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RELIABLE DETECTION OF SCC AND OTHER CRACKS IN GAS AND LIQUID PIPELINES

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PII

Abstract

Cracks and crack-like defects in pipelines can have a serious impact to integrity of pipelines, and in addition they are very difficult to detect. Crack detection has relied mostly on hydrostatic testing and digging on random or predicted locations, both expensive and unreliable methods. Few years ago, an in-line inspection (ILI) tool for detection of cracks and crack-like defects based on liquid coupled ultrasonics, the UltraScan CD, has become available. Pipelines, both carrying liquid and gas, in excess of 3,000 km have been inspected using this technology, and its performance has been thoroughly assessed.

In this presentation, the principle of operation, specifications and performance of the tool will be laid out. Results of inspections along with the according verifications and performance assessment will be shown. Operational aspects and overall benefits of applying this crack detection technology will be discussed as well. Also, other options for internal crack detection and the present status of developments and research in this field will be briefly touched on. In particular a new development, the EmatScan CD, will be presented: the principle of operation of EMATs and how the concept is been applied to in-line inspection of cracks in gas pipelines. Expected performance of the tool and advantages of this particular concept will be discussed.

Introduction

Cracks as a problem

Cracks in pipelines are among the most severe and potentially dangerous defects in pipelines. In particular stress corrosion cracking (SCC) has already caused a significant number of service failures in gas pipelines as well as in crude oil pipelines all over the world[i]. In some cases failures have occurred, especially in gas pipelines, after only a few years of operation. SCC is generated under the influence of internal pressure, a corrosive environment, all combined with a particular microstructural susceptibility found in some pipeline steels. The mechanisms of SCC initiation and growth are still not fully understood and are the subject of ongoing research. SCC can occur in various forms from small isolated cracks to large crack fields (colonies) containing hundreds of cracks[ii]. SCC is usually found on the external pipe surface and, like fatigue cracks, longitudinally oriented.

But other types of cracks and crack-like features can be equally detrimental to pipeline integrity and can lead to catastrophic failures as well. Fatigue cracks, lack of fusion and other types of cracks in and at the long seam weld, to name but a few, have all been known to cause ruptures both in liquids and gas pipelines.

The most widely used tools of in-line inspection (ILI) of pipelines (known as “smart” or “intelligent pigs”) have been the metal loss (corrosion) tools, both ultrasonic and magnetic flux leakage (MFL) ones. However, event though the technology of corrosion detection has evolved in recent years, these tools are incapable of detecting cracks and crack-like defects.

Solutions

For a long time, the use of hydrostatic testing was considered the only reliable way to prove the integrity of a pipeline that was a candidate for SCC. This type of test is expected to remove all critical cracks, i.e. cracks that could cause failure under normal operating conditions. However, since no information on sub-critical cracks is obtained, the estimation of the safe future service life becomes rather uncertain. Additionally, hydrostatic tests are expensive and time consuming, as the line has to be taken out of service.

Another approach to finding SCC in pipelines relies on predictive models and investigative excavations. The effectiveness of predictive models (soils models) for finding sites thought to be susceptible to “significant” SCC depend on a number of parameters thus making this method unsuitable for detection and prioritization of SCC.

The crack detection tools described here are in-line inspection tools (“smart” or “intelligent pigs”) developed with the goal to reliably and accurately detect cracks and crack like defects in pipelines. Since the tools provide much more detailed information on the state of cracks in a pipeline, their usage is a powerful replacement of hydrostatic testing and other historic approaches. The information obtained from an inspection run with the tools will not only reveal the critical cracks, but also cracks as small as 1 mm (0.040 in.) deep and 30 mm (1.2 in.) long, thus enabling prioritization and growth monitoring.

Both crack detection tools described here are based on ultrasonics since ultrasound enables in-line detection of external as well as internal cracks with the necessary sensitivity and high resolution. Since most cracks and crack–like defects, like fatigue cracks and SCC for example, are generally oriented perpendicularly to the main stress component, i.e. hoop stress, the ultrasonic pulses propagate in a circumferential direction in order to obtain maximum acoustic response. The major difference between the tools described here is in how ultrasound in the pipe wall is being generated.

