New Pig for Gas Pipeline Crack Inspections –
Enhancements Derived from 5 Years’ Operational Experience

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Abstract

This paper will summarize the evolution of the EMAT technology since GE’s initial product launch in 2002. A key focus of this paper will be outlining several tool and analysis enhancements that result from the evaluation of over a 1000kms of EmatScan CD pipeline inspection and 250 field confirmations. These tool and analysis enhancements are now incorporated in GE’s new 30 inch Third Generation EmatScan (Gen III EMAT) In Line Inspection (ILI) tool.

Introduction

GE delivered its first EmatScan CD Tool for 36 inch diameter pipelines in 2002. This experience was the subject of papers delivered at IPC in Calgary 2002, 2004[1], [2]. Locating most of the key crack features identified earlier by the benchmark UltraScan CD tool, the initial launch inspection was considered a success. Further inspections, however, encompassing a larger sample set of the pipeline population and variation in pipe conditions and environment, demonstrated limitations to the design which would prevent the tool from achieving the expectations set by the historical performance of the UltraScan CD technology. The 36 inch EmatScan CD has now completed over 1000kms of inspection with various operators in the US and Canada. The results of these inspections have been confirmed with over 250 field verifications.

This initial launch of EmatScan 36 inch has demonstrated the significant potential of the EMAT technology for use in inspection of gas pipelines without a liquid coupling and for location of a wider range of defects with better accuracy than the niche technologies of Transverse Flux Induction (TFI) and Elastic Wave respectively. By overcoming the shortcomings of this first generation, EMAT presents for a pipeline operator a financially superior option to hydrostatic testing. To provide this opportunity to its customers, GE is expanding its EmatScan CD tool fleet to include 24 – 30 inch pipe diameter capability.

The new tool is not a scaled copy of the existing 36 inch tool. In the design process used, GE followed its Design for Six Sigma (DFSS) methodology, which includes an understanding of the “Voice of the Customer” (VOC) as the initial step, and a rigorous Tollgate Review process throughout the life of the project.
This methodical approach mandates that the new design incorporates the lessons learned from operational experience and guarantees that the tool delivers an enhanced set of performance requirements which were quantified up front by pipeline operators. The project effort has leveraged GE’s breadth of internal expertise as well as that of its university partnerships. The project is managed by the Ultrasonics Center of Excellence based in Stutensee, Germany, with experts from its Sensors Group based in Cramlington, UK, sensor designers from GE Sensing in Cologne, Germany, scientists from the GE Global Research Center (GRC) in Schenectady, NY and developers from the Forschungs-Zentrum in Karlsruhe, Germany making significant contributions.

The results of this project, which will be discussed further, demonstrate that the challenges have been overcome, the targets have been achieved, and the tool will deliver the information the pipeline operator needs to conduct an effective Pipeline Integrity Program.

**EMAT Principle Refresher**

Conventional ultrasound generation technique utilizes piezoelectric transducers in which the ultrasound wave pulses are generated by a crystal element and led into the pipe wall via a coupling liquid. In contrast, Electro-Magnetic Acoustic Transducers (EMAT) are dry-coupled. For transmission into the pipe wall, an alternating current in a wire induces an eddy current in the metal surface. When this is combined with a static magnetic field, a force is produced which causes the steel metal grid to oscillate, thus launching a guided ultrasonic sound wave in the pipe wall.

Breaks in the homogeneity of this metal grid (i.e. defects such as cracks) will result in reflections of the sound wave. These reflected waves encountering the magnetic field will generate an eddy current, which in turn, induces a current in the wire. This current forms the received signal, which can be further processed and analyzed. The signal’s characteristics and its time of receipt, when combined with that of other sensors, provide accurate information about the feature’s size, depth and location. Figure 1 shows the concept.

The following are key requirements for EMAT sensor operation and issues that present challenges to the implementation:

- A magnetic field must be applied in the steel
- The transducer coil must be very close [approx. 1mm] to the surface of the steel plate during the inspection, and
- The receiver must be extremely sensitive
Fig. 1: Operating principle of EMAT sensors for pipeline inspection

By mounting sensors on a sensor carrier, oriented circumferentially to the pipeline axis, the emitted sound waves travel circumferentially in the pipe. In contrast to the UltraScan CD tool, which generates 45° vertical shear waves, the EmatScan CD tool uses guided waves e.g. horizontal shear waves and Raleigh waves.

