MULTI-DIAMETER AND QUANTITATIVE INSPECTION TECHNOLOGIES FOR OFFSHORE PIPELINES

By M. Beller[1], T. Jung[2], & K. Reber[1]
[1]NDT Systems & Services AG, Stutensee, Germany
[2]PIT AG, Stutensee, Germany

Abstract:

Offshore pipelines often constitute a real challenge regarding their inspection. Accurate and reliable results are required in order to assess the state and integrity of a line and decide on optimized maintenance procedures in order to safeguard the operation of the pipeline and protect the asset. Major parameters to consider are wall thickness, length, requirements regarding resolution and accuracy and more and more the ability of the inspection tool to negotiate diameter variations.
This paper will provide an overview of available technologies and in-line inspection tools for the inspection of dual- and multi-diameter offshore pipelines. The paper will cover in-line inspection tools based on ultrasound-, magnetic flux leakage- and laser-based technologies covering geometry-, metal loss- as well as crack detection.

Introduction

Offshore pipelines often constitute a greater challenge regarding their inspection than onshore pipelines, due to their wall thickness and length. As pipelines are now also built in deeper offshore regions increasing pressure requirements have to be met. Offshore pipelines constitute a major investment and therefore valuable asset, often with a planned lifetime of 50 years and more. For all these reasons safeguarding the integrity and operational availability of the offshore pipeline infrastructure is of great importance. Accurate and reliable inspection results are required in order to assess the state and integrity of a line and decide on optimized maintenance procedures in order to safeguard the operation of the pipeline and protect the asset.
This paper will introduce technologies available and especially suited for the inspection of offshore lines including multi-diameter pipelines. Two of the technologies introduced stem from a highly specialized portfolio of pipeline inspection equipment based on technologies originally developed by or on behalf of Statoil ASA, the Norwegian oil & gas producer and now available to the international pipeline industry.

Need for Inspection

The inspection requirements regarding pipelines are increasing continuously. The installed pipeline infrastructure is growing in age. Pipelines constitute an important asset for an operator of great strategic value. However, despite greatest care and maintenance efforts flaws and defects can, over time, threaten the integrity of a line. A variety of inspection techniques and processes are available today to provide the information needed in order to assess the integrity of a given line and optimize the maintenance process. It is thereby important to understand, that there is no single inspection methodology which will cover all inspection needs. The "full picture" about the state of a line will require a combination of activities including internal-, external-, direct- as well as indirect inspection techniques. In-line inspection tools represent an integral part of the inspection process providing a wealth of information, mainly regarding the geometries of any anomalies of flaws detected: length, width, depth, location and orientation. A variety of tools exist today covering geometry-, metal loss- and crack inspection and providing accurate and reliable data for the integrity assessment of pipelines /1,2,3,4/.
As pipeline technology evolves the inspection requirements increase, especially for the offshore pipeline infrastructure. Some of these issues are:

- Extending the use of existing pipelines beyond their original design life,
- Upgrading existing pipelines in order to increase throughput,

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- Inspection needs regarding the combination of older and newer pipelines of different sizes in a wider infrastructure such as the North Sea and other offshore regions,
- The inspection of previously termed "unpiggable" pipelines,
- Precise internal inspection data for offshore pipelines,
- Inspection of telescopic lines, i.e. pipelines of dual- or multi-diameter design.

This paper will address and introduce three inspection technologies based on magnetic flux leakage-, opto-electronic- and ultrasound principles respectively.

Specialized Inspection Solution

A special requirement with increasing importance relates to the inspection of multi-diameter pipelines, i.e. pipelines which do not have a constant bore. Special in-line inspection technologies are available today to meet this challenge. These changes in the diameter of a pipeline are part of "smart" design approach, i.e. change in cross section of the pipe due to:

- Smaller size platform risers on offshore systems in order to save weight and money,
- smaller size main valves in a large diameter line in order to save weight and money,
- introduce step changes in long distance gas transmission lines in order to accommodate for the inverse relationship between volume and pressure,
- meet general demand to reduce capital and operating costs.

These requirements have led to two special ILI developments sponsored by Statoil and which form the core of a range of new inspection technologies available to the oil and gas industries:

- a multi-diameter inspection tool (MagnoSurveyor) utilizing extra high-resolution magnetic flux leakage technology and
- a laser based 3D-image optical inspection tool (OptoSurveyor) which provides highly accurate data regarding the pipe cross section and internal metal loss.

