TOOLS, VENDORS, SERVICES - A REVIEW OF CURRENT IN-LINE INSPECTION TECHNOLOGIES

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ABSTRACT

The paper provides an overview of the inline inspection tools (ILI tools) commercially available in the market place today.
After a short summary of flaws and defects found in steel pipelines, the various physical principles utilised by intelligent pigs will be introduced and specific strength and weaknesses will be discussed.
Geometry, metal loss survey, crack detection and inertia tools will be introduced. Especially ultrasonic in-line inspection tools for wall thickness measurement and crack detection will be covered, regarding technology, vendors and defect specifications.

INTRODUCTION

This paper is written with the intention to provide the reader with an overview regarding the in-line inspection tools available on the market today. The technologies utilized are not new and have been described in detail in the literature /1,2,3/. Therefore only brief descriptions will be included. It is in the view of the authors more important to offer some guidance as to the types of tools offered in the market, the flaws and defects they can detect and size, the vendors and some information regarding trends in the development of future tools.

The pipeline inspection industry has never been static. But in the last two to three years events have taken place which will imply major changes and certainly benefits for the customers, the pipeline operators.

The pipeline inspection market has regularly seen new tools and technologies being introduced in the past.

The 1970´s saw the introduction of electronic calliper tools, followed by the first generation of metal loss survey tools. These tools, utilizing the magnetic flux leakage technology (MFL), were supplemented by so called high resolution MFL tools in the 1980´s, high resolution ultrasonic wall measurement tools (UT) in the mid 1980´s, crack detection tools in the late 1980´s and early 1990´s, inertia tools in the 1990´s and finally, towards the end of the last century, transverse field magnetic flux leakage tools /1,2,3/.

The industry grew and, as in all industries, new companies entered the market, whereby some succeed, some fail, some are bought up or merged. The past has shown cycles where new players have entered the field and other periods of time where the number of vendors has consolidated.

However in general the number of vendors has been fairly stable and the names of companies a pipeline operator or potential customer had to be aware of remained little changed throughout the middle 80´s to the late 90´s.

It seems to the authors however, that the industry has started to change dramatically since 1999. The biggest event of that year in the industry has to be the merger of the former Pipeline Integrity International and Pipetronix to form the new PII, now part of GE Power Systems. A previous major event was the merger between Tuboscope and Vetco. Clearly a consolidation in the market place has taken place at that time. Quite noticeably also the main focus of some inspection vendors has changed. From being companies highly focused on pipeline inspection and directly associated auxiliary services, such as cleaning, some vendors are now entering the greater field of pipeline integrity. Initially additional services were mainly aimed at fitness for purpose issues, followed by a whole spectrum of add-on services usually referred to as bundled services, parametric maintenance and finally the range of products PII market as Total Pipeline Integrity or Tuboscope market as Total Pipeline Services.

The changes observed since 1999, now focusing purely on in-line inspection, are dramatic and of benefit to the customers:

- After a period of consolidation new competitors are entering the market offering a wider choice to the industry.
- Start-Ups are introducing new tools, not having to concern themselves with backward compatibility or the protection of existing hardware.
- There are no technological monopolies, i.e. no tool technology is exclusively offered by one vendor only.

Pipelines, Flaws and Inspection

Pipelines do provide the safest and most efficient means to transport large quantities of liquids and gas. With time, as applies to all technical components, flaws will appear which can, if undetected, lead to a failure or will at least impair the integrity of the line.

The flaws which can be observed in pipelines can be sorted into four major categories:

- geometric anomalies (dents, ovalities, displacement etc.)
- metal loss (corrosion, gouging etc.)
- cracks (fatigue cracks, stress corrosion cracking etc.)
- leaks (metal loss or crack feature growing through the wall)

Highly specialised in-line inspection tools exist which can detect, locate and size flaws in pipelines. However it must be noted that no single tool can be used for all inspection requirements. Different tools utilize different physicle principles. In turn different physical principles all have their advantages and disadvantages. The message is that there is no "best" tool in general, but there is a "best" tool for a given inspection requirement. This implies however that an inspection program must be carefully planned, the abilities of the tools to be used must be fully understood and must coincide with the inspection requirements defined.