EmatScan Gen I/II Areas for Improvements

During prototype testing of the original EmatScan CD 36-inch tool, it was determined that the technology delivered the target specification, but this result was limited to light and uncoated pipe. This work identified the influence of coating type and thickness, adherence of the coating to the pipe wall, and soil cover on the attenuation of the EMAT signal as it traveled through pipe wall. The next generation would need to meet specification in all coating types.

A positive side to this discovery, Software Engineers utilized the influence of coating on signal strength and implemented analysis tools to display changes in signal attenuation in a C Scan view. This gave analysts the ability to identify areas of coating disbondment. Gen III EMAT would be tasked to provide advanced maps and better visualization to aid the analyst in this coating condition assessment.

Another operational challenge encountered in the initial inspection was high wear of sensor surfaces from girth welds and pipe surface due to the dry coupling environment. Extensive testing in the lab did not accurately simulate the harsh wear conditions of a real pipeline. An improved wear material was implemented to extend the inspection range of the tool, but impacted the sensitivity of the sensor by introducing extra background noise into the pipe wall. Optimal wear material for both inspection range and sensor sensitivity would be a major requirement for Gen III EMAT.

A final area of enhancement for the Gen III EMAT tool came from the results of the 250 field verifications completed from the EmatScan 36” tool. The analysts...
would need more information from the tool to tighten confidence limits on making feature classifications.

**EmatScan CD Gen III Enhancements**

Geometrical challenges posed by the smaller pipe diameters targeted by this project dictated a scope large enough to allow for consideration of significant design changes from the existing 36-inch tool. This wider scope, while increasing project delivery schedule and associated budget, freed the designers from the constraint of an existing design, and ensured a solution that was more than a simple incremental improvement.

Results of the “Voice of the Customer” surveys and a Quality Function Deployment, which translates customer requirements into quantified specifications, focused the targets for improvement for the new tool in 4 key areas:

| POD (Probability of Detection) | Stretch the capabilities to include 1mm minimum depth detection in all pipe areas and coating types. |
| POI (Probability of Identification) | Provide enhanced information to the analyst, simplifying the process of distinguishing between injurious and non-injurious features. |
| Reliability | Implement an increased level of redundancy. |
| Speed | And at a faster tool speed. |

**POD**

The key to POD is Signal to Noise ratio (SNR) which when maximized, allows for the processing of the key reflected signal, and ignoring the background noise. Several factors play in determining SNR. The first is the strength of the reflected signal compared to background. Since pipe coating has an attenuating affect on the signal as it travels in the pipe wall, sensor spacing in the circumferential direction was considered. Here, a trade-off is required. The closer the receiver is to the reflector, the stronger the return signal will be. Therefore, this closeness dictates an increase in the number of sensors arranged on the circumference. An opposing phenomenon - the entire signal is not reflected by a feature - allows the unreflected portion of the wave to travel further through the pipe. This wave is then affecting the signal of neighboring sensors. This increased density has diminishing returns because increasing noise is detected from other sensors or an overly complicated firing sequence must be devised to limit noise from neighboring sensors. A series of Design of Experiment (DOE) tests were conducted by the Sensor Group, and the optimal sensor spacing was selected.
ensuring significant signal strength, yet limiting extraneous noise from surrounding sensors. Figure 2 demonstrates the concept of optimal sensor spacing. The Gen I/II 36” sensor concept is based on a three-sensor arm design per carrier staggered on a total of four carriers. With the Gen III design an additional sensor arm per carrier is added and the number of total carriers increased by 50% to six in total. A schematic view of all sensor blocks staggered on six sensor carriers is given in the right image of Fig 2. A – D indicating sensor arms on carriers 1 to 6.

