ULTRASONIC IN-LINE INSPECTION: HIGH RESOLUTION CRACK DETECTION FOR PIPELINES USING A NEW GENERATION OF TOOLS

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Abstract: More than three million kilometers of high pressure liquid and gas pipelines are installed all over the world. Generally steel pipelines provide the safest means to transport large quantities of oil, oil related products and natural gas. However, just like any other technical component, they can deteriorate. As a result flaws can appear and grow until the pipeline fails. The appearance of cracks, especially Stress Corrosion Cracking is of increasing concern. These flaws must be identified, before they endanger the integrity of the line.
This paper will introduce a new generation of high resolution inspection tools applying ultrasonic technology to detect, size and locate cracks and crack-like defects in the body and welds of transmission pipelines. These devices are pumped through the section of pipe to be inspected together with the medium being transported therein. They enable an inspection of the entire circumference and length of the pipe of up to several hundred kilometers in a single run. The paper will describe the non-destructive testing principles applied and introduce the major components of the inspection system, including the tool and defect specifications. The paper will also explain the data analysis process, including examples of data recorded by the tools.

Introduction: It is generally accepted that high pressure pipelines provide the safest means to transport large quantities of oil and natural gas. It must be understood, however, that pipelines are exposed to a variety of environmental influences and loading conditions. As a result flaws can appear and grow. One challenging category of flaws are cracks and crack like anomalies such as stress corrosion cracking or fatigue. In order to ensure the integrity of a line cracks must be detected, sized and assessed, before they reach a critical dimension which can eventually lead to a failure of the pipeline. Specialized inspection tools, usually referred to as in-line inspection tools or intelligent pigs, have first been introduced nearly 40 years ago to detect and locate pipeline anomalies such as dents and metal loss. From technical generation to generation these inspection tools have become more refined and sophisticated, incorporating better and better defect specifications. Present day tools have reached a level of sensitivity and accuracy that allows the inspection data obtained to be utilized for advanced fitness-for-purpose calculations and integrity assessments. Detailed information on the history, physical principles used, technologies, tools and vendors is available in the literature [1-4].

Ultrasonic In-Line Inspection Tools: Ultrasonic tools for the in-line inspection have first appeared in the early 1980`s. The mission of these tools was the detection and sizing of metal loss. Crack inspection tools first appeared in the middle 1990´s . The major advantage of ultrasonic tools is their ability, unlike the competing magnetic flux leakage tools, to provide quantitative measurements of the pipe wall inspected. Experience has also proven that only the use of ultrasound provides a reliable means to detect cracks and crack like anomalies in pipelines [5]. This paper will focus on a new generation of ultrasonic crack detection tools.

Ultrasonic inspection tools are in general fitted with a sufficient number of ultrasonic transducers to ensure full circumferential coverage of the pipe. They work in a pulse-echo mode with a rather high repetition frequency. Straight incidence of the ultrasonic pulses is used to measure the wall thickness and 45º incidence is used for the detection of cracks. While the wall thickness measurement is more or less established, in-line crack detection of pipelines has only been available for some years now.

In terms of data processing, ultrasonic tools represent one of the most challenging tasks in ultrasonic non-destructive testing. Several hundred sensors have to be controlled, their echoes have to be recorded, on-line data processing has to be able to reduce the amount of data recorded and ensure that all relevant data are stored. The inspection speed of the tool depends on the medium and may vary within a certain range. The inspection process has to be fully automatic and cannot be supervised during a run. The data are stored on solid state memories that are the safest and most reliable means of storing data in such a hostile environment. The distance is measured using several odometer wheels.

Hardware - Introducing The Tools: Some design elements have been proven successful in the past and have been maintained in the new generation. Others have been completely modified. Figure 1 shows a photo of the newly developed tools in a 24" configuration.