With the range of tools available today, choosing the "right" tool is not a trivial task. Matters are further complicated. For instance:

- different physical principles are applied for similar tasks, e.g. magnetic flux leakage and ultrasonic tools for metal loss inspections
- there is a certain grey zone between areas of application, e.g. some metal loss survey tools can also detect specific types of cracks.

Therefore the best advise is for client and vendor to communicate as early as possible when an inspection is planned in order to discuss:

- the aim of the survey
- the flaws, anomalies and features to be detected and/or sized
- operational parameters relating to the survey.

Pipeline inspections are usually carried out during the operating life of the pipeline, i.e. focused on flaws which appear during normal operations. It must be considered though, that this is not the only time in the entire life of the pipeline-material or the actual section of linepipe, when flaws can be introduced or can grow. Therefore it is beneficial to also consider the full life cycle of a pipeline from a material perspective. It consists of:

- Steel Production (non-destructive-testing in steel mill)
- Pipe Production (non-destructive-testing during pipe production, mainly weld zone)
- Pipeline Construction (non-destructive testing during pipeline construction, mainly girth weld, dents)
- Pipeline Commissioning (inspection prior to normal operations, baseline survey)
- Pipeline Operations (Classic field of in-line inspection)

What Information Do In-Line Inspection Tools Provide?

Despite all the different technologies and types of tools, the information provided is always similar. The information consists of geometric data regarding a flaw or anomaly found:

- length (How long is a flaw from beginning to end, extent in the direction of the pipe?)
- depth (How deep is a flaw, deepest point?)
- width (How wide is a flaw, circumferential extent?)
- circumferential position (Orientation, o´clock position of a flaw?)
- longitudinal position (Where along the line is the flaw?)
- pipeline route (Where is the pipeline and was there any change in position?)

The differences in tools and technologies utilized can usually be identified by looking at detection thresholds, measurement accuracies, probabilities of detection, qualitative or quantitative measurement accuracies, confidence levels etc..

After addressing the question of what information is provided, the next question is, what is the information used for. Today inspection data collected by in-line inspection tools is utilized for defect assessment or fitness-for-purpose investigations. An issue to be considered then is the effect of tool accuracy on defect assessment. As with all measuring devices also the data obtained with ILI tools will have an intrinsic measurement error. Usually ILI vendors state the tool accuracy in the tool data sheets and final reports. A standardization of ILI tool accuracy has been initiated by the Pipeline Operator Forum (POF) /4/ stating in which terms the tool accuracy should be provided. When defect geometries are used for defect assessment purposes these measurement errors are usually ignored and other safety factors are introduced into the assessment codes. Only the code of Det Norske Veritas Part A allows for the input of ILI tool accuracy and measurement technology. It seems reasonable to base the severity of a defect on how accurately its geometry has been measured. The above mentioned considerations focus on metal loss inspection, but the argument is valid in general also for geometric or crack detection surveys. To clarify this, table 1 shows the definition of tool accuracy types for metal loss survey tools.

Tool technology	Resolution	Accuracy for general corrosion at 80% confidence level
MFL	standard (low/medium)	20% of wall thickness
	high	10% of wall thickness
	extra high	5% of wall thickness
UT	high	1 mm
	extra high	0.5 mm

Table 1: Tool accuracies for metal loss ILI tools.

Further information can be found in /5/.

Which Tools Are Available?

The following will focus on ILI tools designed to detect, size and locate flaws at a subcritical size. Leak detection devices, which are designed to find leaks, i.e. flaws that have already penetrated the pipe wall are not considered here, nor will inertia tools be covered in any detail.

Table 2 shows a summary of tools available on the market today and vendors offering them. The authors do not claim that the list is comprehensive. We have included all companies known to us at the time of preparing the paper. If any company or tool technology is missing, we apologize to the provider and would kindly ask for information to be submitted to us, so that we can update the content of this publication. The table only provides generic or general names used for tools and does not include any tradenames.