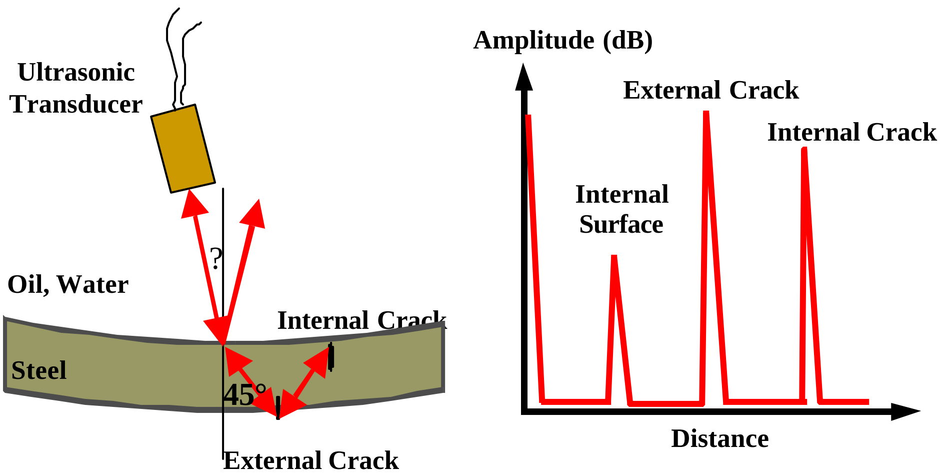

Figure 1 Detection geometry (left) and corresponding A-scan (right)

UltraScan CD

Principle of Operation

The technique applied uses shear waves, which are generated in the pipe wall by angular transmission of ultrasonic pulses through a liquid coupling medium (crude oil, diesel, kerosene, etc.). The angle of incidence is adjusted such that a propagation angle of 45° is obtained in the pipeline steel. This technique has been proven for crack inspection and it is established as one of the standard techniques in ultrasonic testing[iii].

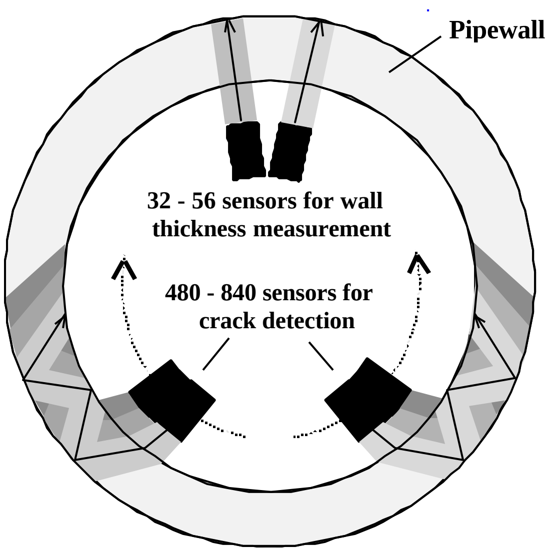

Figure 2 Sensor arrangement for ultrasonic crack inspection

A schematic representation of the detection principle is shown in Figure 1.

The sensor carrier of the crack detection tool is designed such that the complete pipe circumference is uniformly scanned in both clockwise and counterclockwise directions using 240 - 840 (for pipe diameters 16” to 56”) sensors for crack detection (Figure 2). This arrangement provides multiple coverage to ensure that relevant reflectors are detected by several, up to ten, sensors. Additionally two sensors per skid serve to continually measure the actual wall thickness and to detect girth welds, the latter information being used both to produce pipe tallies and assist locating defects as precisely as possible with respect to the nearest girth weld. All sensors are mounted in a highly flexible polyurethane carrier, in order to maintain them at a constant distance from the pipeline wall and at a defined angle of incidence.

Tool Layout

Important technical data relating to the tool is listed in Table 1. The tool is designed to detect longitudinally oriented cracks or crack-like defects at any location in the pipe body wall. Particular emphasis is placed on the longitudinal weld zone that is recognized on-line and all the information from the two sensors detecting it from both inspection sides is stored completely. The tool provides axial resolution, of approx. 3 mm (0.12 in.), at inspection speeds up to 1 m/s (2.2 mph). At higher speeds the axial resolution changes, however, even at speeds up to 2 m/s (4.5 mph) it is still better than approx. 6 mm (0.25 in.).

The UltraScan CD has successfully been used for inspection of girth welds as well. For that application, the sensor carrier was modified such that crack detection transducers (the angled ones) were rotated by 90? to launch ultrasonic waves into the wall in axial direction.

After an inspection run is completed, collected data are pre-processed taking advantage of built-in detection redundancy, thus considerably reducing the amount of indications to be looked at by the interpretation group. The evaluation of the data is performed on personal computers using advanced data visualization software. After completion of data interpretation a features list is compiled in a condensed form, containing all relevant indications. Special features are fully documented including colored images of the corresponding ultrasonic B- and C-scans along with precise information on the location of any defects. The final report includes a features list, fully documented features and a complete pipe tally with full information on each individual pipe joint (distance, measured wall thickness, pipe length, location of longitudinal weld, etc.).

