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Using Laser Scanning Creatively in a Plant Environment

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Introduction

3D laser scans are used regularly during pipeline digs to monitor the fitness for service of pitted pipeline components. Along with this function, the technique has non-routine but equally effective applications for inspecting pressure piping, tanks, well casings, vessels, and other equipment. This article exemplifies 3D laser scans for assessing:

- The reliability of piping subjected to significant thermal stresses
- Bulges and repairs in a tank
- Corrosion under insulation in a tank
- Fit up of a new pump casing
- Internal diameter pitting in a pressure vessel
- Validating/Calibrating heat exchanger remote field testing tube wall loss assessments
- Identifying piping with erosion losses

Technology Summary

This metrology technique is a line-of-sight-based inspection: only what can be seen can be scanned and measured. Laser scanning captures a 3D model (mesh) of the surface. Currently, nondestructive field examination services use short- and long-range laser scans.

Short-range scans (commonly known as handheld) are mainly used for corrosion assessments of small areas. Typically, they have an accuracy of ±0.001 inch and can be performed at distances of 12 inches (or less) from the part inspected.

Long-range scans (commonly known as terrestrial laser scanning) are performed on larger components to assess their dimensions. Typically, they have an accuracy of ± 0.04 inch and can be performed at distances of 3.3 – 164 feet from the part inspected.

Laser scanning was historically generally limited to cylindrical applications such as tanks, piping, heat exchanger tubes, catalytic reforming heater tubes and shells of coke drums and pressure vessels. However, software advances allow for the examination of noncylindrical equipment common in a plant environment, such as bends, vessel heads, heat exchangers, and tank floors. Extracting measurements from noncylindrical objects is reliable and efficient [1-3].

The information in this article focuses on the metrology side of laser scanning, which encompasses extracting a 3D model for the application and extracting measurements for comparison. Typically, the measurements are compared to a standard or code to determine its acceptability. Another common application is reverse engineering, which is not covered in this paper. A common reverse engineering application uses laser scanning to extract a 3D model of a part for which a drawing does not exist. The scans are used to make a 2D drawing, which can then be manufactured.

Example 1: Assessing the Reliability of Piping Subjected to Significant Thermal Stresses

When a newly commissioned plant was started for the first time, an NPS 12 pipe expanded, pushing an NPS 2 drain into an I-Beam (see **Figure 1**). An operator noted that the NPS 2 drain had deflected, so operations immediately shut down the plant to investigate further. One question was whether the NPS 12 and NPS 2 pipes were plastically or elastically deformed. In other words, how prone were they to fail? Based on this information, the mitigation and redesign had to be assessed.

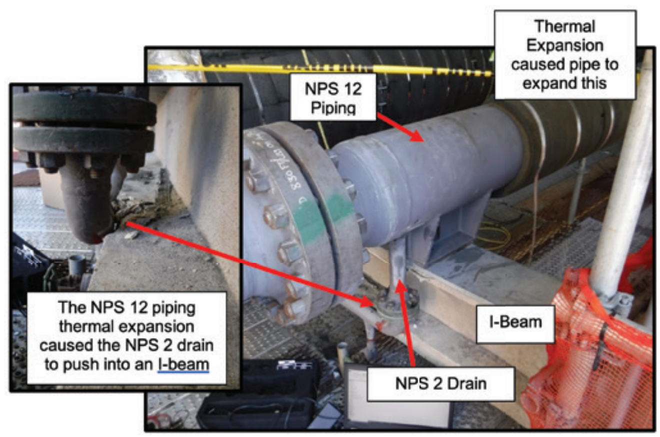


Figure 1. Deformed NPS 2 drains.

The NPS 12 piping did not appear to have local deformation, such as dents or bulges. The ovality was within the manufacturer's ±1%OD tolerance based on the measurements extracted from the laser scans. Thus, it had not been deformed. As seen in **Figure 2**, the NPS 2 drain was at an angle of ~88° (instead of 90°) to the normal axis of the NPS 12 piping. Ideally, one would have a laser scan before the equipment was in operation to compare this result. A prior or baseline scan would provide definitive information regarding how much the NPS 2 drain had deflected from its condition prior to the plant start-up. After talking to the manufacturer and discussing their typical tolerances, it was decided that the NPS 2 drain had plastically deformed. These discussions underline the importance of discussing results with other trades and engineers, as the results from laser scanning can only be put in context once we know typical tolerances.

