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Applying ultrasound for in-line inspection

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Current development is focused on using ultrasound for wall thickness measurement and metal loss inspection in gas pipelines.

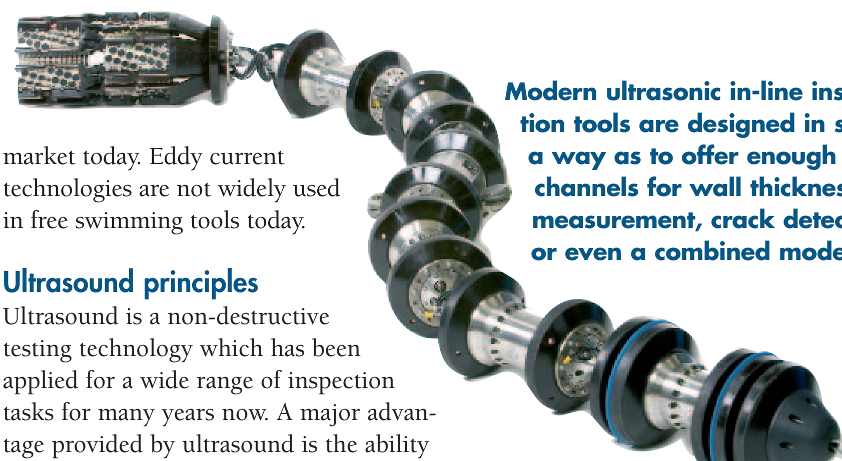
Today, the use of in-line inspection tools is a standard procedure for the collection of pipeline data required for integrity assessment and fitness-for-purpose studies. Their major task is to provide accurate geometric information regarding the length, width, depth, orientation and location of a flaw. The major advantages of in-line inspection tools include their ability to survey the entire pipe circumference while the pipeline remains in operation. They are usually pumped through the line to be inspected (i.e. free-swimming tools), and do not require their own drive. For specific pipeline geometries, there is also a range of cable operated tools, optionally with drive units, some of which can even operate against the pipeline flow.

Applied technologies

Various non-destructive testing methods are applied, each with particular advantages and disadvantages based on the physical principles used. The major technologies are:

- Magnetic flux leakage technology
- Ultrasound technology
- Eddy current and pulsed eddy current technology.

A comprehensive overview regarding the capabilities of magnetic flux leakage and ultrasound tools is available in the literature, but it must be noted that some comments regarding the use of ultrasound tools in thin pipe and for the detection of pittings do not apply to the latest generation of tools available on the market today. Eddy current technologies are not widely used in free swimming tools today.



Modern ultrasonic in-line inspection tools are designed in such a way as to offer enough channels for wall thickness measurement, crack detection or even a combined mode.

Ultrasound principles

Ultrasound is a non-destructive testing technology which has been applied for a wide range of inspection tasks for many years now. A major advantage provided by ultrasound is the ability to provide quantitative measurements. This means that the actual wall thickness of a pipe section can be determined with a high accuracy and reliability. The reporting accuracy regarding depth measurement for the latest generation of tools is ± 0.4 mm. The highest possible resolution 0.06 mm. Usually, threshold for depth measurement of metal loss or cracks are set at 1 mm, lower thresholds are possible.

There are different ways, using different types of transducers, that the ultrasound principles are technically applied. Key examples include piezo-electric transducers, and transducers based on electro-magnetic acoustic transmission or phased arrays. The most widely used tools based on ultrasound, which are available from several vendors, make use of piezo-electric transducers. Ultrasound further constitutes the only reliable technology currently available for the detection and sizing of cracks in pipelines.

Figure 1 shows the principle applied for wall thickness measurement. This principle is used for the detection and sizing of metal loss features, such as corrosion or gouging, and also for the quantitative wall thickness measurement. An added benefit is the ability to detect and identify mid-wall flaws such as laminations and inclusions and also certain categories of material separations and voids, such as HIC (hydrogen induced cracking).

The important issue is that the sensors (transducers) are aligned at right angles to the wall to be inspected. The transducers used are operated in an impulse-echo mode; or, in other words, they act as transmitters and receivers of the acoustic wave used for the measurement. The type of transducer chosen (i.e. dynamic range, focal point etc.) and the characteristics of the electronics used (i.e. pulse repetition frequency, sampling rate etc.) have major influence on the detection threshold, accuracy and depth and length resolution. The width resolution is determined by the arrangement of the sensors around the circumference, i.e. the mechanical design of the sensor carrier. Figure 2 depicts the crack inspection principle. Here slanted probes are used. The sensor carrier design must ensure that the incident ultrasound signals are refracted in a manner that they will propagate under 45° inside the pipe. Ultrasound tools are ideally suited for the inspection of thick wall line pipe. Wall thicknesses of up to 50 mm can be inspected with the same specifications as thinner pipe.