Both tools can deliver survey results with greatly improved accuracy, compared to conventional tools, and are equally suited for offshore as well as onshore service.
In addition specialized cleaning and caliper tools were designed and built to provide complementary services required for an in-line inspection project.

Multi-Diameter Tools

The term "multi-diameter" pipelines is used here with reference to telescopic lines, i.e. pipelines that have a changing available diameter along their length. In general all in-line inspection tools display a certain flexibility, based on their inherent design. Caliper tools are usually quite flexible and can often negotiate diameter reduction of approximately 25%. In addition to the physical principle used, metal loss inspection tools also have to be viewed from a mechanical perspective. Ultrasonic tools are in general more flexible than magnetic flux leakage tools. In turn magnetic flux leakage tools have to be differentiated into bristle- and sled based-design, see figure 1. All these tools show a certain flexibility. In some circumstances this means they can negotiate certain diameter changes, usually in the order of approximately 2 inches. Some tools can also be modified to act as dual diameter tools. Here a distinction exists depending on whether a given tool can negotiate both diameters, but only record inspection data for one of those or on whether the tool can negotiate both diameters and also provide inspection data for both diameters.
True multi-diameter tools are capable of negotiating a given diameter range with full circumferential coverage of the entire range. In addition, as a default, multi-diameter tools can be configured for a dual-diameter of a single diameter application.

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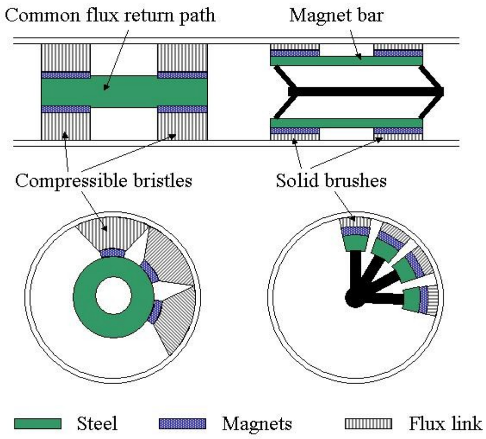

Figure 1: Bristle- and sled based type magnetic flux leakage tool.

Multi Diameter Metal Loss Inspection

The multi-diameter metal loss tool introduced here utilizes the well established and proven magnetic flux leakage principle, documented in the literature /1,2,3/. The development of this tool technology was initiated due to Statoil´s Åsgard development, where it became desirable to tie the 42 inch diameter main export line to a smaller size near platform line and riser, thus saving considerable platform weight and cost. To accommodate this new approach in pipeline design, a specialized inspection tool had to be made available. A development project was started in 1997. The main challenges regarding such a tool were:

- disk design/disk material in order to produce a drive system which would drive the tool reliably within the bore range to be covered, here 28 to 42 inch.
- magnetic brushes and a sensor design to ensure close contact and full measurement capabilites for the bore range to be covered, again 28 to 42 inch.

The mechanical design for the Åsgard pipeline was based on a lay-out whereby a 50% diameter change could be accommodated. Figure.2 shows a picture of the actual tool, ready for launch into a 42 inch diameter land pipeline in Germany. Table 1 provides an overview of key technical specifications of the tool.

Figure 2: MagnoSurveyor metal loss survey tool ready for launching.

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Pressure range	up to 200 bar		
Temperature range	-10° to +60°C		
Inspection speed	up to 2 m/s		
Longitudinal resolution	2 mm (main corrosion sensors)		
Circumferential resolution	4 to 6 mm		
Odometer wheel resolution	2 mm/pulse		
max. wall thickness 42"	31 mm		
max. wall thickness 28"	27.1 mm		
min. internal bore in 28"	625 mm		
active range	750 km		
length of tool	appr. 7.5 m		
weight	4100 kg		
Reporting specifications	metal loss dimension	min. sizing depth*	depth sizing accuracy*
Internal metal loss	Ø>0.25T	15%	± 8%
(T = wall thickness)	Ø>0.5T	10%	± 5%
* % of T	Ø>1T	8%	± 5%
	Ø>2T	5%	± 5%
	Ø>3T	5%	± 5%
External metal loss	Ø>1T	10%	± 5%
	Ø>2T	8%	± 5%
	Ø>3T	5%	± 5%

Table 1: Key specifications for the multi-diameter metal loss inspection tool.

Data analysis and reporting regarding the information collected by the tool is analogous to the procedures followed for other high resolution magnetic flux leakage tools in the industry.