TABLE 1 TECHNICAL DATA OF THE CRACK DETECTION TOOL

Detectable defects	*SCC, fatigue cracks, longitudinal crack-like defects, LW imperfections, lack of fusion*
Defect orientation	*longitudinal (? 15°)*
Defect location	*internal, external base material & longitudinal weld*
Minimal detectable defect length (isolated defect)	*30 mm (1.2")*
Minimal detectable defect depth	*1 mm (0.04")*
Number of sensors (depends on pipe diameter)	*256 – 896 (240 - 840 for crack detection, 32 - 56 for wall thickness measurement)*
Circumferential sensor spacing	*approx. 10 mm (0.4")*
Axial resolution	*approx. 3 mm (0.12")*
Inspection speed	*? 1 m/s (2.2 mph) recommended (higher speeds possible)*
Sizes	*22" - 56" (from 16" up soon)*
Maximum inspection distance (Single run)	*approx. 100 km (63 mi.) to over 300 km (190 mi.) (depending on pipe size and inspection speed)*

Performance

The crack detection tool has to-date successfully inspected over 3,000 km (1,900 mi.) of operational crude oil and gas pipelines. The defects that have been detected range from SCC, fatigue cracks, longitudinal weld imperfections, very narrow axial corrosion, to notches and scratches. In order to facilitate ultrasonic coupling in the gas pipelines that were inspected, the tool was run in a slug of water (the performance of the tool has already been proven in crude oil and diesel, but other liquids can also be used)[iv,vvi].

Detection Accuracy

The sensitivity of the detection method has been tested extensively. It has been found that the tool, designed to detect cracks above 2 mm (0.08 in.) deep and 30 mm (1.2 in.) long, exceeds the design specifications. A significant number of cracks as well as internal and external notches with depths from 0.5 mm (0.02 in.) upwards, located in the weld area and the base material, were reliably detected. Typically, individual defects with a depth of 1 mm (0.04 in.) are detected by three to six sensors, in some cases by as many as ten sensors all dependent upon configuration and location of the defect[vii].

An example demonstrating the sensitivity of the tool is given in Figure 3. The C-scans show SCC damage with depths even below the detection threshold as detected in two subsequent inspection runs. On the C-scans, the longitudinal welds as well as indications from SCC can be matched with impressive exactness. The amplitudes of these indications are below the design criteria. Nevertheless, even such minor reflectors were reproducibly detected by the tool and properly classified during subsequent off-line data evaluation.

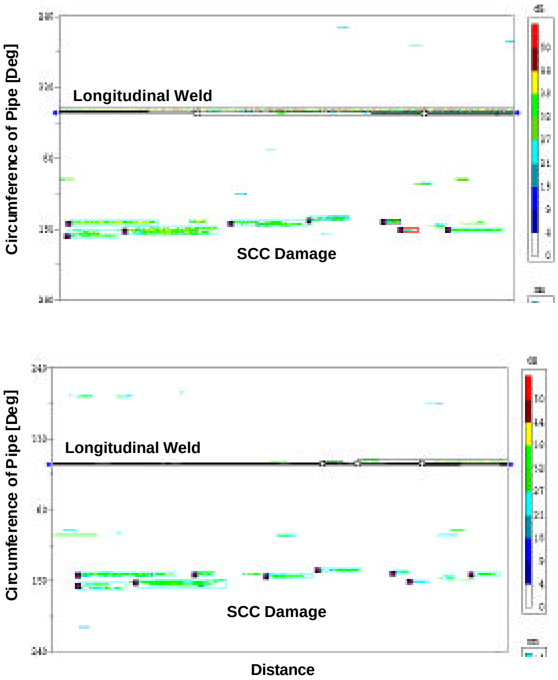

Figure 3 Comparison of C-scans from the same pipe joint recorded during two separate runs (24" crude oil pipeline).

Identification Accuracy

Given the high sensitivity of the tool, a range of different types of reflectors in the pipe wall is being detected. A very important step in the process of data evaluation is discrimination of various types of defects, specifically distinguishing defects potentially damaging from those safe to the pipe.

The detection method, given the high sensor sensitivity and density both in circumferential and axial direction providing high data redundancy, allows for positive differentiation not only between external, internal and even mid-wall defects, but also between different types of defects. In addition, the inspection fully covers the whole body of the pipeline, with no exclusion zones.

