Application of 3D Laser Method for Corrosion Assessment on a Spherical Pressure Vessel

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Abstract

Oil & Gas pressure components found on power plants and refineries must be inspected on a regular basis to ensure fitness-for-service. Corrosion is one of the most critical and recurrent degradation that must be inspected under API-579 code. Various non-destructive methods have been used to measure corrosion. A contact method is always problematic due to the deteriorated external surface. Encoding a scan is also a challenge, requiring mechanical scanners or fixture to fit the specific component geometry for referencing the defect position. 3D laser scanning is emerging as an efficient alternative for accurate surface degradation and offers the versatility needed to inspect various geometries with a same system. The analysis is performed using post-treatment software to generate all required measurements for assessment. This paper describes how metal loss can be measured from a 3D laser mesh file compared to a reference surface. Case study of a corroded spherical pressure vessel will be discussed.

Key Words: 3D laser scanner, NDT, fitness-for-service, pressure vessel, corrosion, API 579, depth measurement.

1. 3D laser system for surface inspection

The EXAscan, manufactured by Creaform, is a portable 3D laser scanner used to accurately map the surface of a free form object as seen in figure 1 and 2. A laser cross is projected on the surface while two cameras read the laser cross profile to build a 3D scan file (mesh) in real time. The scanner is self-positioned by triangulation of randomly positioned reflective targets. This non-contact inspection technique eliminates the need to mechanically fix the scanner to the part being scanned for encoding.

Figure 1: EXAscan in the field with wireless tablet to visualise data

Figure 2: EXAscan 3D laser scanner

The concept of scanner accuracy and resolution must be clarified. The total accuracy of the system is the punctual accuracy in addition to the volumetric accuracy per meter of scan. The accuracy for a 3D laser scanner is defined as the maximum deviation in a spherical radius around the real point value. The volumetric accuracy is the stacking error per meter of linear scan induced by the positioning system or maximum cumulative errors of measurements over a distance. The term accuracy is intrinsic to the scanner design and is not related to the scan resolution for a 3D scanner. The data points in a mesh file are linked together to form an organized pattern of triangles of equal size. Each vertex has the specified accuracy. Resolution is a parameter input specified by the inspector to define the size of the triangles used to build a 3D mesh file. A typical mesh file of a corrosion scan is shown in figure 3.

The 3D laser scanner comes in replacement to the pit gage and ultrasonic probe techniques mainly because of the acquisition speed, the independence from inspector skills, and its 100% coverage of the corroded area instead of single point measurements in a grid pattern.
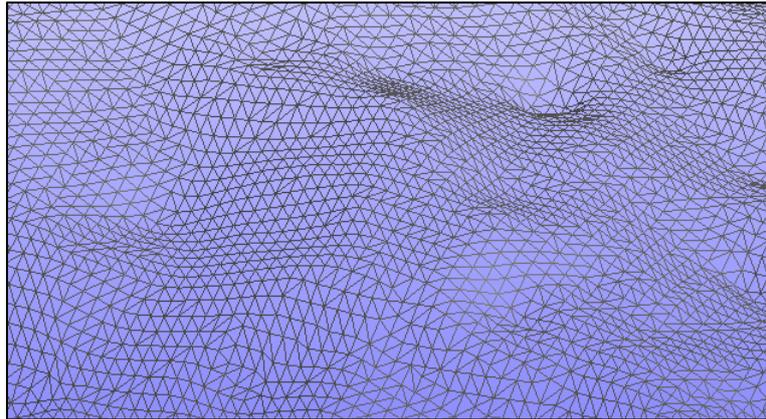
Figure 3: 3D mesh file in STL format

2. Analysis of 3D mesh files

The laser offers a complete coverage of the damaged area in 3D allowing any measurement to be taken from the outside surface. The raw data is a mesh file saved in STL file format in VxElements data collection software and is available for future assessments and audits.

