Pipeline External Corrosion Analysis Using a 3D Laser Scanner

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Abstract

Pipeline operators are getting increasing pressure from regulatory authorities and environmentalists to guarantee the integrity of their pipeline network, while facing financial pressure to minimize their maintenance cost. This paper presents a new approach to pipeline external corrosion and mechanical damage direct assessment using a 3D laser scanner with dedicated software. The improvements over other traditional non-destructive-testing (NDT) techniques such as manual pit gauge will be discussed. We will illustrate how the latest 3D optical innovations support the need for improved data quality, inspection speed and repeatability for this application. The scanner can acquire the damaged surface with constant accuracy in a vibrating field environment by replacing typical mechanical attachments with a contactless dynamic referencing system. Compliance with existing code is of essence and therefore serves as the starting point for the analysis tool. Demonstration of the system capacities applied to this specific application will be discussed.

1. Introduction

Pipeline operators have to inspect their pipeline network directly or through NDT inspection service companies. In-line inspection (ILI) tools allow the identification of critical zones with external corrosion or mechanical damage by magnetic flux leakage (MFL) or ultrasonic (UT) methods. The code specifies that a prove-up from the outside of the pipeline is required for critical zones, often requiring excavation. Various techniques can be used as a direct assessment technique to identify appropriate remediation. Each technique presents certain limitations which can be minimized or avoided with the latest 3D optical innovations coming from metrology quality control and now applied to NDT applications.

A manual measurement method using a pit gauge makes the inspection dependant on the inspector skills. It brings variable results, a lengthy inspection process considering the high number of data points required, and limited report quality. UT methods require constant water coupling, which becomes difficult on rough surfaces due to water loss and probe misalignment. Precision is also limited by the front wall echo interface. UT probes must be positioned with a mechanical scanner complying with different pipe diameters, adding complexity while reducing portability. Furthermore, the small size of a UT probe for a full coverage C-Scan requires high

speed displacement for reasonable inspection time. This method is more suited for internal corrosion considering a smooth external surface.

Conventional one-line laser systems eliminate the need for water coupling and offer a much larger coverage. Unfortunately, they also bring other limitations in portability caused by the mechanical fixture to hold the system as it rotates around the pipe. We also need to consider the system sensitivity to laser lift-off and its incapacity to compensate for vibrations which quickly impact measurement accuracy.

The latest innovations in 3D optical keep the advantages of the conventional laser method while solving most of its disadvantages. The EXAscan (1) shown on figure 1, patented and manufactured by Creaform (2), uses a dynamic referencing system which allows a light scanner design with small dimensions and a non-contact process. The 3D scan is perfectly scaled to be representative of the real geometry and allows easy external defect visualisation. The analysis software must be able to manage a large quantity of data to generate a report in minutes with comprehensive results to facilitate decision making.

This document presents how these issues can be addressed using a portable 3D laser scanner and appropriate analysis software. The scanning procedure will be described, followed by the impact of 3D laser technology on data quality, scanning speed and finally, reproducible results.

2. Scanning Procedure with a 3D Laser Scanner

2.1 Equipment

It is fairly simple to use a 3D laser scanner. Required material includes the 1 kg 3D scanner, a laptop computer with Pipecheck (3) software installed, and a rugged Field-Pack with its touchscreen wireless tablet allowing real-time data visualisation in field environments. The equipment is shown in figure 2.

Figure 1: Portable 3D laser scanner

(1) EXAscan: Product trademark property of Creaform
(2) Creaform: Registered company under Creaform inc. in Canada
(3) Pipecheck: Pipeline integrity software trademark property of Creaform

2.2 Setup

The first step is to prepare the pipeline surface for the scan and calibrate the unit. As with all other inspection techniques, a sandblasted surface clean of dust and dirt will yield better results. The 3D scanner requires the use of reflective targets that are typically 6 mm diameter stickers or magnets applied randomly on the pipeline. The spacing between targets will be approximately 10 cm but varies depending on the pipe diameter. This 3D positioning system allows the scanner to be highly portable and to compensate for vibrations in field environments to preserve accuracy.

2.3 Data Collection

The second step is to acquire the corroded area of interest on the pipeline outside diameter. Once the acquisition parameters are set, the inspector holds the scanner at approximately 25 cm from the pipe surface and pulls the trigger to start the acquisition. The scanner is manually moved along the pipe to paintbrush the area of interest. The inspector will look at the laptop screen or tablet to validate the scan coverage. The 3D file is saved in STL format.