Metal loss inspection

Metal loss inspection entails finding and accurately sizing flaws and wall thickness losses due to corrosion or gouging. The data obtained, e.g. length, depth, width etc., is then used for integrity assessment, corrosion growth assessment or the determination of service intervals.

All measurement principles have specific characteristics regarding their accuracy and error margin. The better the accuracy and the more reliable (less errors) the method, the better the suitability for use in any integrity assessment work. An important factor here is the confidence level. The confidence level quoted for ultrasound technology is usually 95%, compared to an average value of 80% for magnetic flux leakage.

Accuracy of magnetic flux leakage tools is usually around 10% of wall thickness, although there are some tools available that quote a 5% accuracy regarding the detection of internal flaws. For an average onshore line, assuming an 8-mm wall, this would translate into ± 0.8 mm. For an offshore line with, let us say ¾-in. wall (19 mm), this already translates into ± 1.9 mm. The quoted reporting accuracies, i.e. stated depth measurements in a final report for ultrasound tools, is usually in a range of ± 0.4 to 0.5 mm, depending on the vendor and tool used.

Depth resolutions are usually in the order of 0.1 to 0.2 mm. With latest technology, ultrasound tool depth resolutions of 0.06 mm can be achieved. Regarding the detection, sizing and comparison of flaws based on corrosion or grooving, this is a major advantage of tools utilizing ultrasound technology.

Another advantage is the fact that ultrasound tools can quantitatively measure the contour of a metal loss flaw. This implies that the "shape" of the bottom of a corrosion or gouge can be measured, a true river bottom. This is an added advantage regarding higher degree maximum allowable pressure calculation, such as RSTRENG or calculations based on the DNV code. This ability also provides the options to use the geometric data provided as input for the modeling of a mesh for Finite Element Calculations. Figure 3 shows the contour of a metal loss flaw

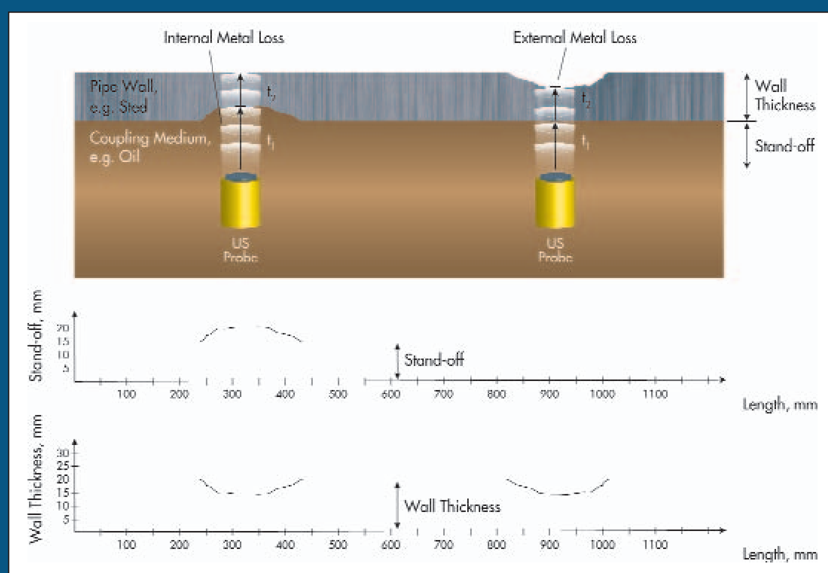


Figure 1. Ultrasound principle wall thickness measurement.

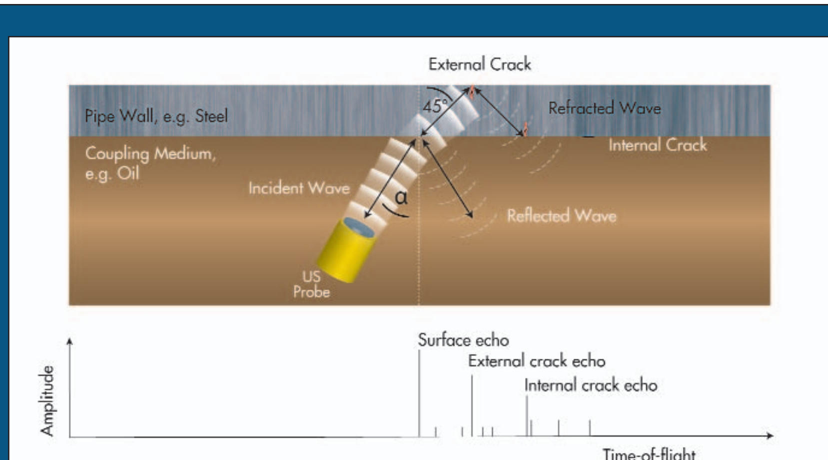


Figure 2. Ultrasound principle crack inspection.