In order to measure depth based corrosion from a mesh, a reference surface must be created to recreate a localized nominal surface without corrosion. There are three ways to generate a nominal reference surface. The first one consists in comparing the scan to the original CAD model. However, the CAD model for components under maintenance is rarely available and can present deviations from the actual geometry. A second method is to create in post-treatment software a theoretical geometry approximating the object initial geometry. The third and most accurate method is to reconstruct a surface based on a free-form model best-fitted to the real component geometry.

The same technique can be used on various structure geometries such as cylindrical, conical or spherical pressure vessels, pipelines, and structural beams with flat surfaces. Pipecheck software should be used to improve efficiency on pipeline inspection.

3. External corrosion assessment on a spherical pressure vessel

3.1 Introduction

In order to evaluate fitness-for-service of a pressurized component, level-2 assessment is based on a series of depth measurements. Gathering a maximum number of data points with a 3D laser scanning will yield the best estimate of the real component condition, providing the analysis is performed properly.

This case study of external corrosion assessment on a 12.4m diameter spherical pressure vessel describes the different aspects to consider when analysing the data.

Figure 4: Spherical pressure vessel

3.2 Scan Procedure

The corroded area must be cleaned to obtain optimal results since the scanner will scan what it sees regardless of the material. Then, positioning targets are randomly placed around the corrosion pattern to allow 3D encoding of the scanner. Typical spacing between targets is approximately 10cm. The area of interest is scanned at 1mm resolution with the Handyscan3D to acquire 100% of the area of interest. A mesh file is created in VxElements and saved as STL file format. This file is imported in Polyworks post-treatment software to create the reference surface, take measurements and generate a report.

Figure 5: Corrosion at the bottom of pressure vessel

3.3 Creation of a reference surface using a perfect geometrical feature

The local scan area is used to fit a perfect sphere geometrical feature to serve as a reference surface. We need to choose the best geometry to represent the object. Figure 6 shows the fitted sphere represented in grey.
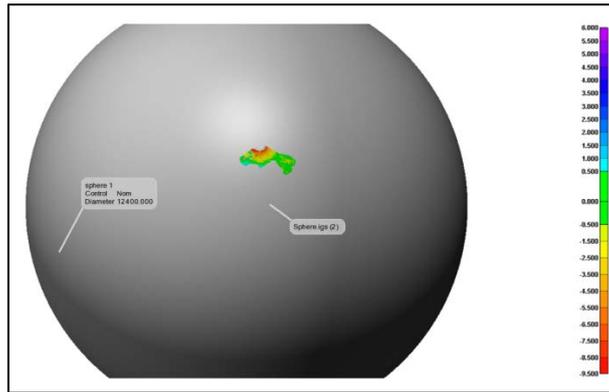
Figure 6: Spherical fit reference

The color map in figure 7 shows a change in curvature at the bottom of the vessel. The deviation from the perfect sphere is shown in red and orange colors; green represents a good fit. It means using a perfect sphere is a good solution for most of the vessel but certain areas should be analysed separately for optimal results.
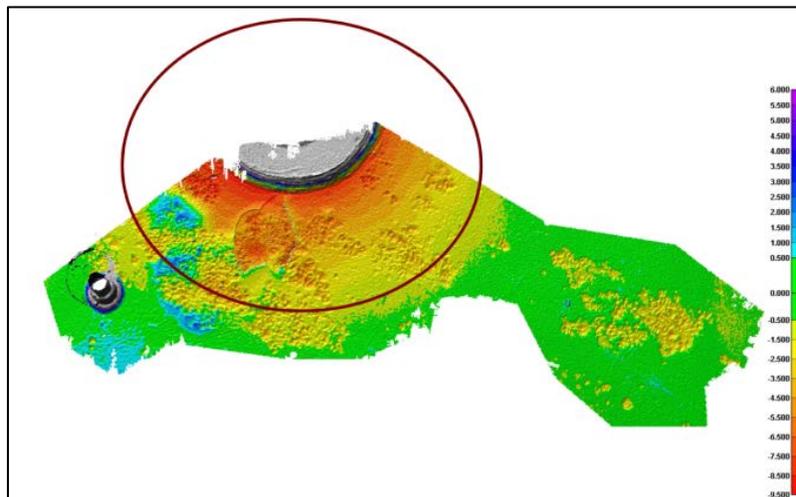