Figure 2: On-site inspection with the 3D laser scanner solution

2.4 Analysis

The third step is the data analysis. The inspector enters the pipeline parameters and analysis criteria before calculation are launched with the pipeline 3D scan file. These parameters are useful for burst pressure calculation and to apply interaction rules. A report is auto-generated in Excel format, ready for assessment to determine pipe remediation.

3. Improved Data Quality

3.1 Dynamic Referencing System

Dynamic referencing represents one of the most important innovations for pipeline external corrosion and mechanical damage inspection with laser. Ensuring in-situ laser acquisitions with constant accuracy within specifications is a challenge that can be easily overcome by positioning the scanner spatial referential directly on the pipe, as shown in figure 2 and 6. Since the pipe and the spatial referential are linked together, they both move in a synchronised manner which compensates the pipe and scanner movements. On the other hand, a static measurement system will only achieve comparable results in a controlled lab environment.

3.2 Virtual Pit Gauge Method

The manual pit gauge inspection technique is the point of comparison for all other techniques developed for external corrosion analysis since the ASME B31G and equivalent code were written based on single point measurements in a grid pattern. The numerical method must therefore reproduce the manual method to obtain comparable depth measurements. The proposed analysis software uses a virtual pit gauge to simulate the physical contact between the pit gauge and the pipeline.

Depth measurement with laser requires a virtual reference surface to find the distance between the actual pipe topography and the nominal external surface. The construction of this pipe reference surface is essential to obtain meaningful results. One method consists in regressing a perfect cylinder feature aligned with the scanned pipe. However, this method does not compensate for any flatness, ovality or deformations affecting the real pipe geometry, as demonstrated by the light blue line across the scan on the left side of figure 3. The proposed method using a virtual pit gauge compensate for the pipe geometrical deviations with a best-fitted surface made from the unaffected areas around the corrosion, as shown on the right side of figure 3.

Figure 3: Cylindrical reference vs Virtual pit gauge reference surface
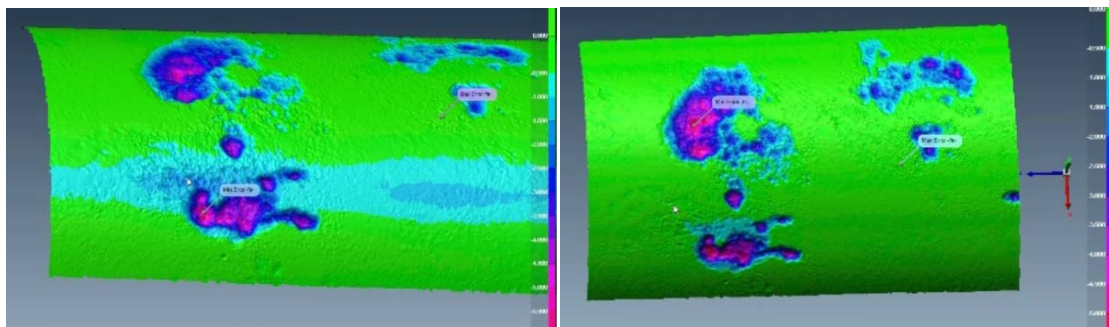
3.3 Repeatable Results

Corrosion depth measurements on a 8mm wall thickness pipe were taken using a virtual pit gauge analysis method. The data collection and the analysis were performed 3 times by 3 different inspectors. The variations between the scans were kept within +/-50 microns, regardless of the inspector who performed the scan and analysis.

