locating almost every crack in the C-scan and precisely characterising each of them. This Sharck probe enabled discriminating very short cracks in SCC colonies (as short as 2 mm/0.08 in.) and the automated analysis tools clearly indicated the deepest point of each crack. Assessing the deepest point in a colony is critical, because it allows calculating the burst pressure for a given section of pipeline – a result that plays a crucial role in the pipeline’s integrity and safe operation.

The colour palette of the C-scan in Figure 5 was adjusted beforehand for cracks 1.5 mm (0.06 in.) or deeper to appear red. The deepest crack in the colony was 2.2 mm (0.09 in.) deep, while a few others were reported to be 1.5 - 2 mm (0.06 - 0.08 in.) deep. These results were obtained without extensive surface preparation, but corrosion can affect the eddy current signature of defects, hence depth sizing accuracy. The high resolution Sharck probe demonstrated an adequate ability to manage small amounts of corrosion, but when the corrosion gets too deep and severe, light grinding helped smooth the surface and enabled accurately measuring the remaining crack depth in pipeline walls.

**Conclusion**

In-ditch testing in North America (as well as Europe) has demonstrated that TECA can be an excellent complement to magnetic particle testing and ultrasonic testing, offering several benefits that they do not.

Based on actual inspection results, TECA technology demonstrated its capacity to mitigate potential errors caused by human factors and those from the unrepeatable results of current methods used in-ditch today. Unskilled technicians can also often jeopardise the results necessary to make critical public safety decisions. Questionable data quality from unrepeatable technology can create unnecessary doubt within integrity departments and reduce the effectiveness of in-ditch NDT if data must be validated multiple times.

TECA technology can, therefore, eliminate causes for errors and enable more informed decisions, offering a truly integrated and efficient solution for crack inspection on pipelines.