Laura Seto, Enbridge Pipelines Inc., Canada, and Dr. Thomas Hennig and Thorsten Sickinger, NDT Global GmbH, Germany, introduce an innovative multi-diameter crack and corrosion tool for challenging pipelines.

Multi-diameter methods

A 36/48 in. dual diameter pipeline needed to be inspected for wall thickness and axial cracking in a single run. Each pipeline segment differs in length, and has a different range in wall thickness. A challenging characteristic of the line was the 36 in. launcher and 48 in. receiver in 28 of the sections. Thus, the resulting outer diameter change is about 305 mm or 33%. From an intelligent inspection perspective, additional boundary conditions had to be taken into account, for example tight 1.5 D bends and a medium with high attenuation – which is especially important for the crack inspection technology. A tool utilising ultrasonic inspection technology was requested by the pipeline operator, because current conventional MFL technology was limited in detecting and identifying certain metal loss morphologies, such as narrow axial external corrosion (NAEC). Additionally, UT technology would provide direct measurement of features, compared to magnetic flux leakage technology (Kopp & Willems, 2013).[1]

The project objective was to design, build, and test a multi-diameter (36/48 in.) capable inline inspection (ILI) tool based on ultrasonic technology that could inspect for both metal loss and cracking in a single pass. The minimum tool performance was to meet or exceed current published

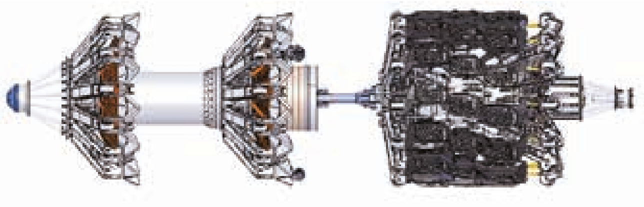

Figure 1. Design of two segment 36/48 in. multi-diameter UM/UC combo tool. The pull unit with batteries (left) and sensor carrier with tool electronics (right).

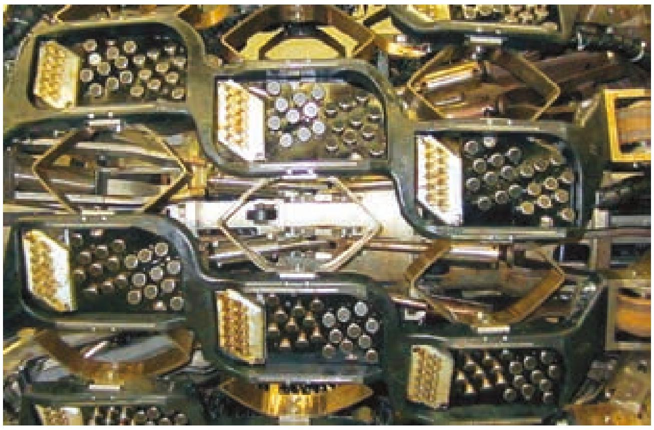

Figure 2. Photograph of the expanded sensor carrier mounted on transport frame. Three groups with black/grey (crack transducers) and silver/bright (wall thickness transducers) are visible within each skid.

Table 1. Overview of mechanical requirements for a 36/48 in. multi-diameter metal loss and crack inspection tool

	36 in.	48 in.
Wall thickness range	4 - 20 mm	
Temperature range	-10 ˚C to 50 ˚C	
Maximum pressure	120 bar	
Minimum ID in straight pipe	813 mm	
Velocity range at full specification	0 - 1.4 m/s	
Minimum bend radius	3 D	1.5 D
Circumferential UC sensor spacing	10 mm	
Circumferential UM sensor spacing	8 mm	
Number of crack/WT sensors	760/468	
Battery life time approximately	65 hrs	
Tool length	<9 m	

Figure 3. Picture of launching tube connected to transport frame.

performance specifications for NDT's conventional UT tools for metal loss (UM/UMp) and cracking detection and sizing (UC) tools.

Tool design

NDT was asked to develop a tool and prove functionality based on a pre-agreed testing procedure. The main challenges within this development process were:

- Mechanical passage and reduction capabilities in 36 in. and 48 in. section.
- 100% coverage in 48 in. section for wall thickness and crack detection.
- Handling, launching and receiving equipment for 36 in. and 48 in. section.