Figure 4 illustrates the identification accuracy in detecting a SCC colony. The C-scan on top depicts the cracks as detected by the tool, and the magnetic particle image of the same area on the bottom not only confirms the presence of cracks, but also shows that their distribution is as predicted by the tool.

As opposed to cracks and crack-like defects, non-injurious defects exhibit different patterns and the overall information given by the tool is such that discrimination can positively be made. In Figure 5, a C-scan of a transition from a relatively inclusion free pipe joint (left-hand side of the scan) into a joint full of inclusion (right-hand side of the scan) is shown. It can be seen that some of the inclusions in the picture are at the girth weld thus illustrating that there are no exclusion zones for this tool. The C-scans at the bottom show the results of the wall thickness sensors indicating the location of the girth weld.

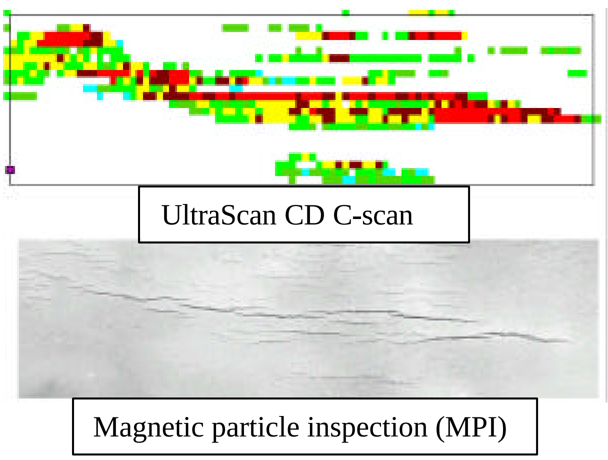

Figure 4 SCC colony in a 56" gas transmission pipeline – matching of findings of the tool and field verifications

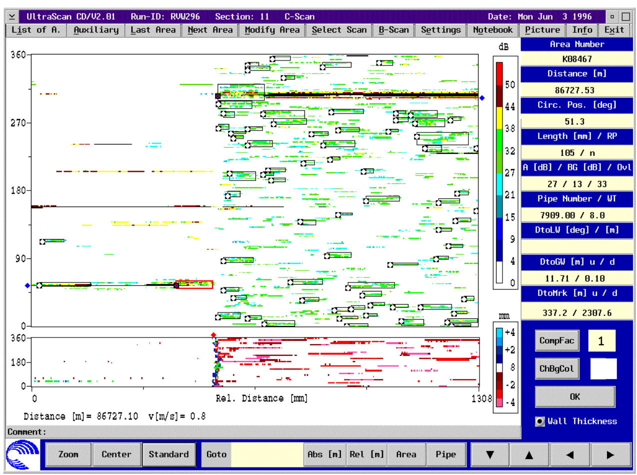

Figure 5 C-scan showing a pipe joint relatively free from inclusions (left-hand side of the scan) followed by a joint full of inclusions (right-hand side). Boxes indicate reflectors identified by the system to comply with certain preset criteria. Girth weld is visible in the lower box of the scan.

Sizing Accuracy

Excavations performed up to now have proved the axial defect location accuracy of the tool to be better than ? 100 mm (4 in.) relative to the nearest girth weld and the circumferential defect location accuracy better than ? 50 mm (2 in.) [viii].

Typical accuracy of defect length measurements for individual defects is ? 10 mm (1/4 in.) for defects up to 100 mm long and ? 10% of the length for longer ones.

The estimation of depths of detected defects that can be obtained from the inspection method depends on the crack size and other features within the detected signal, such as: detection signal overlap, shading effects and crack tip signal. In some cases, when the crack tip signal has been detected for example, the estimation of crack depths is possible with a precision of ? 1 mm (0,04 in.).

However, the detection and interpretation procedure is such that, even in cases where not all of the above listed features are found, a depth classification is feasible. As a result, depths of isolated cracks (or maximal depth in a colony) are given in categories:

< 12.5%	W.T.
12.5% - 25%	W.T.
25% - 40%	W.T.
> 40%	W.T.

Locations and sizing of the tool have been verified in over 200 excavations and all critical cracks indicated by the tool were confirmed. In all the excavations there were no false calls and all cracks predicted to be non-critical were also verified to be such[ix,vi]. Figure 6 shows results of defect depths measurements in the field for 40 features verified in a set of excavations on a 36 in. gas transmission line, compared to those estimated by the tool. Figure 7 shows comparison of measured to predicted defect lengths for the same 40 defects.