Optical Laser-Based Inspection Tool

A New Type Of Inspection Tool

The opto-electronic tool has been designed to provide an accurate and cost-effective solution for the inspection of the internal surface of pipelines and consists of a highly compact optical system built into a suitable mechanical pig frame. As with other in-line inspection tools the mechanical components must incorporate a drive unit, house the energy supply and provide room for the measurement and data storage devises. The development originates from an earlier attempt to visually inspect the interior of risers and shorter sections of pipe by conventional video recordings. However, the use of video proved to be impractical for other than very short lengths, due to severe power and data storage limitations. The solution to these challenges came with the introduction of a novel line scan camera and laser illumination technology. Figure 3 shows the principle applied. A continuously moving laser line illuminates the inner pipe wall. The reflected high intensity light is projected onto camera/optical sensors which are aligned at angles between 30º and 60º to the wall. By utilizing a triangulation principle on a two-dimensional sensor, the system can both measure the position of an anomaly and its intensit. By combining these two measurements, a three-dimensional image of the pipe surface can be displayed.

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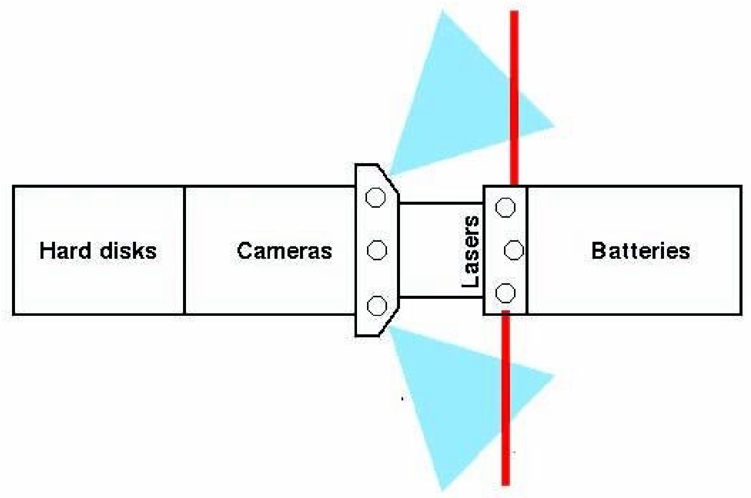

Figure 3: Opto-electronic inspection tool, working principle

In order to compensate for any disturbing vibrations during the ride through the line, the tool and for smaller diameters the individual tool bodies are supported by spring-loaded wheels. The tool consists of an inspection (e.g. laser/camera) unit and a carrier unit. The inspection unit, for instance for the 42 inch version, consists of eight lasers and eight cameras and is mounted on shock absorbers inside the carrier body. To simplify data and image processing, an anti-rotation facility is built into the carrier.
The inspection tool is fully autonomous, carrying onboard battery power and all necessary computer hard- and firmware. The laser based line scan technology is extremely power and data friendly making it possible to cover inspection ranges of up to 1000 km for the larger size tools, traveling at 5 to 10 m/sec.
The general mechanical design of the tool makes it suitable for use in telescopic lines, i.e. pipelines with varying diameter.

Self-Cleaning System

In order to make sure that all the optical lenses and orifices are kept clean, a permanent flow of gas is induced across the length of the tool due to the differential pressure across the tool. Any dirt or debris, due to dust or sediment in the gas transported is thereby kept from settling on the tool.

Data Visualization

Data recorded during a survey can be displayed immediately after a run has been completed and are easy to interpret. What you see is what you have, as can be seen clearly in figures 4a and 4b. This technology provides a very direct and quick means to assess the state of the internal surface of a line inspected. The data analysis software includes a variety of viewing options.

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Figure 4a: Photograph of a circular defect of 25 mm

Any anomalies are initially viewed by simply "surfing" through the pipeline. Viewing options include 2D- and 3D-representation as well as wire-frame configurations. The latter enable a detailed inspection of the pipe and the sizing of any flaws found. Figure 4a shows a regular photograph of an anomaly on the surface with a diameter of 25 mm. Figure 4b shows the same defect as seen by the tool and presented in a 2D mode. The software is also capable of providing a 3D visualization of that anomaly and a corresponding wire frame model, the latter used for depth measurement. The pictures clearly show that the resolution of the optical system is such that the viewer/data analyst obtains a "photographic" image of any anomaly detected.