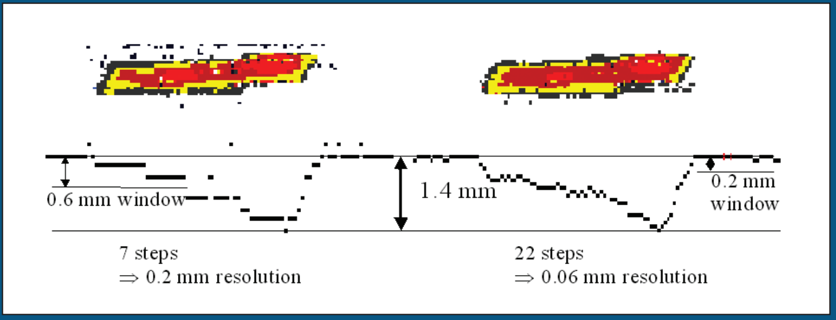


Figure 3. Effect of improving depth resolution.

Figure 4. Typical stress corrosion cracking detected with an in-line inspection tool.

and the difference in resolution achieved by improving the resolution from 0.2 mm to 0.06 mm.

Quantitative measurement

The advantage of quantitative wall thickness measurement is the ability to provide an accurate value for local wall thickness. The quality of data from modern ultrasonic tools is such that they can also be used for quality inspection purposes, i.e. comparing actual with nominal wall thickness. Such data is also of value regarding base line surveys, sometimes also referred to as "finger printing." The data obtained during such an inspection constitutes a reference for further inspections. It is clearly advisable that a reference should be of the highest possible accuracy and reliability. Otherwise, readings obtained from consecutive inspections and their comparison with the original data are of limited use indeed.

Another application which is becoming more popular is related to the uprating of pipelines. Transportation demand is increasing and the construction of new pipelines is a complex and costly process. It is therefore an interesting option to see whether the throughput can be increased for a given line by increasing the operating pressure. However, this directly implies that it must be proven that the pipeline can withstand the resulting increased stresses, which in turn requires knowledge of the true local wall thickness actually existing at every point in the line. The accuracy requirements for this approach are usually even higher than for metal loss inspections. The accuracy aimed for is ± 0.1 mm.

Crack detection

Although other technologies can also in principle find cracks and crack-like flaws, it is widely accepted that only ultrasound technology can be seen as a reliable means (high confidence level of detection) to detect and size cracks and other singular defects in the pipeline wall. Typical examples are fatigue cracks, stress corrosion cracking, hook cracks or various types of weld cracks. Figure 4 shows a typical crack configuration found with an ultrasonic tool.

Special applications

Modern ultrasonic in-line inspection tools, such as the LineExplorer range, use a modular design concept. This refers to the electronic design as well as the mechanical design. What it basically means is that the electronics of the tool are designed in such a way as to offer enough channels for wall thickness measurement, crack detection or even a combined mode. Special inspection tasks can be performed by using specialized sensor carriers (i.e. sensor carrier where the orientation of the transducers is optimized for a given inspection requirement). A modular mechanical design means, that only a small number of base units are necessary which can be adapted to any required diameter by using mechanical adaptation kits. In the sections below, some special configurations will be introduced briefly.

Pitting inspection. The pitting configuration has been designed because of a requirement to run specialized surveys for corrosion flaws where the depth extent of the flaw is very much larger than the surface area. This local type of corrosion is usually referred to as "pitting." For this inspection requirement, several approaches and steps can be used:

- Using smaller sensors and increasing the number of sensors across the circumference in order to find smaller corrosion flaws. This implies that more channels are needed to record the data, in turn requiring a suitable electronics unit.
- In addition, special transducers can be used with a focused beam.

By applying this approach, tools can be configured to inspect for flaws as small as 5 mm in diameter. Utilizing small and focused probes, pittings with a surface area as small as 2.5 mm can be detected today. Figure 5 shows a specialized sensor carrier for pitting inspection.