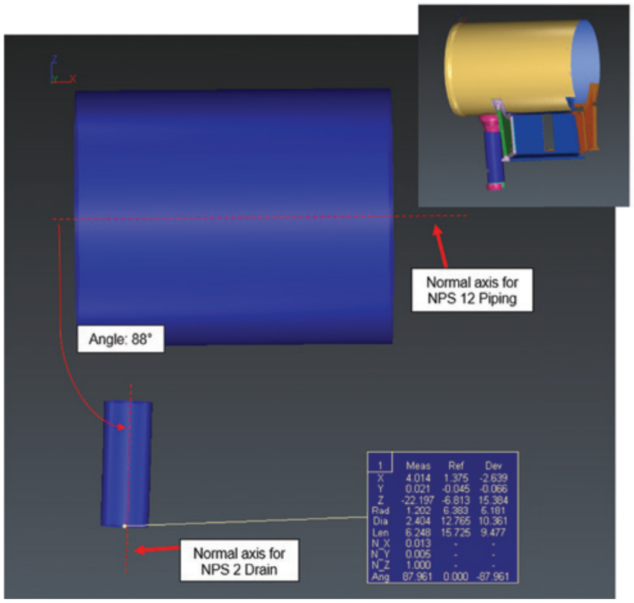


Figure 2. Laser Scan and Measurements.

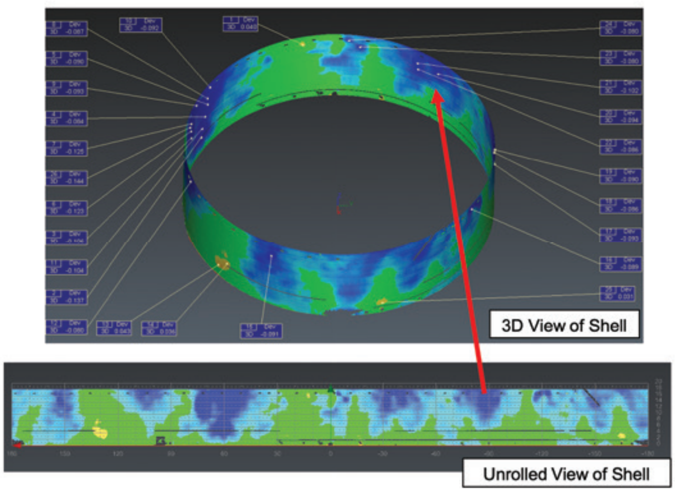


Figure 3. Depressions on the shell of a 215 feet diameter by 60 feet tall tank. The red is on bulges that swell away from the center of the tank, while the blue are depressions towards the center of the tank.

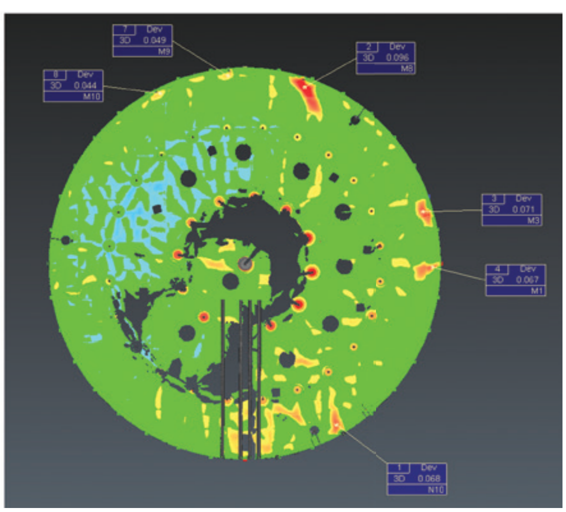


Figure 4. Bulges on the floor of a 215-foot diameter by 60-foot tall tank. The red indicates bulges out of the center, while the blue are depressions into the center.

From this data, a repair plan was made, and the NPS 2 drain was repaired. Further measurements were not required after the plant continued to operate. The NPS 12 line remained intact without requiring further changes.