Besides the challenging mechanical boundary conditions, a detailed test procedure was agreed upon to determine the capabilities of the tool, including mechanical aspects, feature detection and sizing capabilities. Table 1 provides an overview of the major requirements for the tool design from a mechanical point of view.

The proposed design for the 36/48 in. multi-diameter ultrasonic wall thickness and crack detection (UCM) tool consists of only two segments (Figure 1).

For the sensor unit, a combination of wall thickness (UM) and crack (UC) transducers on one skid was proposed. The approach offered the possibility to gather all relevant wall thickness and crack information in one inspection run and reduce the effort and costs for both the pipeline operator and inline inspection company. Furthermore, the combination of both technologies on one tool offered the data analysis team an excellent combined and synchronised dataset.

The major challenge within the sensor carrier design was the 100% coverage in 48 in. and collapsibility down to 36 in. dia. The proposed solution is shown in Figure 2. A staged arrangement of three transducer groups within each skid was selected as a basis component. The black/grey sensors represent the crack detection; the bright/white plate on the left side is the wall thickness transducers; every group contains clockwise and counter clockwise transducers. In the 36 in. section the entire sensor carrier is compressed and all skids are close to each other – the space in between neighbouring skids is minimised. In the 48 in. pipeline the gap between the skids increases, but the required 100% coverage is still guaranteed with this staged approach.

Launching and receiving equipment

Due to the wide operating range, from inflated to compressed tool, special launching equipment had to be developed. Different options were analysed, and the option pursued limited the number of times the launcher trap door would be opened. The main aspect to consider during the design of the launch equipment was the force required to compress the pull unit and sensor carrier from 48 in. to a 40 in. launching size. Figure 3 depicts the extended hydraulic launching equipment fully expanded.

The transport frame is connected to the launching tube with a short reducer spool to assist the compression of the tool from a 48 in. to a 40 in. OD. Once inserted in the launching tube, the entire assembly is mounted in front of the opened launcher trap and the tool is pushed with a hydraulic system into the launcher.

Workshop and validation procedure

As previously mentioned, Enbridge and NDT agreed on a standardised test and validation programme for the new tool. Generally, two main aspects would be validated:

- Mechanical passage and collapsibility in 36 in. and 48 in.
- Detection and sizing capabilities for wall loss and crack like indications according to specification.

A test loop was designed and built in the NDT test area in Stutensee that included a 3 D bend and a 36/48 in. transition zone according to the client's specification. For safety reasons the test was separated into a pull test, and if successful then a pump test. Neither the pull test from 36 in. to 48 in., nor the pump test showed any negative indications. The recorded speed profile in combination with the pressure readings at launcher and receiver indicated excellent sealing capabilities of the pull unit in the 36 in. and 48 in. segments, and within the bend.

For validating the detection and sizing capabilities a variety of test defects were introduced in two spools of different diameter. All test defects were made using the electrical discharge machining (EDM) technique. Almost 200 internal and external metal loss defects and notches were introduced in the pipe spools. The defects were located in the base material, close to and in the long seam (Figure 4).

Three pump tests (two with straight pipe and one with a bend) in a combined 36/48 in. line with artificial UM and UC features were conducted and analysed. For the UM features, the tool fully met the feature specification in detection and sizing in both pipe diameters. Table 2 provides an overview of the achieved detection and sizing capabilities for the wall thickness data in 36 in. and 48 in. pipe.

With successful pull and pump testing, the next step was to run the tool in an operational pipeline. The data quality check post run showed no indications for degradation of data/tool performance. The mechanical condition of the tool was excellent.

Figure 4. Photograph of 48 in. test spool with test defects.

Table 2. Statistical pump test results performed at NDT test facility for wall thickness features in 36 in. and 48 in. spool

		All test anomalies	In spec	POD (%)/ confidence level (%)
36 in.		162	117/117	100
36 in.	Depth +/- 0.4mm (%)	99	100	100
36 in.	Length +/- 6mm (%)	95	95	98
36 in.	Length +/- 8mm (%)	94	92	96
48 in.		168	117/113	99
48 in.	Depth +/- 0.4mm (%)	98	100	100
48 in.	Length +/- 6mm (%)	95	92	96
48 in.	Length +/- 8mm (%)	97	96	98