![Sensor Carrier Diagram](image)

**Fig 2:**
left: 3 sensor blocks per carrier - Gen I/II 36”
mid: 4 sensor blocks per carrier - Gen III 24” to 30”
right: schematic view of all 24 sensor blocks of main detection sensors evenly distributed around pipe circumference - Gen III 24” to 30”

A second key to POD is selection of important wave characteristics. The modeling work conducted by the Global Research Center provided the Sensor Group the basis to identify appropriate characteristics from the waves which could be used to develop accurate transfer functions describing the pipeline features as a function of the signals reflected.

A comprehensive set of pipe samples were produced containing machined defects (notches) for testing various aspects of the tools performance. Data was collected from these by pulling through a fully assembled sensor carrier, including the operational electronics.

Figure 3 shows a B-scan data from a helical array of defects 1mm deep and 50mm long, spaced 30mm circumferentially. The pipe was bitumen coated. The data is from a clockwise and a counter clockwise firing sensor. From the number of notches detected, the optimal sensor spacing can be determined based on receiver listening window.
Figure 3  B-scans for a clockwise and a counter clockwise firing sensor from a helical array of 1mm deep x 50mm long defects

Figure 4 shows a typical defect set that is used for developing a depth sizing model. The defects are all the same length (50mm) and have depths (from left to right) of 5.0mm, 4.0mm, 3.0mm 2.5mm, 2.0mm 1.5mm, 1.0mm and 0.5mm. The pipe is tape coated. The image shows the B-scan for all the sensors that have detected this defect set, eight in total. The 1mm x 50mm deep notch is detected by all sensors, and the 0.5mm x 50mm is detected when it is at close range.

Figure 4  B-scan images for all sensors detecting the ‘depth sizing’ set of notches in tape coated pipe

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For certain combinations of coating types and pipeline environments Stress Corrosion Cracking (SCC) principally occurs in the toe of the long seam or immediately adjacent to it. For this reason it was essential that the same detection performance could be achieved in this region as for the pipe body. Figure 5 shows data collected from a depth sizing set (all defects 50mm long and depths from 0.5mm to 5.0 mm) where the notches are machined in the toe of the seam weld. The pipe was bitumen coated.

Figure 5  B-scans for depth sizing set in seam weld in bitumen coated pipe

POI

POI is affected by the selection of the sensor type. Sound waves are often depicted in A scans as simple peaks. A study of sensor types by the Sensor Group demonstrated that different sensor types generate complex and unique wave forms which react differently to the same feature in the pipe wall. Evaluating the unique reactions of these sensor types forms the basis for a critical transfer function which describes a feature type in a very exact manner. Leveraging the knowledge from over 250 dig verifications, the Sensor Group
could focus its efforts on the most challenging feature classifications for the EMAT technology. Having at its disposal pipe spools from earlier EmatScan 36-inch inspections which contained both injurious and non-injurious features, GE could confirm the transfer functions with results that extend beyond the standard machined defects often used in prototype work. Figure 6 shows the results of data collected from excavated pipe which contains both SCC and laminations. Note the very clear segregation between the two feature types. This clarity provides the analyst with crucial information, removing any doubt in a classification. The benefit to the customer is fewer misclassifications and more consistency between analysts, plus Software techniques automating the classification with reduction in analysis cycle. The calculation of the POI for this data set when normalized to reflect a similar population of features represented by the 250 verified field features equates to a most probabilistic value of 81%.

Figure 6: Discrimination of pipeline anomalies achieved via sensor signal processing

Reliability

Many challenges exist inside the pipeline so redundant systems have to be in place to overcome any unforeseen issues. On the new 30-inch EmatScan CD tool, additional redundant sensors of each type have been placed on the tool. As mentioned earlier, increasing sensor density increases background noise, so the additional sensors have been packaged in duplicate sensor carriers and spaced outside the interference distance. This increase in the quantity of sensors not only compensates for sensors that may be damaged during an inspection, but also provide redundant feature information, which improves the confidence of the feature existence, classification, sizing, and location.

Each sensor carrier is equipped with its own drive electronics, signal processing and data storage capacity. The pressure vessel and suspension systems have

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been designed to allow passage of large, unbarred T sections and negotiation of 1.5D bends. A pendulum has been placed in each of the sensor carriers as well to allow for a better compensation in mechanical play between sensor carriers. This is a critical requirement for resolving feature location seen by multiple sensors. An additional benefit is a higher run reliability and a greatly reduced chance a re-run will be required.