Figure 7: Comparison of 3D scan with spherical fit reference

3.4 Localized fit of a perfect geometrical feature

By fitting a spherical entity to a very small area manually selected around the corrosion, we are able to improve the fit locally to obtain more accurate results. With this method, we need to reject all surfaces outside of the selection as shown in figure 8 and 9. This is an extreme case of an area less spherical than most of the vessel. Therefore, it is possible to quickly analyse corrosion with a perfect localized sphere even if the overall real shape is subject to slight mechanical deformations.
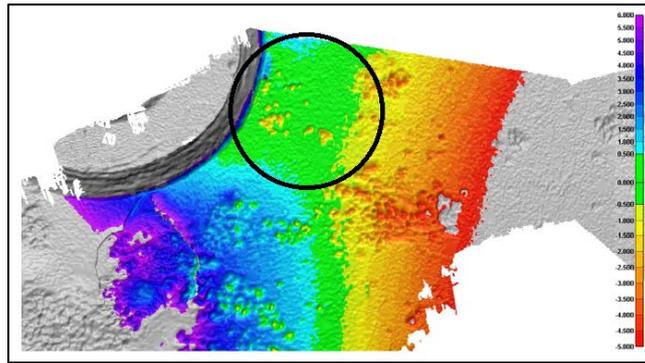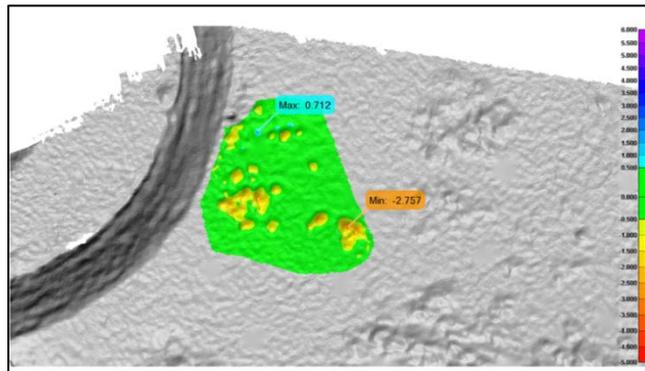
Figure 8: Localized spherical fit

Figure 9: Corrosion analysis with localized fit method

3.5 Creation of a free-form model from the scanned geometry

A model following the scanned surface geometry can be created by applying NURBS patches to the surface. The model shown in figure 10 becomes a realistic CAD model representation in IGES file format which can be compared to the initial STL for depth measurements.
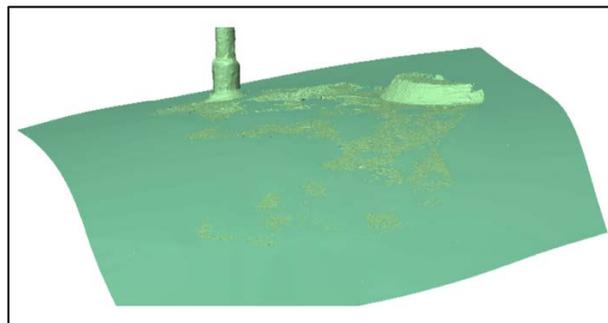