Tool	Mission	Physical Principle Used	Vendors
Caliper Tools	detection, sizing, location of geometric anomalies	mechanical, magnetic induction	PII, TDW, Enduro, Analytic Pipe, MEFS, NDT AG, DiaScan, Weatherford-Kopp, Pipeway, Rosen, Tuboscope, NGKS, Spezneftegaz etc.
Metal Loss or Corrosion Detection Tools	detection, sizing, orientation, location of metal loss features	magnetic flux leakage (axial and transverse), ultrasonics, eddy current	PII, Rosen, BJ, Tuboscope, C-Pig, Magpie, NDT AG, Trapil, NGKS, DiaScan, Spezneftegaz, 3P, Orgenergogaz, Spektrum etc.
Crack Detection Tools	detection, orientation, location of cracks, where possible also sizing.	ultrasonics	PII, Tuboscope, NDT AG, NGKS
Inertia Tools	Mapping, pipeline displacement	gyroscopes	BJ, PII, NGKS, Tuboscope, Rosen, PSL etc.

Table 2: ILI tools commercially available.

Magnetic Flux Leakage tools utilizing transverse field technology can detect certain geometries and sizes of cracks. However they are not specifically designed as crack detection tools and display a probability of detection regarding cracks which is not satisfactory compared to ultrasonic crack detection tools. They are therefore not included into the crack detection category.

The table furthermore only includes tools commercially available today and focuses on freely swimming ILI tools. Crawler tools are not included.

Caliper Tools

Caliper tools are designed to detect, locate and size geometric anomalies in the pipe wall. Ideally all pipes, including pipelines should have a circular cross section. In reality this often does not apply. A certain "out-of-roudness" is already caused by the shear weight of a pipe, although usually negligible. Dents can be introduced during construction of the pipe or caused by third party interference during the operational life of a pipe. Any critical changes to the free available cross section of the pipe should be detected and sized. One very important aspect is to prove a line prior to a metal loss or crack detection in-line inspection.

The most widely used tools use some arrangement of mechanical fingers or spiders with mechanical fingers. The fingers are pressed against the internal surface of the pipe and deflected by any change in the cross section. This could be due to a dent, out-of-roundness, wrinkles or debris attached to the inside of the pipe.

The mechanical signals obtained through the deflection of the mechanical fingers are then transformed into electrical signals and stored onboard. Today mostly solid state memory devices are used. After a run the data is retrieved and can be analysed and displayed using the appropriate software. Sensitivities of the calliper tools available on the market fall broadly into a range of 0.2-1% of diameter and accuracies into a range of approximately 0.1-2%. These are general figures found in the industry and might vary to some extent from vendor to vendor. The range of sizes offered covers diameters from 4" to 60". The authors were made aware of a 3", but have not had any access to technical data.

Metal Loss Tools

Eddy Current tools will not be covered here, as they are currently not actively used in the market place.

Magnetic Flux Leakage (MFL) Tools

Today two types of MFL tools have to be differentiated. Tools inducing a magnetic field into the pipe to be inspected which is parallel to the line, i.e. extends in an axial direction and tools which induce the magnetic field in a circumferential or transverse direction.

The most widely used, if not to call them the work horses of the pipeline inspection industry, are axial MFL tools. These tools can be differentiated into standard, also referred to as low/medium resolution tools, and high resolution tools.

Fig.1 shows the principle used.