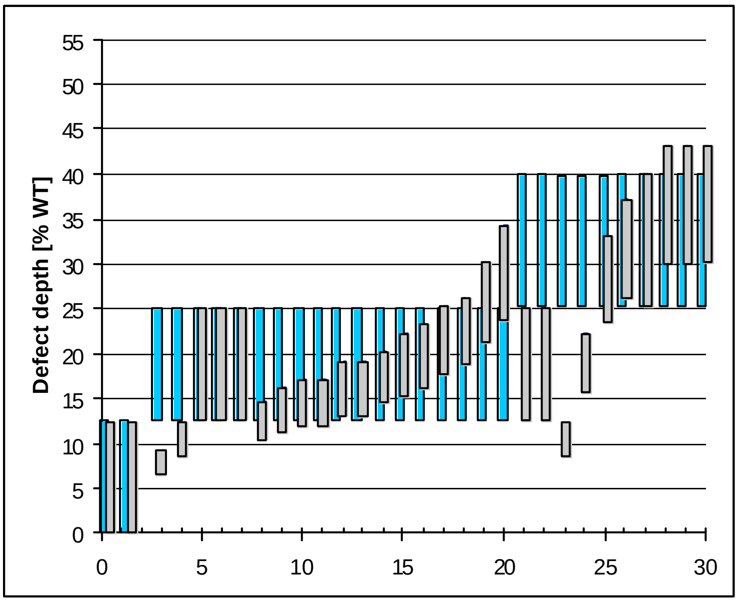

Figure 6 Depths of verified defects – tool predictions vs. measurements in the field:
- tool predictions (given in depth ranges)
- findings in the field – ranges indicate estimated inaccuracy of the measured value

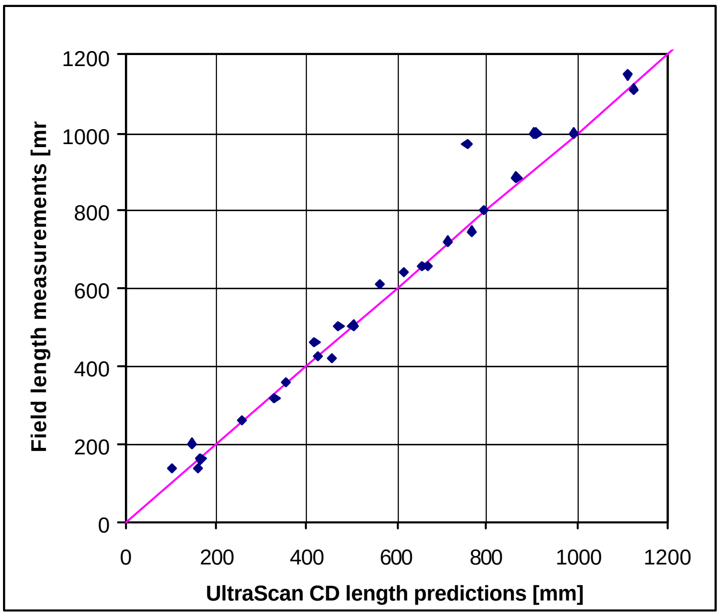

Figure 7 Comparison of defect lengths predicted by the ILI tool and measured in the field.

Hydrostatic testing

The performance of the tool was analyzed by comparing the inspection results to results of hydrostatic testing in a 56 in. gas transmission pipeline. A selected section was hydrostatically tested after the inspection run. Two ruptures occurred at locations where critical SCC was detected by the tool.

The results of the in-line crack inspection have a far greater information content than hydrostatic testing. Not only have all the cracks that had led to ruptures been detected, but also all the cracks from sub-critical down to still much shallower and shorter ones were revealed as well. This, in turn, makes it possible to prioritize the defects, allowing for a planned mitigation action, as well as monitor their growth by repeating the inspection after a desired time period.

In addition, hydrostatic testing may potentially be harmful to the pipe. As some research indicates[x], consecutive pressure tests lead, in case of ruptures, to repeated static loading, which in turn may cause the sub-critical cracks to grow, thus worsening the condition of the pipeline.

EmatScan CD

Principle of Operation

With liquid coupled ultrasonics (UltraScan WM and CD), ultrasonic waves are excited outside of the pipe wall using piezoelectric transducers, and launched into the pipe wall through a coupling medium (water, oil, etc.), as shown in Fig. 8a. The UltraScan CD is based on such transducers and can be operated readily in most of the liquids (crude, light oil, diesel, kerosene, etc.)