The laser scans gave quick and reliable maintenance information on a complex topic. Thermal stresses in piping systems depend on support movement and design, transient loads, constraints, and many other variables. Laser scans before operating newly commissioned piping can ease piping management.

Example 2: Bulges and Repairs in a Tank

A 215-foot diameter by 60-foot tall tank was scheduled for a routine five-year in-service inspection. During the inspection, the inspector noticed depressions on the upper shell courses. Being well-versed in laser scanning, he asked for an external laser scan assessment of the depressions. The long-range laser scans flagged the depressions as outside API 653 roundness tolerances. See **Figure 3**.

Often, tank shell deformation initiates with tank floor settlement anomalies. Consequently, after several months, the tank was taken out of service and scanned internally with a long-range laser. The tank had six well-mapped rejectable floor bulges next to its outer diameter. All the bulges were lined up with large nozzles or manways. See **Figure 4** and **Table 1**.

Table 1. Floor Bulge Dimensions.

Bulge Identifier	1	4	3	2	7	8
Bulge Radius (ft)	3.13	1.80	3.61	4.59	1.80	1.80
Bulge Height (in)	2.68	2.64	2.80	3.78	1.93	1.73
Permissible Height (in)	1.16	0.67	1.34	1.70	0.67	0.67
% Permissible	231%	394%	209%	222%	288%	258%

The laser 3D model was used to determine the dimensions of the plates required for repairing the tank bulges. The model and discussions with the repair company resulted in a successful repair where the repair plates were fit in through the manway. Ideally, the tank should have been scanned before it was in service—after construction—as a baseline. In this case, we compared the floor to what the drawing indicated: a 1/100 sloped floor. Nevertheless, the post-damage scan facilitated the tank's repair and maintenance.

Example 3: Corrosion Under Insulation Losses in a Tank

A 40-foot diameter tank, with a shell wall thickness ranging from 0.250 inch – 0.375 inch, was out of service for several years due to corrosion under insulation (CUI). The owner wanted to know the extent of repairs needed to put the tank back into service. The tank had CUI around the entire circumference and its entire height. Scanning the entire tank with laser scanning was not feasible due to the extensive surface preparation and time constraints. Consequently, the client wanted to use a qualitative screening technique to identify areas for follow-up quantitative laser scanning.

Non-intrusive screening technologies such as pulsed eddy current (PEC), guided wave testing (GWT), and various types of radiography have become very popular in the industry due to their ability to quickly screen large areas for corrosion. Following up these techniques with a more quantitative technique is imperative. Laser scanning is a popular choice to quantify external corrosion. The client chose to use a pulsed eddy current array (PECA) to perform the screening portion of the inspection and follow up on the worst areas with a laser. Due to the absence of insulation, the PECA was used directly on the tank's surface, taking roughly 20 hours to complete. With it, the entire tank surface was screened, and the areas needing laser scans were identified in another 8 hours.

The PECA and laser data were compared, and the results are shown in **Table 2**. The PECA was expected to have a measured thickness accuracy of ±10% thickness. However, the laser measurements found an accuracy closer to ±17% of the thickness. This discrepancy is expected since many equipment tolerances are developed in a lab setting.

Table 2. Comparison of PECA and Laser Pit Depth Assessments.

Scan Location	Laser	PECA	Difference	PECA Result
	Pit Depth (%NWT)			
Course 1 Scan 3	43	59	16	Overcall
Course 2 Scan 5	53	37	-16	Undercall
Course 4 Scan 2	44	61	17	Overcall

Nevertheless, the two techniques, when combined, gave an expedient and accurate assessment. This exemplifies the importance of challenging your qualitative inspection results to gain greater confidence in their strengths and weaknesses. Laser scanning is a quick and effective tool to quantify external corrosion from various qualitative techniques.