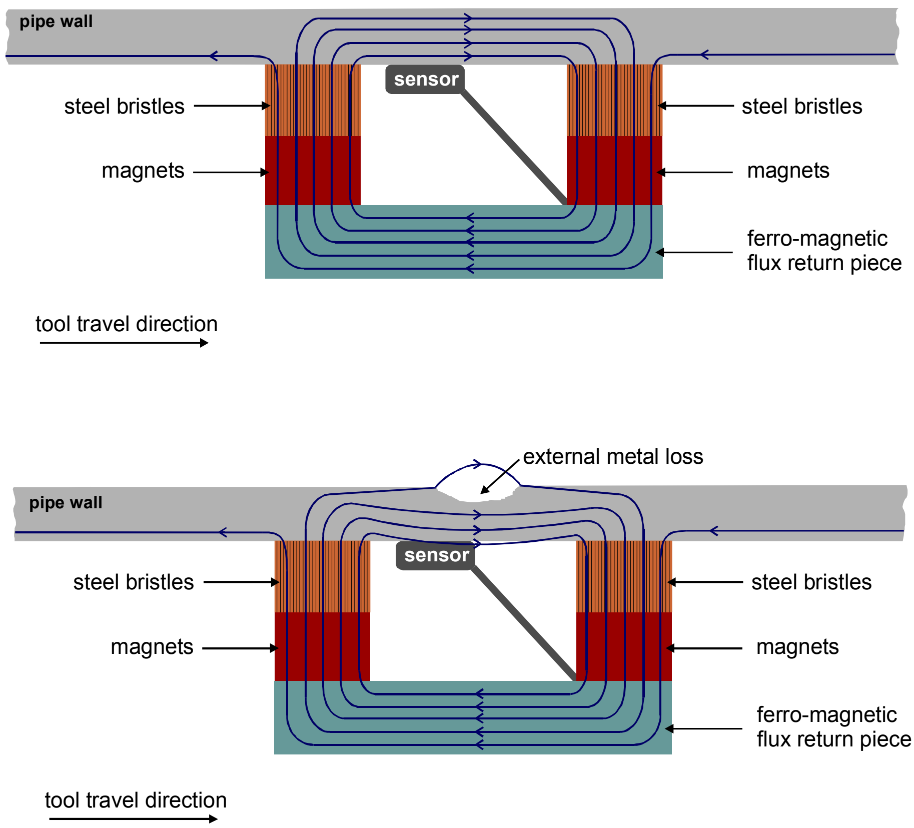

Fig.1: Magnetic Flux Leakage Principle

Strong powerful magnets are used to induce a magnetic field in the pipe wall to be inspected. A successful survey depends on achieving full magnetic saturation of the pipe. In the presence of a flaw a portion of the field will "leak". This leakage can be picked up by sensors and correlated to a volumetric metal loss. It must be noted however that this is an indirect measurement method, i.e. a magnetic field or a change in flux density is measured, depending on the type of sensor used, and then a metal loss volume is calculated using appropriate algorithms. A large part of the expertise of the vendor lies in the sizing algorithms used.

When assessing the suitability of a specific type of tool to find certain types of flaws it is useful to remember some simple issues regarding the physics of magnetic flux.

The largest signal generated by a flaw will occur if the flaw is at right angles to the induced magnetic field. Considering an axial field tool, this already provides good guidance on the types of flaws and features which an axial MFL tool will be able to detect and size well. These include general corrosion, localized corrosion, pittings which have a certain minimum depth and circumferential extend. Long and narrow axial defects, i.e. flaws parallel to the magnetic field induced, are difficult to pick up. The tools are also good at identifying metal objects touching the pipeline, as this will also alter the distribution of the magnetic field lines. Even certain sizes of cracks, if orientated in a circumferential direction, can be picked up, if they reach a certain length and depth.

Shallow flaws or a gradual change in wall thickness, as experienced in seamless pipe for instance, is difficult to detect, simply because the magnetic field might be retained, i.e. no magnetic flux leakage occurs which the sensors can pick up.

Flaws which are parallel to the field and in addition narrow, i.e. long compared to their width, are also very difficult to pick up. This has originally led to the development of Tranverse Field Tools. They use the same physical principle as described above, but the magnetic field is rotated through 90°. It is also claimed by some vendors that transverse field tools can be applied as crack detection tools. This would be very beneficial, because as an MFL tool they can be used directly in gas pipelines, whereas ultrasonic crack detection tools require a suitable liquid batch. However it has to be noted, purely based on the physics used, that the crack sizes and geometries, which need to be detected in order to reliably define the integrity of a line are too small to be detected by MFL tools with confidence. With other words the probability of detection and the confidence level of transverse field tools currently available are not satisfactory. Transverse field tools really should, in the opinion of the authors, be seen as tools specialized on the detection and sizing of certain geometries of metal loss features. Transverse field tools are offered by a variety of vendors, including PII, Spezneftegaz and Rosen /6/. Axial MFL tool sizes available in the market in general range from 6" to 56". Some vendors offer 4" tools, and recently a 3" tool has also been successfully applied. The range of sizes offered for transverse field tools is still limited, but growing.