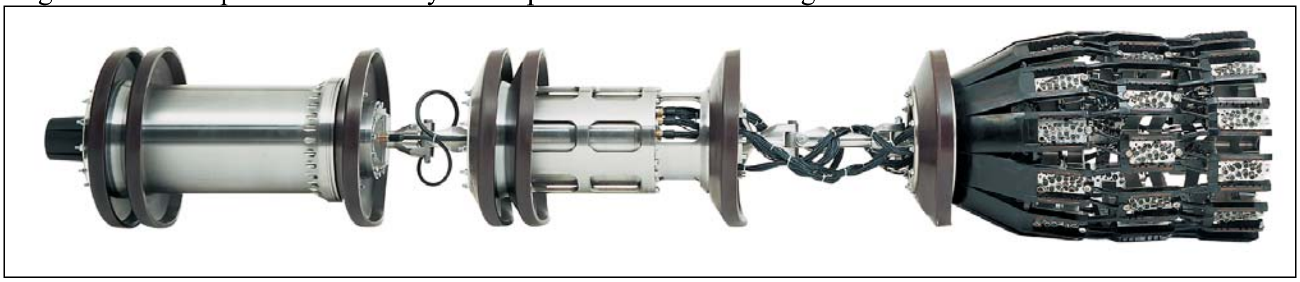

Figure 1 High Resolution Ultrasonic In-Line Inspection Tool for 24" pipelines. The tool is made up of two pressure vessels housing batteries, electronics, recording devices and a trailing sensor carrier housing the ultrasonic transducers.

The tool is made up of a number of pressure vessels and a trailing sensor carrier. The front of the tool is covered by a protecting bumper unit, covering the transmitter housing shown here. The individual pressure vessels are connected through universal joints which allow the tool to negotiate bends. The first body contains batteries ensuring a safe supply of power to the tool for up to several days. The electronic and recording unit of the tool is housed in the second vessel and incorporates enough channels to cover pipeline diameters from 20" to 42" for crack detection application. The sensor carrier is made of polyurethane and houses the ultrasonic transducers. To adapt the tool to a different pipe diameter the polyurethane cups are exchanged, which can be done quickly. Tools sizes to cover pipeline diameters below 20" are also available, the current smallest diameter for crack detection being 10".

In general there are two different sensor carrier designs for ultrasound tools. One for wall thickness or corrosion measurement and one for crack detection. The crack detection version, shown here, contains sensors orientated at a predetermined angle to the pipe wall which ensures that ultrasonic shear waves will travel under a 45º-angle within the metal. Figure 2 shows the arrangement of the ultrasonic sensors for crack detection. In order to avoid any blind zones in the vicinity of the longitudinal weld half the sensors are mounted in a clock wise orientation and the other half in an anti clockwise orientation. All sensors are mounted on metal plates. The polyurethane sled will ensure a constant stand-off.

Figure 2 The assembly for the crack detection sensors

The design will also have to ascertain that wax cannot clog the exposed parts of the sensor carrier. In the crack detection mode for this given diameter there will be 360 inclined sensors corresponding to a sensor pitch of 10 mm for either direction (clockwise and counter clockwise), together with 24 sensors for wall thickness measurement. These latter sensors are needed for the detection of girth welds, allowing a precise location of the defects. The sensor spacing is designed such that every part of the pipeline is covered by several sensors. Figure 3 shows the configuration of the ultrasonic sensors on the body of the sensor carrier for a crack detection sensor carrier.

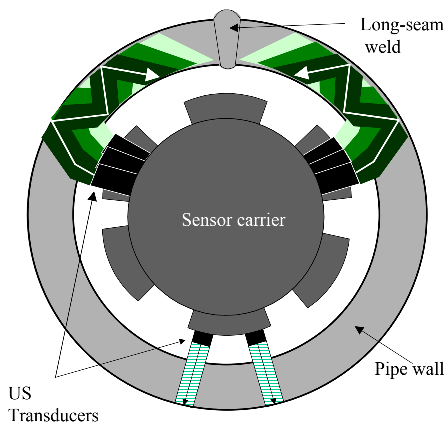

Figure 3 The configuration of the sensors in the crack detection version is such that every part of the pipe wall is measured multiple times from clockwise as well as counterclockwise direction.

Improvements Regarding Earlier Tool Types: When newly designing an ultrasonic inspection pig with the intention to remedy many of the problems of existing tools, there are several topics, where technological improvements were desired and have been accomplished.