Figure 10: Spherical fit based on localized selection

A free-form model will compensate for geometric deviations such as out-of-roundness, flatness, bends, or any deviation from a theoretical geometry. A better fitted model means more accurate results due to compensation for surface deviations. A good fit is represented in green in figure 11. The warm colored indications represent corrosion based on the color scale which can be adapted according to a specific threshold or critical factor. The cold color indications help to identify positive material deviations on the surface such as paint bubbles and flaking. Paint should be removed from these areas before inspection for improved results.
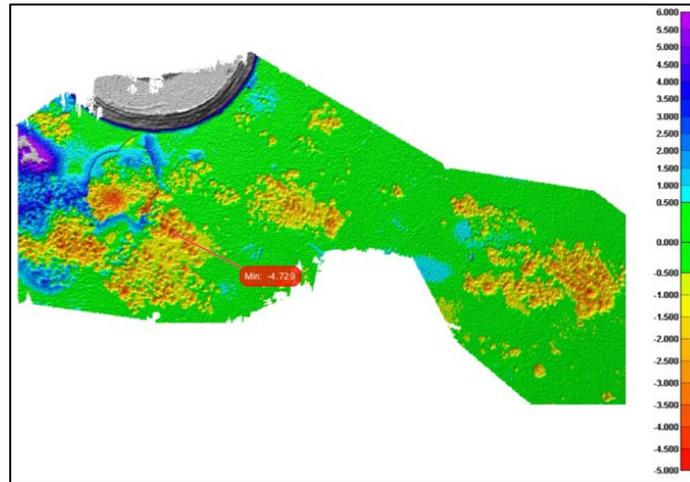
Figure 11: Reference surface using a free-form model

4. Measurements comparison

4.1 Comparison of a 3D color map maximum depth measurement with a pit gauge

A curved surface inspected with a real mechanical pit gauge will measure depth values smaller than 3D color map comparison generated from a spherical reference. The pit gage creates a straight edge from both side of the corrosion. Therefore, the larger the corrosion pit, the smallest the depth value will be if measured with a pit gage sitting on un-corroded surface.
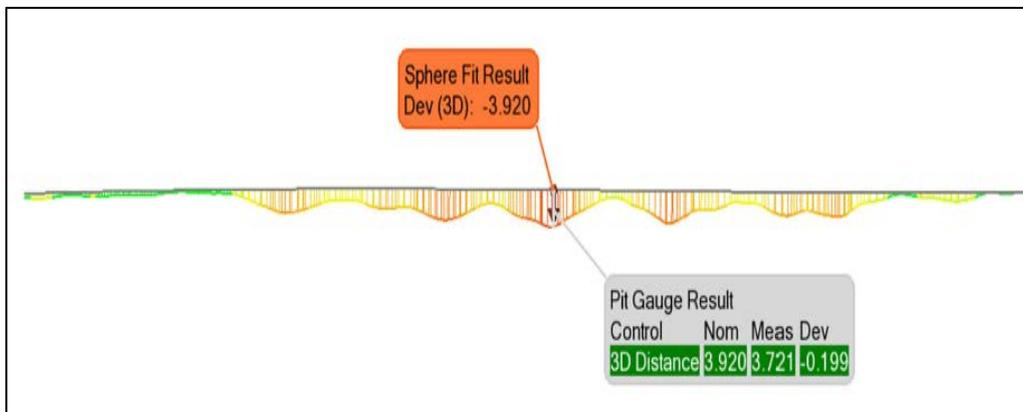

Figure 12: Maximum depth measurement with spherical fit

The maximum depth is automatically found for each corrosion feature. In this case, figure 12 and 13 show the maximum depth is measured at 3.920mm using a spherical fit reference. A straight edge pit gage measured 3.721mm for the same point, which represents 0.2mm (5%) less than a spherical fit. Hence, a spherical fit measurement will be more conservative than pit gauge. The pit gage offset value is not predictable since it depends on the size of the damage area and the location of contact points. A fitted reference surface will yield much more consistent results by extrapolating the real shape as if there was no metal loss.
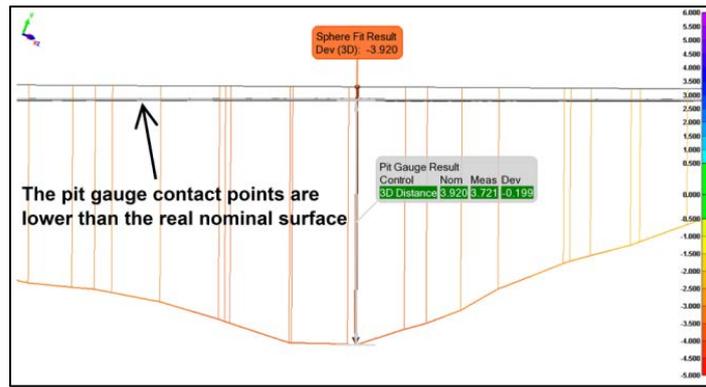
Figure 13: Maximum depth measurement with pit gauge