Table 1: 3D Scanner Repeatability

	Position	1	2	3	4	5	6	7	8	9	10
Inspector 1 **Scan 1**	**Depth (in)**	0.032	0.032	0.036	0.036	0.034	0.040	0.039	0.053	0.049	0.056
Scan 2	**Depth (in)**	0.032	0.032	0.037	0.035	0.035	0.040	0.039	0.054	0.048	0.056
Scan 3	**Depth (in)**	0.032	0.033	0.035	0.035	0.033	0.039	0.038	0.055	0.049	0.055
	Δ Depth	**0.000**	**0.001**	**0.002**	**0.001**	**0.002**	**0.001**	**0.001**	**0.002**	**0.001**	**0.001**
Inspector 2 **Scan 1**	**Depth (in)**	0.032	0.032	0.038	0.035	0.033	0.038	0.039	0.051	0.046	0.053
Scan 2	**Depth (in)**	0.031	0.033	0.037	0.036	0.032	0.038	0.038	0.053	0.045	0.054
Scan 3	**Depth (in)**	0.031	0.032	0.036	0.035	0.033	0.039	0.040	0.051	0.047	0.054
	Δ Depth	**0.001**	**0.001**	**0.002**	**0.001**	**0.001**	**0.001**	**0.002**	**0.002**	**0.002**	**0.001**
Inspector 3 **Scan 1**	**Depth (in)**	0.033	0.035	0.038	0.036	0.033	0.038	0.037	0.052	0.045	0.053
Scan 2	**Depth (in)**	0.034	0.034	0.037	0.038	0.035	0.038	0.037	0.052	0.045	0.055
Scan 3	**Depth (in)**	0.033	0.034	0.038	0.037	0.035	0.039	0.039	0.054	0.047	0.055
	Δ Depth	**0.001**	**0.001**	**0.001**	**0.002**	**0.002**	**0.001**	**0.002**	**0.002**	**0.002**	**0.002**
Inspector 1	**Max Depth**	0.032	0.033	0.037	0.036	0.035	0.040	0.039	0.055	0.049	0.056
Inspector 2	**Max Depth**	0.032	0.033	0.038	0.036	0.033	0.039	0.040	0.053	0.047	0.054
Inspector 3	**Max Depth**	0.034	0.035	0.038	0.038	0.035	0.039	0.039	0.054	0.047	0.055
	Δ Max Depth	**0.002**	**0.002**	**0.001**	**0.002**	**0.002**	**0.001**	**0.001**	**0.002**	**0.002**	**0.002**

3.4 Auto-Generated Reports

Code compliant inspection results are available immediately after the analysis is done as shown in figure 4, and through an auto-generated report in Excel format shown in figure 5. Having both 2D and 3D representations of the corroded pipe ensures a clear visualization and understanding of the surface condition for the entire scan. A color scale helps to quantify the variations in corrosion deeper than a specified percentage of the nominal wall thickness. The analysis software will automatically find the deepest points to retrieve the most probable path of failure on the corrosion zone and apply an overlay on the 3D view. Each corrosion zone is analysed separately, according to the selected interaction rules, to obtain its position, maximum depth and burst pressure.

A separate software module in Pipecheck allows the analysis of mechanical damage on pipelines because it requires different measurement methods and output information. The scanning procedure is the same but the analysis will provide specific dent related information such as dent profiles, radius of curvature, deepest point in the dent, and pipeline ovality.

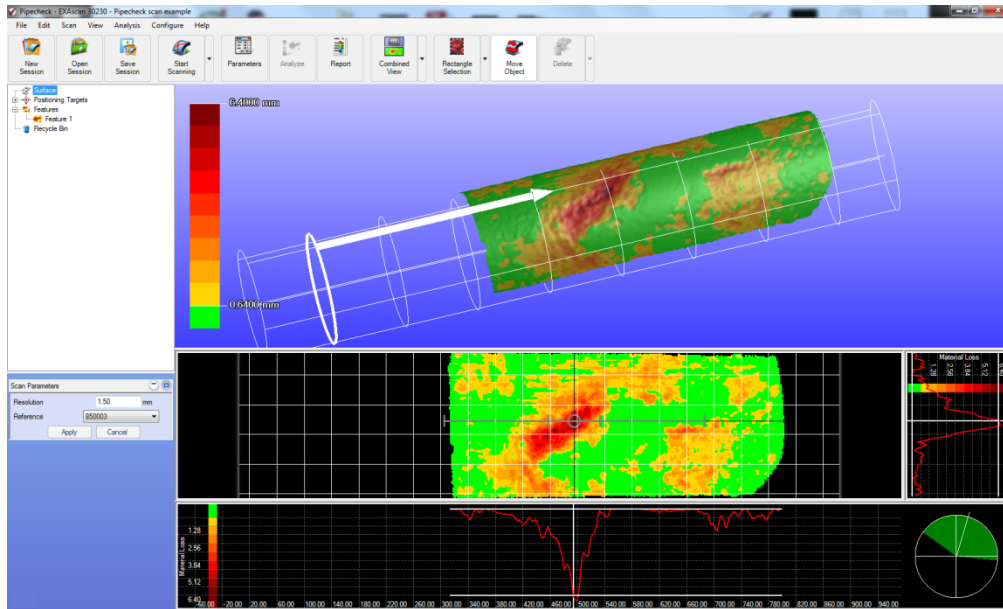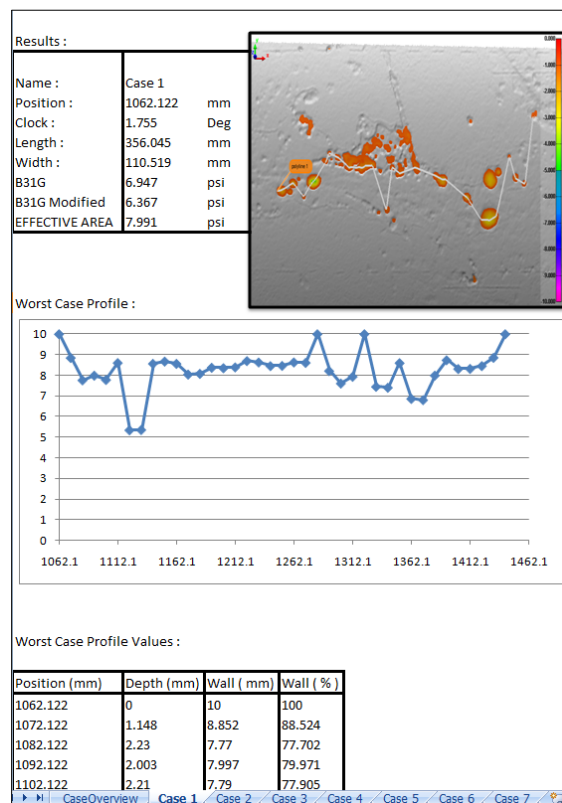Figure 4: Analysis results in 2D and 3D after calculation