The overall mechanical and electronic design of the tool is modular allowing adaptation for individual pipeline sizes through mechanical adaptation kits and corresponding sensor carriers. The components are designed in a modular way that will allow to use the same basic tool bodies for pipe diameters from 20" to over 40". Electronic boards can be used from 10" upwards. Only smaller diameters require special modifications. As a result adaptation of tools can be achieved in a short time. Although focusing on crack detection here, it has to be stated, that the design of the electronics make the tool suitable for crack detection as well as wall thickness measurement. This is a unique feature of this new generation of tools. For specific pipeline diameters the tool can even be configured to perform wall thickness and crack inspection simultaneously. In the past the data acquisition and processing technology for wall thickness and crack detection have been distinctly different from each other. Today there is no necessity for this handling. The ALOK data reduction implemented in the tools introduced here can be applied to the A-Scan generated during metal loss or crack detection. In the new tool generation it will only be necessary to change the sensor carrier to switch from one method to the other. All other changes are achieved by reparameterizing the tool. Another important issue in tool design is the system availability. Inspection pigs are inherently complex tools. In addition there is never a large number being built and thus most tools have some prototype characteristic. This is one of the reasons, why in-line inspection tools are not commodities but are maintained by a service vendor. For easy serviceability the new tool can be hooked up to the internet. This will allow to do service on the tool from a remote place. In addition a data analyst will be able to check the data via internet directly.

Tool Specifications Crack Configuration	
Recommended Velocity Range at Full Defect Specs	0.2 - 2.0 m/s
Maximum Wall Thickness	
Maximum Pressure	20 mm
Standard Temperature Range	120 bar
Tool Length	-10 to +50 °C
Tool Weight	appr. 4000 mm
Distance Range	appr. 750 kg
Axial Sampling Distance	300 km @ 1.5 m/s
Circumferential Sensor Spacing	approx. 3 mm
	approx. 10 mm
Defect Specifications Crack Configuration	
Defect Type	axial cracks and crack-like defects (e.g. SCC, fatigue cracks, weld cracks)
	30 mm
Min. length	1 mm in base material, 2 mm in long
Min. depth	seam
	<± 10°
Axial Orientation	<± 45°
Radial Orientation	± 10 mm for L ≤ 100 mm
Length Sizing Accuracy	± 10 % for L > 100 mm
	axial: ± 10 cm from nearest girth weld
Defect Location Accuracy	circumferential: ± 10°

Table 1 Tool and Defect Specifications for the 24" crack detection tool.

The new electronics design has also led to improved data processing power, in turn resulting in shorter processing times. This has a direct influence on the achievable inspection speeds. The inspection speed affects the possible production loss of the pipeline operator. It is desirable that production should not have to be throttled during an inspection. Therefore faster achievable inspection speeds will lower any production loss. Using the latest processor technology a pigging speed of up to 2 m/s for crack inspection is possible whilst fully meeting the defect specification. The maximum speed is constrained by the requirement to sample every 3 mm. This is a considerable increase. To summarize the capabilities of the tool Table 1 shows some general tool and defect specifications.

Data Analysis: Major steps forward have also been possible in the field of data processing and handling. Changes compared to earlier tool types can be categorized in the following fields. With regard to on board data processing several steps are carried out on the tool. The analog A-Scan is AD-converted and processed according to the ALOK algorithm [6]. In a next step, there is a crack detection algorithm that will determine which signals result from potential crack candidates, differentiating spurious from relevant signals and select them for storage. In addition, the position of the long seam weld is evaluated. The data is then stored in a more suitable format such that no time consuming data translation process is required. This means that the data retrieved from the tool can be directly loaded into a desktop or laptop PC for visualization or analysis.

Reporting: With the data quickly ready to analyze there is still a lot of work to be done. The actual analysis work was speeded up as well. Some of the post-processing steps like generation of a pipebook (girth weld list) and a defect search can be carried out in the inspection tool making use of its large computing capabilities. An artificial intelligent network will select defect candidates and reduce the number of indications to be manually checked. The display of the data will allow the analyst to quickly access the relevant portions of the data and enter conclusions. The actual compiling of the report can be automated using reporting tools that work on a centralized database.

Typical displays of cracks found with the tool are shown in the screenshots in Figure 4 and 5.