A special type of magnetic flux leakage tool is the MagneScan XHR tool offered by PII. The tool is based on a cooperation project by the former Pipetronix and Statoil of Norway. It should really be seen as a special development for offshore application. The challenge consisted of the need to inspect extremely long, thick walled offshore pipelines. Here the major focus was placed on detecting the onset of internal corrosion, in order to check the quality of the anti-corrosion measures taken, inhibition etc., and to ensure the extended life the pipelines have been designed for.

Typical defect specifications for axial MFL tools are shown in table 3.

High Resolution MFL:	**defect specification:**
Detection threshold depth (minimum depth) Detection threshold width sizing accuracy (depth)	0.1T (general corrosion), 0.2T (pitting) 3T (general corrosion), 2T (pitting) approx. 0.1T
Extra High Resolution:	
Detection threshold depth (minimum depth) Detection threshold width sizing accuracy (depth)	approx. 0.05T (internal) 0.25 T (internal), 1T (external) approx. 0.05T

T = wall thickness.

Table 3: Typical defect specification, axial MFL.

Ultrasonic Tools

The major advantage of ultrasonic tools is their ability to provide quantitative measurements of the pipe wall inspected. Their high accuracy and confidence level make them ideally suited for providing ILI data for fitness-for-purpose calculations. Drawback is the need for a liquid couplant, which makes their application in gas pipelines difficult.
Fig. 2 shows the principle used:

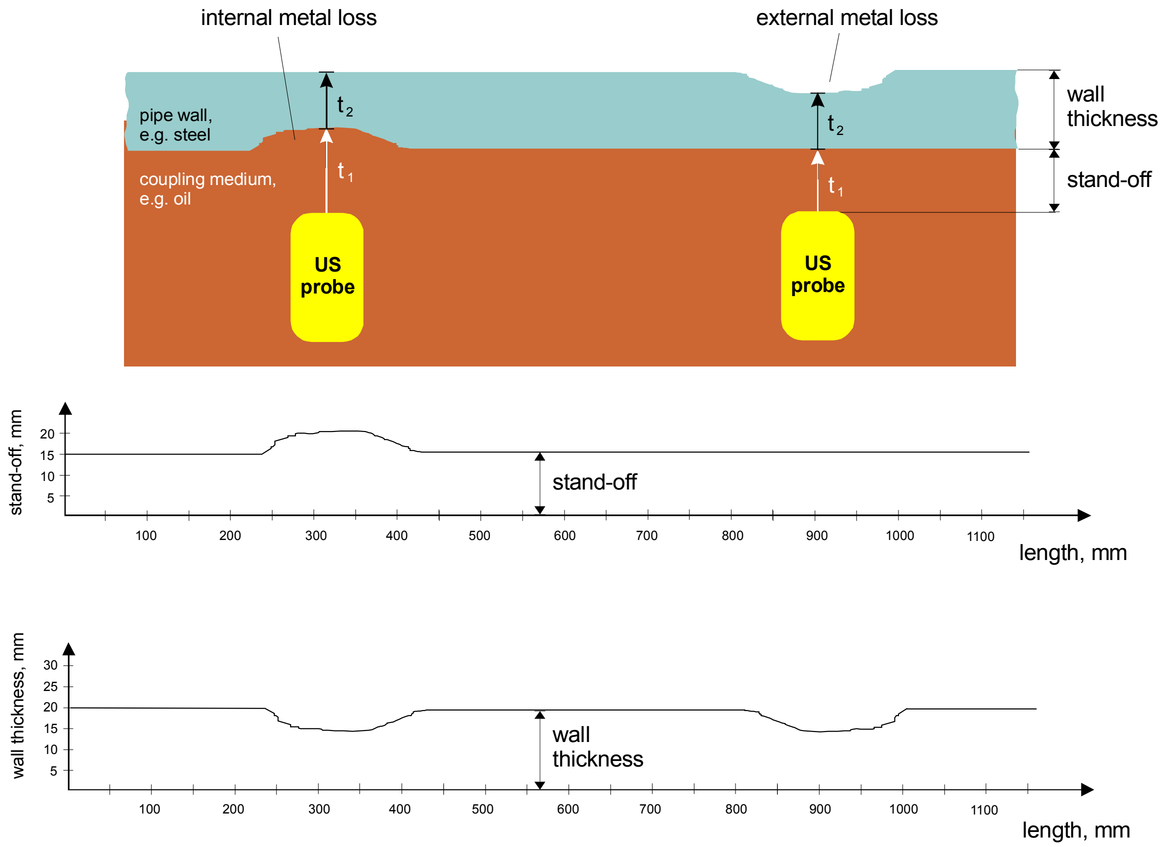

Fig.2: Ultrasonic Measurement Principle.