Figure 5: Auto-generated external corrosion report in Excel

Results :

Name :	Case 1	
Position :	1062.122	mm
Clock :	1.755	Deg
Length :	356.045	mm
Width :	110.519	mm
B31G	6.947	psi
B31G Modified	6.367	psi
EFFECTIVE AREA	7.991	psi

Worst Case Profile :

Worst Case Profile Values :

| Position (mm)	Depth (mm)	Wall (mm)	Wall (%)
1062.122	0	10	100
1072.122	1.148	8.852	88.524
1082.122	2.23	7.77	77.702
1092.122	2.003	7.997	79.971
1102.122	2.21	7.79	77.905

4. Inspection Speed

With an acquisition rate of 25 000 points per second, the scanned surface is reconstructed in real-time to form a 3D mesh file (.stl). The inspector can validate the data collection by looking at the laptop computer screen or tablet, as shown in figure 6. It takes less than 10 minutes to scan a 1m² area. Running a complete analysis will take less than 30 seconds. One person alone is able to carry the system on-site and perform both the scan and the analysis.

Figure 6: Data collection mode in Pipecheck
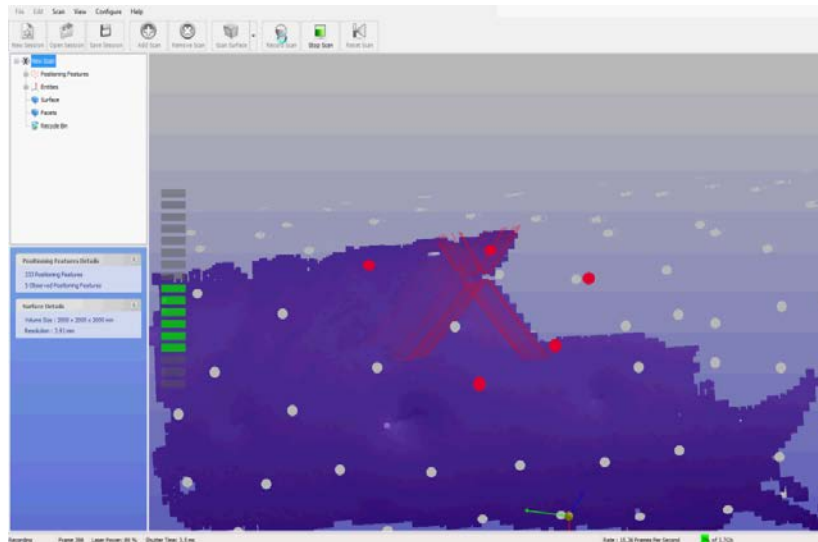
Graph 1 shows a scanning speed comparison between the pit gauge technique and the 3D laser scanner solution using a 10mm grid pattern. This trial takes into consideration setup, scan and analysis time. The larger the scan, the more advantageous it becomes to use the 3D laser solution. Using the 3D laser method for a large corrosion zone can reduce the inspection time by a factor of 10 and more.