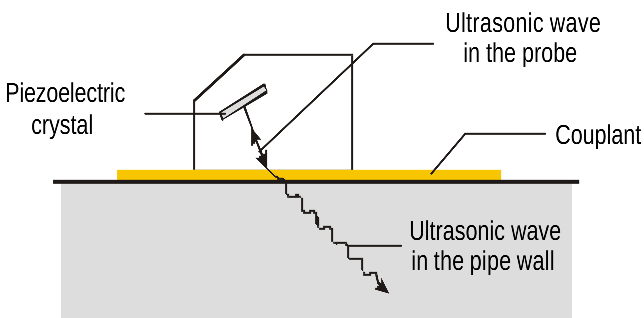

Figure 8 a Conventional ultrasonic transducers

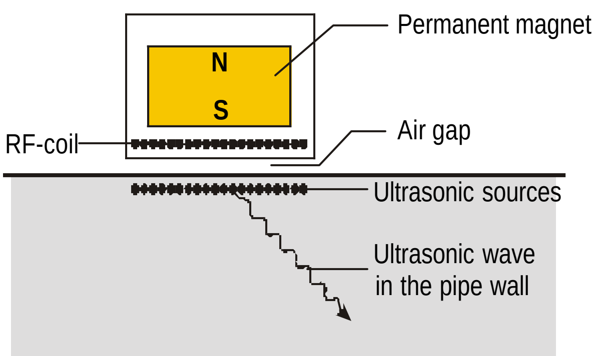

Figure 8 b EMAT

Electromagnetic acoustic transducers (EMATs), on the other hand, use electromagnetic fields to generate ultrasonic waves directly in the pipe wall (Fig. 8b). Since the source of ultrasound is in the pipe wall itself, i.e. there is no coupling of ultrasound to the pipe steel (like in the case of piezoelectric transducers), no couplants are needed and gas pipelines can be readily inspected.

The principle of operation of EMATs is shown in Fig. 9. A coil driven by a current at a certain frequency placed under a magnet at the internal surface of the pipe wall, induces Eddy currents $\boldsymbol{j}$ within the pipe wall. Periodic Lorentz forces $\boldsymbol{F}$ are created that act on moving charged particles in static magnetic field $\boldsymbol{B_o}$. These forces cause lattice collisions and other microscopic processes in the steel making them act as a source of ultrasonic waves. Reciprocal mechanisms also exist whereby waves in pipe steel can be detected in the coil at the surface of the pipe wall.

Practical EMAT transducers are more complex then just a coil and a magnet. Their type and configuration define the modes of generated ultrasound, which in turn define the characteristics of ultrasound propagation through the pipe wall

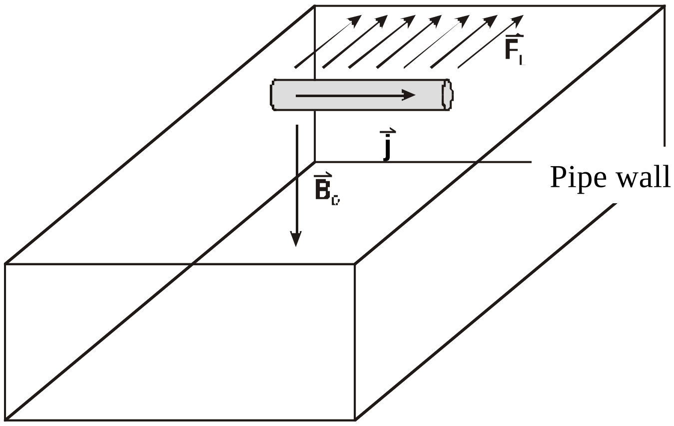

Figure 9 Basic principle of operation of EMATs

and suitability for inspection of pipelines and crack detection. Types and modes of ultrasound have to be carefully selected to allow reliable detection and sizing of defects.

The performance of an ILI tool and its performance limitations will depend on the choice of the detection principle, and the way in which it is applied in the rugged pipeline environment. EMATs have been used in different fields of non-destructive testing (NDT) but until now haven’t been used successfully for pipeline inspection.

Guided Shear Horizontal (SH) waves have such characteristics and propagation properties that make them the most appropriate for detection of cracks and crack-like defects in pipelines. The EmatScan CD is a new development that uses a unique combination of ultrasonic wave modes generated with EMATs. The properties of propagation of these waves are such that potential problems encountered in pipeline inspection are addressed, and that sufficient sensitivity, accuracy and reliability of detection can be achieved.