The final major area of reliability improvement is in sensor wear plate selection. Canvassing the metallurgical experts at the GRC, the project team selected three potential materials candidates. After extensive lab tests failed to rule out any candidates, a live test in a 100km pipeline was conducted. All 3 materials proved successful in the wear trial, meeting the wear tolerance specified for the test. This outcome allowed the team to pick the material based on impact to SNR rather than wear characteristics.

**Speed**

All POI and POD testing has been carried out via pull tests where the target speed has been achieved. The results, which have been demonstrated in earlier sections, confirms that the tool can operate in the range of 0-2.5 m/s. The benefit to the customer is the tool is in the pipeline for a shorter period of time therefore disruption to normal operations is minimized.

**Additional Enhancements**

**Modularity**

Additional information from the “Voice of the Customer” surveys indicate that tool length is also a concern, but to a lesser degree to the previously mentioned target areas. Taken this into account, the tool has been built with modularity in mind. As seen from Figure 7, tool length can be easily adjusted depending on the customer’s emphasis on tool length versus pipeline length and even redundancy requirements.

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Detection of coating disbondment

SCC is a main threat to the pipeline integrity of many gas pipelines. But waiting to find SCC may not be soon enough to efficiently manage the pipeline’s integrity. Therefore it is important to provide information on factors that can lead to SCC formation. One such factor is coating disbondment.

As mentioned earlier, sound waves pass through the pipe wall. The term transmission signal is used to describe the signal that is transmitted by one sensor and received by another remote sensor. The external coating plays a major role in attenuating the signal as it transmits through the wall. An area where the coating is less tightly bonded has a lower attenuation effect on the signal. Comparison of transmission signal amplitudes from various signals allows for the calculation of an attenuation map corresponding to the pipe surface. Changes in attenuation indicate differences in bond integrity of the pipe coating.

An example of an attenuation map correlation with disbanded tape coating is displayed in Figure 8.

![Correlation of Attenuation Map](image)

The improvements to the Gen III EMAT have enabled a high-resolution attenuation map of the pipe surface to be constructed, with the attenuation map being synonymous with a map of the coating condition. Advanced algorithms have been devised to combine this data, eliminating channel-to-channel variation and correcting for the presence of the long seam. Figures 9 and 10 show coating holidays introduced into a Polyken® coated test spool and the attenuation map from this test spool.
Figure 9 & 10  Schematic (left) showing location and size of coating holidays in test pipe and attenuation map (right) showing detection of these coating holidays

Safety

ATEX certification is now a requirement for ILI inspections in EU countries. The code addresses safety issues presented during launch and receive activities by applying additional levels of redundancy and fail safe mechanisms to the tool and dictating safe field practices. An ATEX certified tool implies not only that the tool design is certified to meet the ATEX requirements, but also the company demonstrates sufficient rigor in controlling operational and maintenance processes that guarantee the tool’s certified condition after commercial launch. GE is delivering the new EmatScan 30-inch tool with its full ATEX certification.

Conclusions

Meeting the harsh environment inside an operator’s pipeline is a challenging undertaking. Only through a rigorous and methodical approach is it possible to deliver an inspection vehicle that will successfully manage all the challenges. Using the GE standard DFSS approach for New Product Innovation (NPI), which requires incorporation of input from the customer and operational lessons learned, the EmatScan project team has worked systematically and logically through all design challenges and meeting or exceeding the targets, mitigating all the key risks associated with NPI. The result is a new tool, a new generation, which is ready to meet that challenging environment and deliver a superior service for the pipeline integrity manager. The benefit to gas operators is true crack management without the need of a liquid batch or hydrotest.
EmatScan CD is ideally suited to the detection of:

- SCC colonies
- Sub-critical SCC
- Longitudinal-oriented fatigue cracks, toe cracks
- Cracks in or adjacent to the long seam weld
- Lack-of-fusion cracks
- Coating disbondment

**Key Features of the Gen III EmatScan 30” tool**

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* base material and seam weld for all coating types

**References**

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