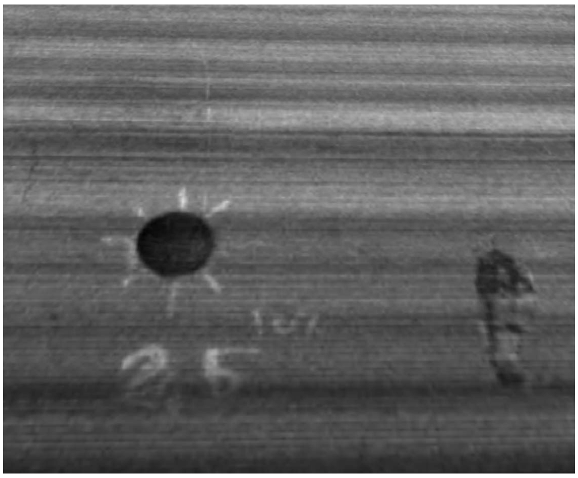

Figure 4b: 2D visualization by opto-electronic tool of defect shown in fig. 4a.

Technical Specifications

The optical and electronic system of the tool works with a depth resolution of 1 mm and a minimum defect size (area) of 2 x 2 mm. The optical resolution of the image is thereby better than 1 x 1 mm. The available mechanical adaptation kits enable the tool to be used for any nominal pipeline diameter from 10 inch through to 52 inch. The design incorporates the ability of the tools to inspect multi-diameter pipelines.

Inspection speeds of up to 5 m/s in gas and operational pressures of up to 200 bar can be accommodated. The tools are fairly light weight. For instance the weight of a 40 inch configuration for the inspection of a 100 km pipeline is only approximately 70 kg. Figure 5 shows a photograph of the 42 inch configuration of the tool.

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Figure 5: Picture of opto-electronic (OptoSurveyor) inspection tool.

Acceptance Tests

The opto-electronic tool has been used for a number of inspection projects to date including a positive "Factory Acceptance Test" (FAT) by DNV. The tool fully complies with a number of technical requirements placed upon it:

- high sensitivity and measurement accuracy regarding internal anomalies and flaws,
- internal corrosion/metal loss as well as any type of internal anomaly including geometric changes are detected and sized with a very high resolution,
- data access and data review are possible at site immediately after an inspection run,
- the tool has a full multi-diameter capability including the ability to negotiate diameter reduction (bore restrictions) of up to 50%.

Further Multi-Diameter Services

Prior to an inspection a pipeline must be properly prepared in order to ensure the success of the survey and achieve high quality data. This can be a challenge even for single diameter lines, but even more so for multi-diameter lines. For this reason a range of cleaning and geometry tools had to be designed and built. The caliper tool available is a single track electronic caliper tool with a multi-diameter capability.

True Quantitative Measurement

Wall thickness measurement and metal loss

Another technology available and ideally suited for the inspection of thick walled offshore pipelines is ultrasound. Ultrasound offers the advantage over other techniques of providing true quantitative wall thickness measurement capabilities of unparalleled sensitivity and accuracy. Ultrasound in-line inspection tools have been introduced in earlier publications /5,6/, therefore this paper will focus on latest development only.
By their mechanical design ultrasonic tools are usually also more flexible than conventional MFL inspection tools, i.e. tools which have not specifically been designed for multi-diameter use. 2 inch to 4 inch steps can usually be accommodated for by UT-tools without the need for major modifications. Other steps are possible if the tools are adapted for such an inspection. Wall thickness is no issue for a UT tool and there are no practical limitations with regard to offshore pipelines. A draw back from an operational point of view is the need of an ultrasound tool for a suitable liquid batch, i.e. the tools cannot be applied directly in a gas pipeline. However, if the improved measurement capabilities of a UT tool is needed, for instance due to increased integrity assessment requirements, then these tools can

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be run in a liquid batch, today a routine procedure. Many thousands of kilometers of gas pipelines have been inspected with ultrasonic tools to date.
New developments include ultrasonic tools in the size range of 6 inch and 8 inch which include the improved tool and defect specifications incorporated in the new generation of tools (LineExplorer) available since 2003. Improvements and advantages compared to earlier tools on the market are included in table 2.

Higher Inspection Speed	2.4 m/s for wall thickness measurement instead of 1 m/s at full defect specifications. (1.5 m/s for crack detection instead of 1m/s)
Improved Resolution	0.06 mm instead of a range of 0.2 to 0.4 mm for older tools.
Improved Resolution for Stand-Off Measurement	0.014 mm.
Higher Dynamic Range	Less echo loss, less sensitive to debris.
Higher Circumferential Resolution On Smaller Diameters	for instance 112 sensors on 8".
Combined Metal Loss and Crack Detection	Same tool can be used in a variety of configurations for metal loss, crack inspection, combined inspection etc.
Minituarized Electronics	Shorter tool length
New Electronic Design	Less Power Consumption therefore greater range.