Tool Concept

Figure 10 shows schematically the concept of detecting axially oriented cracks using SH waves that propagate circumferentially through the wall of the pipe, perpendicularly to axial cracks.

The EmatScan CD is in its development phase and is being designed for inspection of the whole pipe body including the regions at the long-seam weld and the weld itself. Four EMAT transducers are deployed around the perimeter of the pipe to cover 360?of the circumference, operating in both pulse-echo and transmission mode. Another set of four transducers is mounted behind the first set, but rotated by 45? to cover its blind spots and provide redundancy.

The tool is being developed for pipe size of 36 in., but it will be modifiable for inspection of pipelines from 20 to 48 in. In order to be able to perform inspections in gas pipelines under operational conditions, the tool is being streamlined and optimized for minimal gas flow losses and maximum bypass.

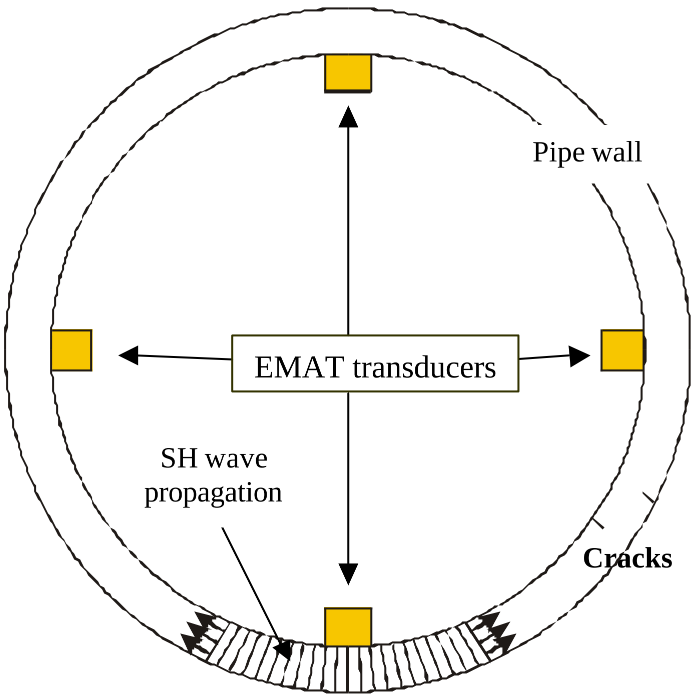

Figure 10 SH EMATs for detection of external and internal cracks and crack-like defects in the pipe wall

Experiments performed in the proof-of-concept phase were conducted to address the issues that might have an impact on the performance of the detection method when applied in the real pipeline environment. In particular, physical and geometrical characteristics of pipes (size, steel quality, coating, welds, changes of wall thickness, etc.), design and performance characteristics of EMATs (construction, detection range, repetition rates, power consumption, etc.), and operational characteristics (inspection speed, transducer lift-off, etc.).

Results

Tests with cracks from real pipelines and machined defects have confirmed that the SH wave is sensitive enough to detect cracks that are 30 mm long and 1 mm deep with a sufficiently high S/N (signal to noise) ratio to provide reliable detection in real pipelines. Combination of SH and other wave modes will be used for discrimination of external and internal defects and for crack depth classification. It was also found that non-injurious anomalies in pipe, like for example inclusions and laminations, could not be confused with cracks and crack-like defects.