4.2 Depth grid measurement

A grid pattern of a size determined by the inspector can overlay the 3D scan. In this case, a 10mm x 10mm grid is used for the analysis.
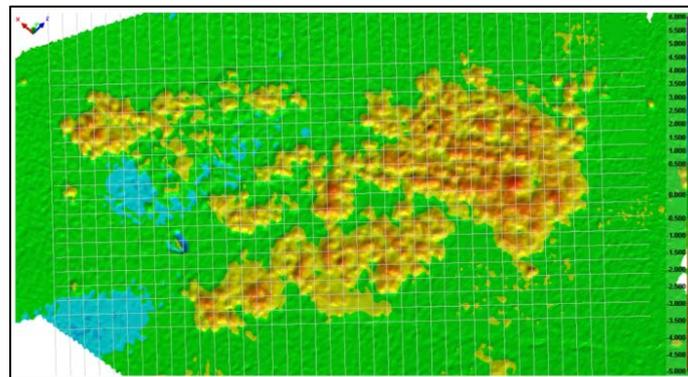

Figure 14: Grid overlay

The deepest point for each square grid is automatically found and can be exported in an Excel table. Estimated burst pressures can be calculated from this depth measurement table. A square grid contains a certain number of data points based on the resolution chosen for the scan as seen in figure 15. The software will calculate the depth of each point within the square grid boundaries and find the maximum value.
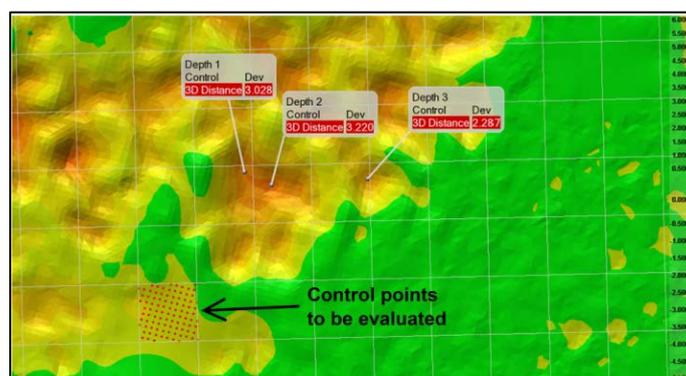

Figure 15: Square grid data points

5. Conclusion

3D laser scanner technique proves to be a very efficient method for external corrosion assessment on pressurised components with the use of a reference surface compared to the 3D scan file.

Three methods exist to create a reference surface depending on the level of precision required: comparing to a CAD file, to a theoretical geometric feature, and a free-form best-fitted model. The level of precision is higher with a reference surface based on a free-form model because it compensates for surface variations to the ideal geometry.

Corrosion on a spherical pressure vessel was inspected based on API-579 level-2 procedure using the 3D laser technique. The pit gage was shown to be less conservative on a curved surface by 5% for that specific case. A depth grid can be automatically created and exported in Excel to estimate burst pressures.

In a case where level-3 assessment is required, the same STL 3D laser scan can be exported for Finite-Element-Analysis. STL files are compatible with most FEA software. STL files can also be converted into parametric files such as IGES or SAT if needed.

Many oil & gas components with various geometries such as pressure vessels and pipelines can be inspected with the same equipment because of the scanner design being non-contact and the software versatility.

References

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