Ultrasonic inspection tools are in general fitted with a sufficient number of ultrasonic transducers to ensure full circumferential coverage of the pipe. Fig. 2 shows one single transducer located on the inside of the pipe to be inspected. The transducers used operate in an impulse-echo mode. This means that they switch from being emitters of an acoustic signal in the ultrasonic sound range to being receivers. How often this is done is determined by the pulse repetition frequency.

As shown in the diagram the sensor emits an ultrasonic signal, which is partly reflected at the internal surface of the pipe and partly at the external surface of the pipe. The first reflection provides a measurement of the stand-off distance, the second a value for the wall thickness. As the tool travel through the pipelines the sensor will take measurements at regular intervals, set by the travelling speed of the tool. This data is displayed in the so called B-Scan as shown above. Internal and external flaws can be easily identified by the stand-off distance. In turn, the data from all sensors around the circumference of the pipe is displayed in the C-Scan, as shown in fig.3.

Tool sizes available in the market range from 6" to 60".

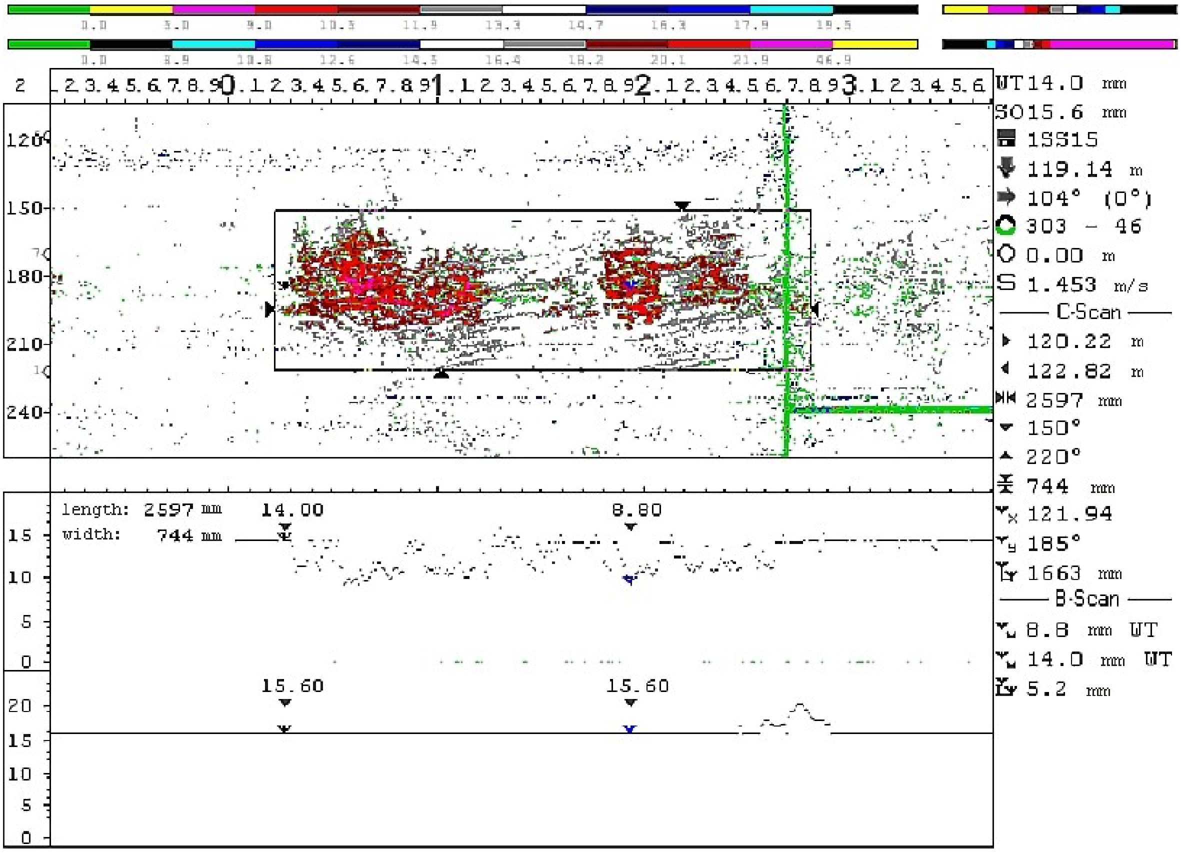

Fig.3: Typical display of ultrasonic data showing C-Scan and B-Scan views.