Graph 1: Scan speed comparison
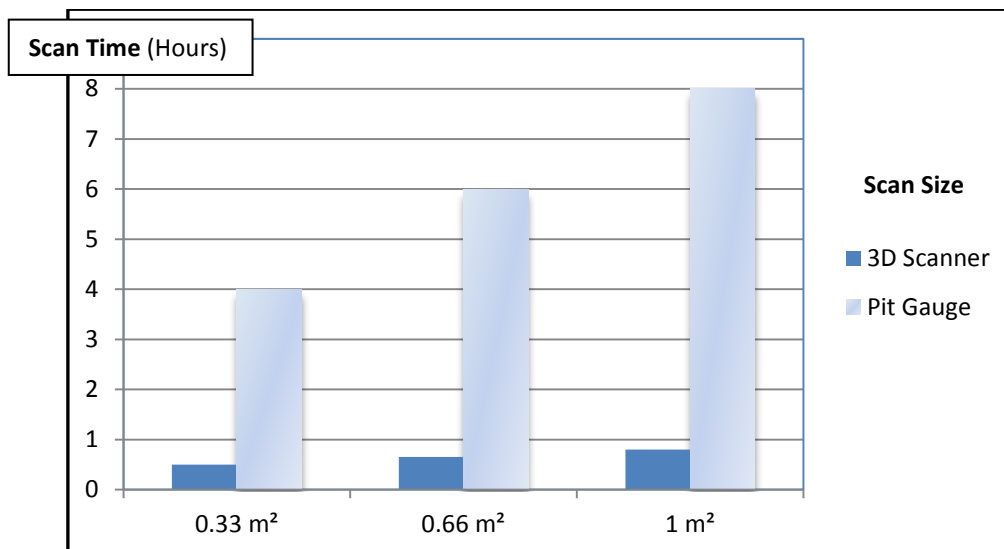
5. Repeatable Data Collection

This section explains the importance of various scanner and software features to ensure repeatable results, regardless of the environment and operator.

5.1 Positioning System

Reflective targets must be positioned on the pipe so the scanner can reference itself by triangulation with its binocular vision. The reflective targets are randomly positioned on the pipeline to create a unique pattern and also facilitate the setup, as shown on figure 7. If the same pipe surface is scanned twice with different target positioning, both scans will be the same, again to eliminate the operator skill factor.

Figure 7: Reflective targets randomly positioned

Since data is not distorted from a scanner misalignment with the pipe, using 3D surface representation increases depth measurement accuracy. The 3D scanner allows scan angles up to 45 degrees in any direction and scanner orientation.

5.2 Focal Distance

Another important scanner feature to consider is the focal distance, considering optimal inspection can only be achieved within a certain distance range between the scanner and the pipe. Using a proximity indicator on both the software scanning window and scanner using LED, the inspector is kept informed at all time during acquisition. However, the system will automatically stop data acquisition if the scanner is out of focus or out of tolerance.

5.3 Surface Reconstruction

During the acquisition with the 3D laser scanner, a mesh surface file is updated in real-time to avoid computing point clouds. When data points are not linked together, it leaves the possibility of overlapping multiple points on the same location creating noise in the scan. Furthermore, merging point clouds generate deviations like roof angles or offsets that can be avoided with a mesh file.

5.4 Automated Analysis

Data analysis follows the same approach to ensure repeatability with pre-programmed calculation and software operations. The inspector only needs to input the known pipeline parameters required for burst pressure calculation and interaction rules in the table shown in figure 8. The analysis is based on ASME B31G code to comply with code and ensure best practices.

Figure 8: Pipe parameters input table for data analysis

6. Conclusions

1. The portable 3D laser scanner solution discussed in this document is the logical evolution over traditional NDT techniques for pipeline external corrosion and mechanical damage inspections.
2. The latest innovations in 3D laser scanning provide improved data quality using a unique dynamic referencing system and appropriate reference surface.
3. The inspection speed can be reduced by a factor of more than 10 times the pit gauge technique considering the time to setup, perform the inspection, and run the analysis to generate a report.
4. Repeatable results are ensured by the scanner design and auto-generated report within a +/- 50 microns accuracy.
5. This inspection procedure proves to reproduce the manual pit gage technique and follows code regulation.

References

1) ASME B31G, Manual for Determining the Remaining Strength of Corroded Pipelines, American Society of Mechanical Engineer, 2009