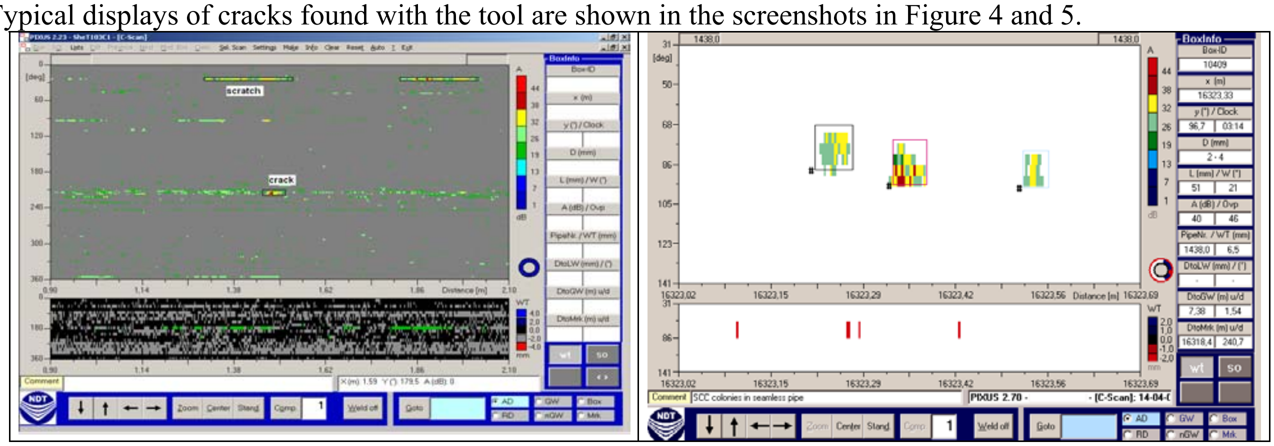

Figure 4 Typical display of a cracks (left) and stress corrosion cracking (right).

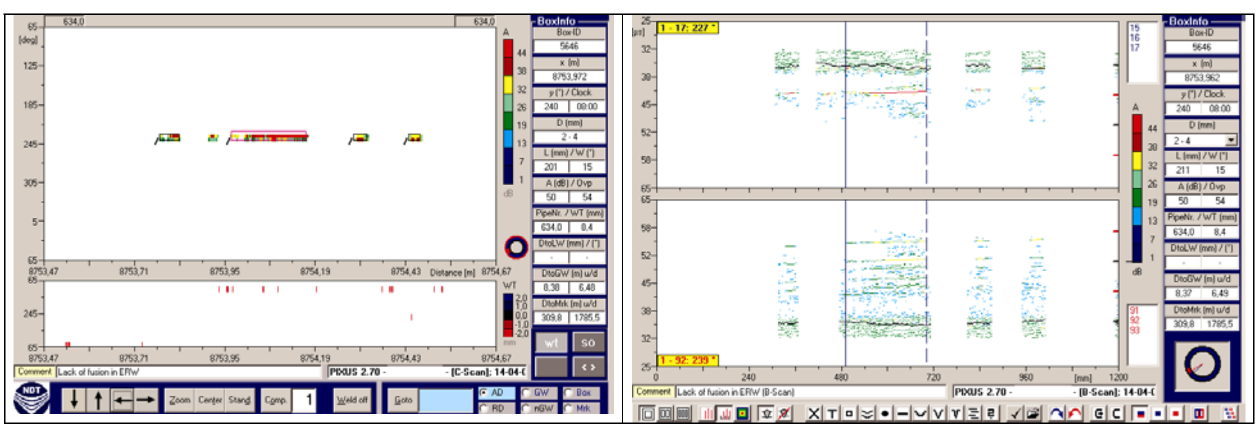

Figure 5 Lack of fusion in ERW (left), Lack of fusion in ERW: B-scan (right)

Experience: This new generation of ultrasonic in-line inspection tools has come into use during 2003. In the meantime crack inspection surveys have been performed in Europe as well as North America proving the design of the tool.

Conclusions: A new generation of ultrasonic crack detection tool has been introduced. It has been demonstrated that even for a well proven technology of non-destructive testing, like 45º shear wave crack detection, there are several fields where technological improvements make a considerable difference in the inspection quality. The improvements achieved by the new design make the ultrasonic inspection of pipeline even more competitive.

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