The C-Scan displayed shows an area of external metal loss. The associated B-Scans can be seen in the lower portion of fig.3.

Table 4 shows typical defect specifications for ultrasonic tools offered by the different vendors in the market.

High Resolution Ultrasonics:	**defect specification:**
Detection threshold depth (minimum depth) Detection threshold area (minimum area) sizing accuracy (depth)	approx. 1 mm 20 mm 1 mm
Extra High Resolution Ultrasonics:	
Detection threshold depth (minimum depth) Detection threshold area (minimum area) sizing accuracy (depth)	approx. 0.7 mm 5 mm (3 mm for internal flaws) 0.5 mm

Table 4: Typical defect specification, ultrasonic wall thickness measurement tools.

Tool speeds for ultrasonic tools are generally in the range from 1 to 2 m/s. Lower speeds are possible, but higher tool speeds during the survey can lead to loss of coverage.

Crack Detection

The reliable detection of cracks constitutes a further challenge for the pipeline inspection industry. Again potential flaws and defects have to be defined. Depending on the type of pipeline, type of pipeline material and the operating conditions different types of cracks or crack like anomalies could occur.

Much research has been carried out world-wide into the understanding of how these material defects are initiated, how they propagate and how they can be avoided. Fracture research has been carried out extensively for the nuclear and for the aviation and space industries.

Cyclic loading, for instance possible in liquid lines, can lead to the formation of pure fatigue cracks or corrosion fatigue. Strictly speaking all cracks incorporate a corrosion component unless they are placed in an inert environment. This class of cracks is most likely to be initiated at local stress concentrations. These could be due to macroscopic features such as dents or microscopic such as material voids, inclusions or local brittle zones. Stress corrosion cracks can initiate at any point where the local stress intensity surpasses the actual resistance of the material. Research has and is being carried out into dynamic crack growth in pipeline steels and this is of paramount importance considering safety, especially of high pressure gas transmission lines. However some attention should also be paid to investigating sub-critical crack growth in pipeline steels.

Tools which can detect cracks are already available. It is widely accepted that the most suitable available technology for the detection of cracks is ultrasound. For completeness it has to be stated that the first commercially available ILI tool developed especially for the detection of cracks was an eddy current tool developed in the late 1970`s early 1980`s by Dr. H. Goedecke GmbH. This particular tool was developed for the detection of fatigue cracks in the longitudinal seam weld of liquid lines. The tool went out of operation in the late 1980´s. Another tool to be mentioned is the Elastic Wave Crack Detection tool developed by the On-Line Inspection Centre, now PII. This tool is still being operated.

A crack tool using ultrasound sensors placed in a flexible sensor carrier was introduced into the market by former Pipetronix in 1994. Today crack tools are also offered by several vendors.

Crack detection tools in their normal configuration are designed to find axial cracks, i.e. cracks along the axis of the pipe. They can detect and locate fatigue cracks as well as stress corrosion cracking. The detection of girth welds, which are orientated in a circumferential direction is also possible, but requires a different configuration of sensor carrier.

Fig. 4 shows the physical principle used.