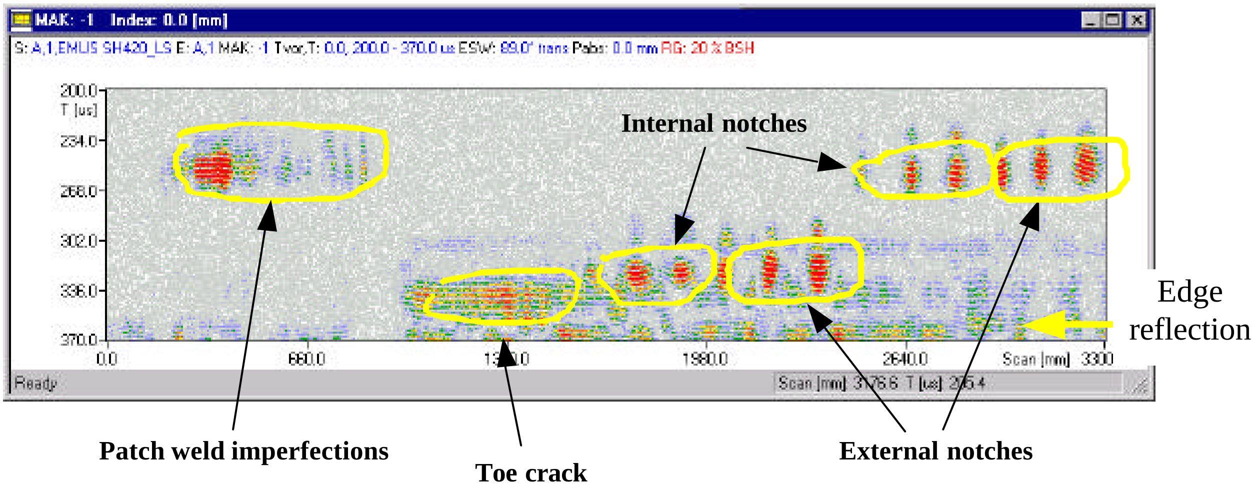

Figure 11 B-scan made with an SH EMAT transducer illustrating detected reflections and the corresponding defects.

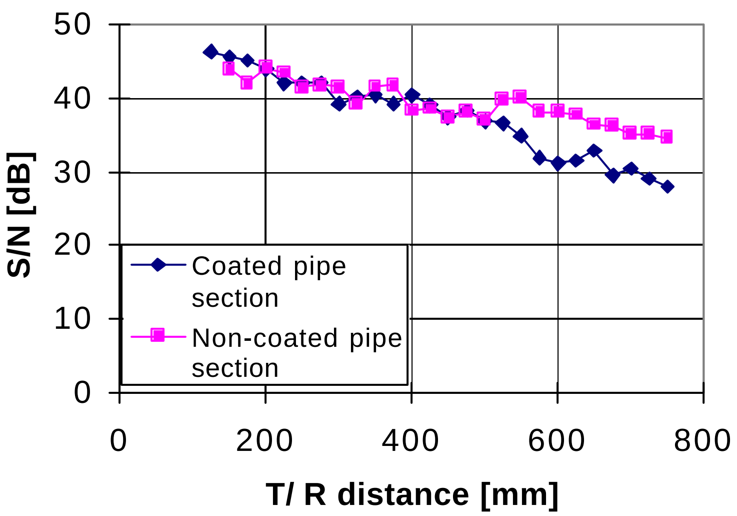

Figure 12 Attenuation of signal amplitude due to coal-tar coating.

Fig. 11 shows results from pull tests done with SH wave EMAT transducers on a segment of pipe taken from a gas transmission line. The segment contained some very shallow SCC and some machined notches for studying detection sensitivity, and the scanning was done in a pull test, allowing also studying dynamic behaviour of the EMAT transducers. It can be seen from the picture that all the defects can be clearly distinguished from the background of sound pipe and identified.

The suitability of SH waves for pipeline inspection is further illustrated in Fig. 12. The graph shows the dependence of the ultrasonic signal on the distance it travels circumferentially in the pipe. The curves show that the signal is only slightly attenuated by the presence of coating, a very important property of the used wave mode, since defects (e.g. SCC) are usually associated with disbonded coating, and its influence would negatively impact the sensitivity, accuracy, and ultimately the reliability of inspection.

Conclusions

Most reliable detection of cracks and crack-like defects is generally performed using ultrasound since even very tight cracks in steel cause significant reflection of ultrasound. The problem with ILI is how to produce ultrasound in the pipe wall. Two concepts have been established: liquid coupled ultrasonics, specifically suited for inspection of liquids pipelines, and EMAT based ultrasonics, for use only in gas pipelines.

UltraScan CD, the liquid coupled tool, has been in use since 1995, inspecting pipelines in the range of sizes from 24 to 56 in. Its performance has been verified and the results confirmed in numerous verification excavations. The detection principle and the inherent redundancy make it extremely reliable. Any other ILI tool will hardly surpass its sensitivity and accuracy as well as the ability to discriminate and size defects. It is readily applicable in most liquids pipelines, and can be used for inspection of gas pipelines only in a slug (batch) of suitable liquid. The technology is available in the range of sizes from 16 to 56 in., but it could be scaled down to sizes as small as 6 in.

EmatScan CD is a tool in development based on guided SH waves generated in pipe steel using EMATs. Prior to beginning building the tool, all potential problems associated with usage in the rugged pipeline environment have been thoroughly studied and addressed, and a tool is being built. It will be capable of detecting cracks from critical down to insignificant ones, allowing for early detection and mitigation and it is geared towards use in gas pipelines only. The development covers a range of tools from 20 to 48 in.

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