Girth weld crack inspection. Crack inspection is usually aimed at finding axially orientated cracks. The major reason is that the internal pressure acting in the pipe will induce hoop stresses acting in a circumferential direction. Therefore, the actual stress distribution would lead to cracks extending in an axial direction and growing into the wall (radial direction). If, however, strong additional loading is experienced, such as overlayed bending due to subsidence, then a distribution can occur that would favor the circumferential growth of a crack or crack-like feature. Flaws in the heat affected zone of a girth weld are another possible reason. An inspection requirement, especially in the offshore sector, has therefore been a configuration aimed at detecting and sizing circumferential cracks in pipelines.

Spirally welded pipe. Finding cracks adjacent to the spiral weld of a line pipe are another special application requested from operators. As above, this requirement can be met by applying a special sensor carrier, where the transducers are aligned parallel to the weld and slanted with respect to the wall.

Stainless steel pipe. Pipe made of austenitic steel or which has such components, i.e. cladded pipe or duplex, cannot be inspected with magnetic flux leakage technology, because of its magnetic properties. These types of pipe can be inspected utilizing ultrasound technology.

Combined inspection. Performing an inspection always constitutes a special, non-routine operation during normal pipeline operations. The goal is therefore to perform an inspection, thus providing valuable data needed for integrity assessment, with the least possible disturbance to the normal operation of the line being surveyed. One element is therefore to operate the pipeline inspection tools at or near to the normal pumping speed of the line. Another element is to combine different inspection tasks and to limit the number of runs that are needed to meet the inspection requirements of the pipeline. Combining metal loss and crack detection inspection is therefore of great value. Performing both tasks in a single run results in savings regarding pipeline preparation, cleaning, mobilization and demobilization costs, as well as optimizing of procedural methods. In addition, performing both inspections in one run provides enhanced correlation between metal loss and crack inspection data.

Coating inspection. Modern ultrasonic tools are also capable of finding coating faults. This is very helpful for correlating coating defects and flaws in the pipe wall.

Some misconceptions

Unfortunately, there are some misconceptions about ultrasound which might in some cases have been justified in the past, but which have to be reexamined today, because of improved inspection technologies, major advances in electronics and also operational procedures. These include:

Can't get the line clean enough. It is true that cleaning is of major importance regarding a successful ultrasonic inspection. The reason is that a surface covered with excess debris or thick layers of wax will disperse the ultrasonic signal. Instead of being reflected back to the transducer, a dispersed signal will be spread over a very wide area, resulting in a total loss of signal or in a weak signal. Modern ultrasonic tools, however, use electronics and transducers which have a higher dynamic range and gain. In a simplified way, it can be said that the signal strength is greater and a greater portion of the signal will be received by the transducer, compared to earlier tools. Cleaning is still of great importance, as with all high resolution inspection, but the tools are more tolerant to the presence of waxy deposits, scale or debris. An effective and efficient cleaning program is without doubt a critical factor in the process of obtaining robust inspection data.

Can't be used in gas pipelines. The use of ultrasound requires a suitable couplant. In liquid lines, for instance transporting crude oil or product, this is no problem. In gas pipelines this liquid couplant is not available. Unlike magnetic flux leakage tools, ultrasound tools utilizing piezo-electric transducers cannot be applied directly in a gas pipeline, but require a suitable liquid batch. This means that the tool is introduced into the line within a batch of liquid, for instance water or diesel, contained within a set of sealing pigs. Batching is not a routine procedure and does constitute an additional effort. However, where additional accuracy and/or quantitative data is needed, this is a viable option. Many thousands of kilometers of gas pipeline have been successfully inspected making use of batching procedures, including, amongst others, very long large-diameter lines in Russia, the Gulf region and Canada. The procedures are well established; however, it must be understood that for these special application pipelines are usually taken out of operation, albeit only for a limited time.

Outlook

Today, some vendors are also offering ultrasonic tools using electromagnetic acoustic transducers (EMAT). Here, the ultrasound signal is generated at the surface of the pipe to be inspected and a liquid couplant is therefore not necessary. Both tools, commercially available, are designed for crack inspection. They do not have the track record of ultrasound crack detection tools utilizing piezo-electric transducers, and still need to prove whether they can achieve the same measurement accuracies. Another issue is the use of EMAT transducers for the quantitative wall thickness measurement in gas pipelines without the need of a liquid couplant. Such a tool is currently being developed and tested, and will be commercially available later this year. ■

Figure 5. Sensor carrier being prepared for pitting inspection.