Example 4: Fit Up of a New Pump Casing

A customer was experiencing difficulties installing a new pump casing, causing start-up delays. See **Figure 5**. The new pump casing had not gone through the proper quality assurance to determine if the pump casing matched the manufactured drawing. Laser scanning is a useful tool for parts that require high accuracy to confirm dimensions before the equipment is sent to the field. This ensures that start-up delays due to fit-up issues are avoided. Following fit-up issues, the new pump casing was laser-scanned to compare dimensions to those of the drawing. Based on the comparisons, several casing dimensions did not meet the tolerances in the drawing (refer to **Figure 6**). The customer was forced to return the old pump casing to service for a limited time while a new one was procured. The client was motivated to find a solution with the existing new pump casing instead of waiting for a new pump casing that had the correct dimensions. A creative solution was found by leveraging a model of the old pump casing generated through a previous laser scan. From comparing the laser scan of the old pump casing to the new pump casing, modifications could easily be made to the supports and pump to accommodate the new pump casing. At the next scheduled maintenance outage, the old pump casing was replaced with the new one once the supports and pump had been altered slightly. This illustrates the importance that historical laser scans have. They can be accessed at any time to help solve problems many years down the road.

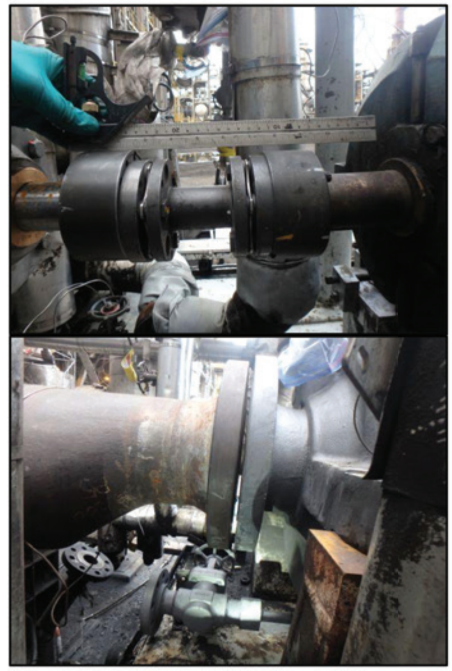


Figure 5. Note the offset between the coupling and line on the top image and the suction piping and line on the bottom image.

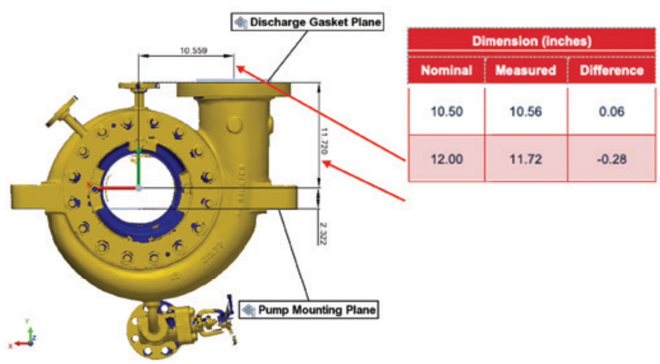


Figure 6. Note differences between drawing and laser measurements.

Typically, 2D drawings are used to manufacture new parts. However, rotating equipment requires accurate dimensions for fit-up and to minimize vibrations. In this instance, laser scans identified dimensional inaccuracies, facilitated fit-up, and prevented further downtime.

Example 5: Internal Diameter Pitting in a Pressure Vessel

A 5-feet diameter, 15-feet-long horizontal vessel had pits along the shell bottom ID (4 – 8 o'clock position). The bottom outside surface of the insulated corrosive service vessel was not accessible

Figure 7. Vessel pitting morphology.