Table 2: Improvements and Advantages

Figure 6 shows such an ultrasonic tool in its 6 inch configuration. Special version of the tool are also available for high temperature and high pressure applications. In order to also inspect loading lines and a variety of other pipelines with limited or difficult access the tools can also be configured for bi-directional operations.

Figure 6: 6" configuration of the ultrasonic wall thickness measurement tool (LineExplorer).

Table 3 includes key specifications for this range of tools. Figure 7 shows a typical examples of features found and displayed using the data interpretation software.

Inspection velocity at full spec	≤ 2.4 m/s
Maximum pressure	120 bar
Minimum bend	1.5 D
Axial sampling	appr. 3mm
Circumferential sensor spacing	appr. 8 mm
Detection metal loss at POD ≥ 95%	min. diameter 10.0 mm min. depth 1 mm
Discrimination int/ext.	yes
Depth sizing accuracy	resolution of wall thickness measurement 0.06 mm resolution of stand-off measurement 0.014 mm accuracy of depth sizing ± 0.4 mm
Length sizing accuracy	± 6 mm

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Width sizing accuracy	± 8 mm
Detection of mid-wall defects	e.g. laminations, inclusions etc.

Table 3: Key specifications for ultrasonic metal loss survey tool.

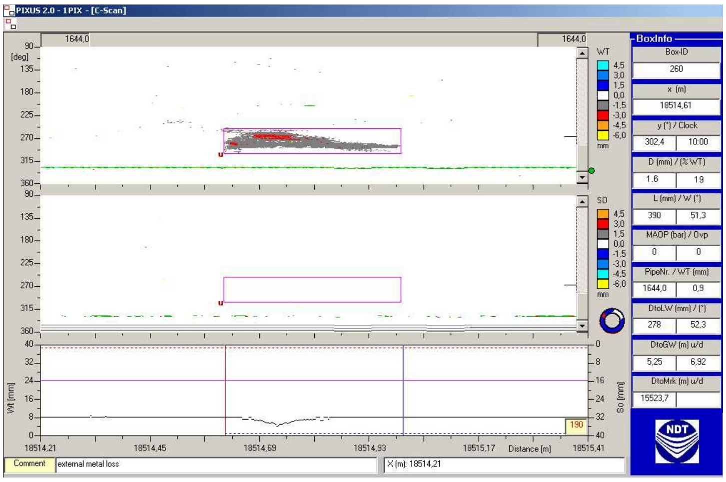

Figure 7: Typical display of an external metal loss detected and sized with an ultrasonic tool.

Crack Detection

A major advantage of the new generation of ultrasound in-line inspection tools available today is their ability to be used for metal loss surveys and for crack inspection surveys. If need be they can also be configured to perform both surveys in a single run. The tools have originally been designed to detect and size axial cracking, i.e. detecting and sizing cracks extending in the direction of the pipe. Typical examples of such crack geometries are fatigue cracks or stress corrosion cracks including stress corrosion colonies. Recently demand has however also grown to find cracks which have been experienced in the girth weld of pipelines. These cracks grow in a circumferential direction and require a special sensor carrier. This configuration is now available and has already been successfully applied during the inspection of offshore pipeline in the North Sea.
Table 4 includes key defect specifications for ultrasound crack detection tools.

Inspection velocity at full spec	≤ 1.5 m/s
Maximum pressure	120 bar
Minimum bend	1.5 D
Axial sampling	appr. 3mm
Circumferential sensor spacing	appr. 10 mm
Defect type	axial cracks and crack-like defects, e.g. SCC, fatigue cracks, weld cracks. (optional: circumferential cracks).
Discrimination int/ext.	yes
Min. Length Min. Depth	30 mm 1 mm in base material & at weld (2 mm in weld)
Length sizing accuracy	± 10 mm for L ≤ 100 mm ± 10 % for L ≥ 100 mm

Table 4: Key specification for crack detection tool.

Combined Metal Loss and Crack Inspection

The ultrasound tool described above is also available in a special configuration combining metal loss and crack detection, incorporating the full defect specifications. Such a tool has been successfully run for the first time commercially in a pipeline in Europe this summer. Combining both inspection tasks leads to major cost savings from a logistics and from an operation point of view.

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