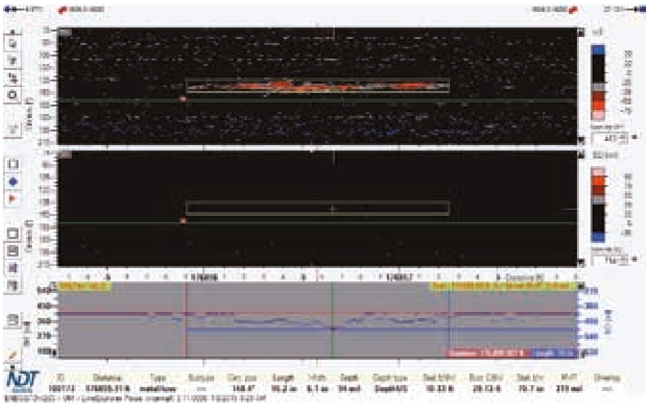

Figure 5. C-Scan representation of wall thickness data. Top: wall thickness reading. Bottom: stand-off data.

Analysis of wall thickness and crack data

The selected tool design provides both crack and wall thickness data in one dataset; the data is synchronised in the axial and circumferential direction. No additional effort is needed within the data processing to adjust or synchronise the data. The advantage of having the data synchronised is obvious, such as the improved classification of anomalies. For example, the crack data displayed in Figure 6 shows an indication of a crack-like anomaly in C-Scan representation of ILI data.

The wall thickness data shows a clear decrease of remaining wall thickness, and an external corroded area was identified by the analyst (Figure 5). The upper part of the plot represents the wall thickness reading, the lower plot is the stand-off information. Black represents the nominal wall thickness; coloured areas indicate a decrease of wall thickness. The maximum depth for this corrosion was about 94 mils (2.4 mm). The shape and contour indicated steep sided corrosion. The crack data on its own would have led to classification of a 'crack-like' feature, whereas the combined analysis clearly characterised it as a corrosion feature. Due to the steep sided morphology and the narrow corrosion signals generated within the crack dataset, characterisation of the feature may be misleading in the analysis. Consequently a combined inspection and analysis increases the overall quality of the inspection service.

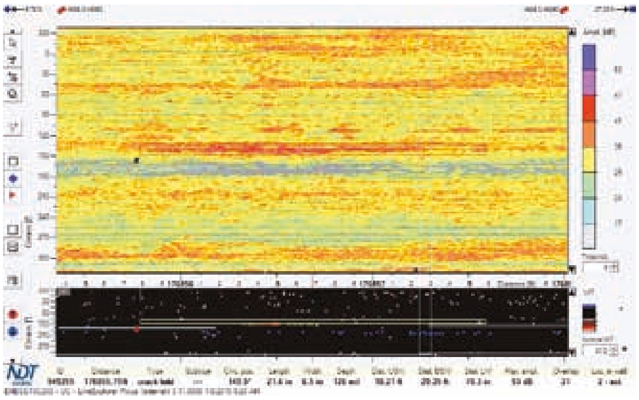

Figure 6. C-Scan representation of crack data. The red box indicates a crack-like anomaly defined by the automatic boxing algorithm.

Evaluation of results and outlook from client

The tool was conditionally validated and commercialised in early 2013, after seven performance evaluation runs. With respect to metal loss detection (UM performance), the tool is fully tested and validated. The conditional validation is for the crack detection (UC performance), because the tool has not yet had the opportunity to detect and evaluate cracks greater than 2.5 mm in depth. From April 2014 onwards, additional verification campaigns are scheduled to further validate the tool and its sizing capabilities.

Since July 2012, the tool has been run 31 times in different segments of the dual diameter line, which equates to approximately 2000 km. The overall first run success rate for the 36/48 in. UCM tool, including the prototype inspections and pre-agreed inspection to analyse repeatability, sums up to 91%.

The tool's design also allows for inspection of single diameter lines ranging from 36 - 48 in. OD. Therefore, the benefits of the tool are not isolated to the dual diameter line, and can be applied to any single diameter line that requires metal loss and crack inspections in a single run.

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References

1. KOPP, G. and H. WILLEMS, Sizing limits of metal loss anomalies using tri-axial MFL measurements: A model study, NDT&E International, pp 75 - 81, 2010.
2. United States Patent: Device for moving a pig through a conduit, such as a pipeline, and sealing means for a device of this type, 2002, Patent No.: US 6 381 797 B1, 7 May, 2002.