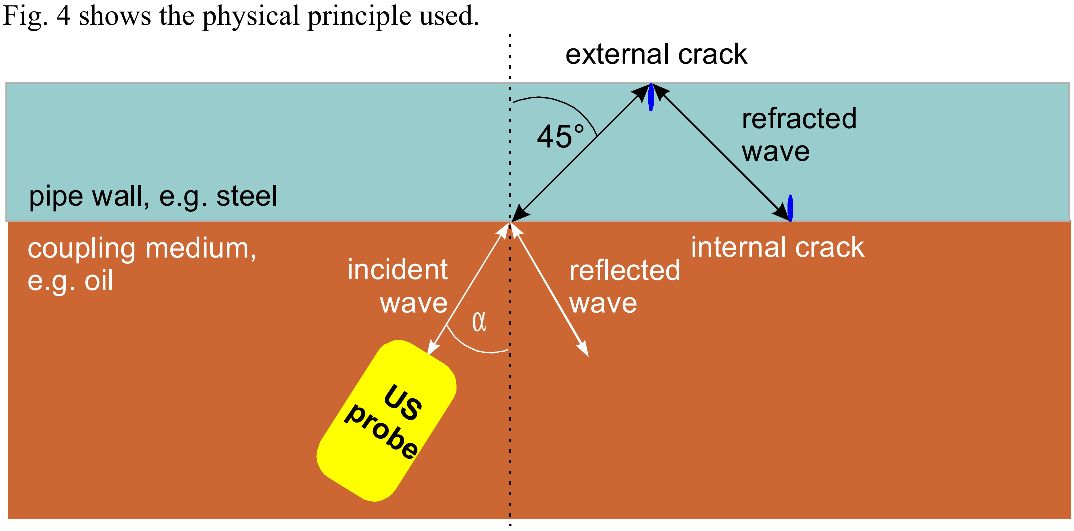

Fig. 4: Ultrasonic principle used for crack detection.

As with the metal loss survey tools, ultrasonic crack detection tools utilize a sufficient number of sensors for a given diameter to ensure full circumferential coverage of the line inspected.

Here the sensors are inclined at an angle which enables the refracted wave to travel at an angle of 45° within the pipe wall, as shown in fig.4. As before the transducer acts as a transmitter and receiver and "listens" for signals being reflected. The methodology of using ultrasonics for crack detection is long established and is state of the art. The great challenge lies in the amount of data that has to be handled by an ILI crack detection tool during a survey run. This amount of data can easily reach over 100 Tbyte. Even with the advancements made in storage technology crack detection tools therefore make use of data reduction and data compression algorithms. Especially the data reduction routines need to meat the highest quality standards in order to ensure that all relevant data necessary to identify a crack or crack-like feature is available and spurious defects or rather indications can be filtered out.

Table 5 shows current defect specifications for crack detection tools. As with all information provided in this paper, the specifications provided are taken from the literature and should be verified by asking the vendors for current tool data and defect specifications sheets prior to selecting a tool for a survey.

minimum defect length for detection	30 mm
minimum defect depth for detection	1 mm
location accuracy (with reference to next girth weld	± 0.2 m

Table 5: Typical defect specifications for ultrasonic crack detection tools.

Sizes currently available on the market start from 16". Smaller sizes down to 10" will probably be available towards early 2003. New ultrasonic crack detection tools being introduced into the market shortly will display similar defect specifications. Their advantage will, however, be that they offer improved inspections speeds. The tool will be able to inspect with up to 1.5 m/s offering the same defect specifications as tools currently being offered which can handle inspection speeds of up to 1 m/s.

Outlook

What will the future bring? The industry will in the short term probably not see any new non-destructive-testing technologies being incorporated into ILI tools. Emphasis will be placed on tool reliability, multifunctional tools, improved tool handling, improved reporting times (log turn out) and the provision of software to manage the huge amount of data ILI tools provide.

In the past the main focus regarding client software lay in providing visualization tools for the ILI data obtained. Today pipeline inspection is not treated in isolation but is seen as part of an overall monitoring program, in turn part of an integrity program for pipeline assets. This leads the way to the need to record, store, manage and correlate large amounts of integrity data, including ILI data, external inspection data, material data, operational parameters and records relating to the pipeline history. Special data bases and GIS systems cater for these requirements. Inspection companies have also seen this trend and introduced powerful software packages, such as Tuboscope with their TrueView suite of programs.

As far as inspection tools are concerned the future will bring further developments and refinements in MFL tools, especially with regard to transverse field tools. Combo-tools will provide multiple inspection capabilities. Initially this will include geometry- and metal loss capabilities, later it may well include combined metal loss and true crack detection tools. The future of pipeline inspection will be exciting.

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