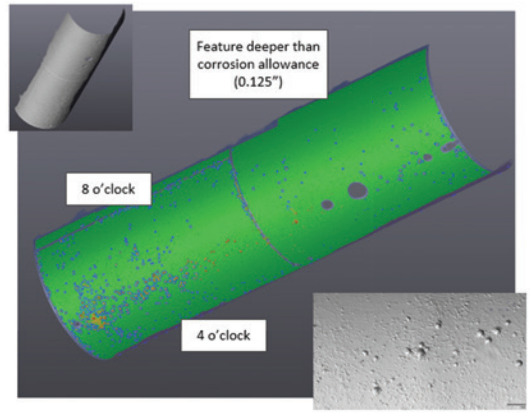
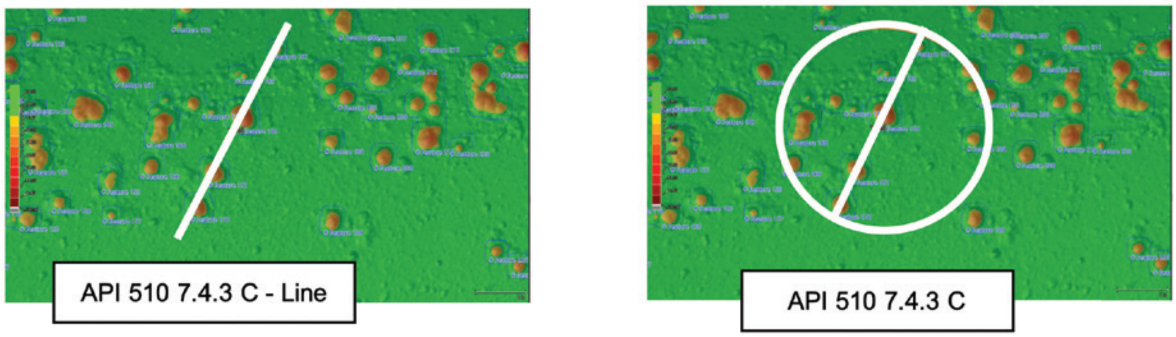


Figure 8. Overview of pitting.



API 510 7.4.3 - Evaluation of Scattered Pits							
Feature identification	Max. depth axial pos.	Max. depth circ. pos.	Max. depth	Length	Width	API 510 7.4.3	
	in	in	in	in	in	b) Area	c) Line
Feature 001	0.256	107.734	0.160	0.433	0.395	Pass	Pass
Feature 002	1.083	123.025	0.254	1.378	0.711	Pass	Pass
Feature 003	0.217	95.011	0.168	0.315	0.356	Fail	Pass
Feature 004	0.217	97.737	0.193	0.433	0.830	Fail	Pass
Feature 005	0.295	87.029	0.271	1.024	1.146	Fail	Fail

Figure 9. Vessel pitting laser data table summarizing the use of API 510 Clauses 7.4.3 b) and c).

due to limited access and insulation. Its corrosion allowance was 0.125 inch, and its nominal thickness was 0.500 inch. Due to extensive pitting and cratering, this vessel was routinely taken out of service to assess and repair the pitting. Previous pit gauge inspections had taken several days and had challenges identifying individual pits and evaluating pit depths. **Figure 7** shows some of the vessel pits. This illustrates the challenges of doing extensive pit gauging. Repeatability and accuracy are a concern, especially after doing it for several days. The laser scan took six hours and identified about 700 pits, resulting in below corrosion allowance thickness values. See **Figure 8**.

The laser scanning data was initially correlated to the prior pit gauge measurements. The average and maximum corrosion rates were calculated and determined per the features identified by the laser scan. Laser scans facilitated overlaying 3D models from different inspections to determine corrosion rates.

Then, to determine what repairs were needed and expedite the repairs, the laser scans were evaluated using the API 510 Clauses 7.4.3 b) and c) [4]. See **Figure 9**. These clauses state:

- "The total area of pitting deeper than the corrosion allowance does not exceed 7 in.^{2} within any 8 in. diameter circle.
- The sum of the pit diameters whose depth exceeds the corrosion allowance along any straight 8 in. line does not exceed 2 in.."

This evaluation would have been impracticable on the manual pit gauge data. From the 3D models, the pitting requiring repairs to satisfy the API 510 criteria was more easily identified. From the 700 pits, the anomalies requiring repairs were reduced to 270. The downtime initially planned for 10 – 14 days was reduced to 5 days. As well, additional repairs were planned for the next scheduled maintenance period. Laser scanning was the right tool for this evaluation. Manually applying the criteria from API 510 Clauses 7.4.3 b) and c) accurately would be extremely difficult given the widespread pitting.

Example 6: Validating/Calibrating Heat Exchanger Remote Field Testing Tube Wall Loss Assessments

Reports from five remote field testing (RFT) vendors on the tube thickness losses from various carbon steel heat exchangers were extensively different. On one tube, one vendor identified 66% internal thickness losses and recommended plugging; three others identified 0% losses and did not see further preventive

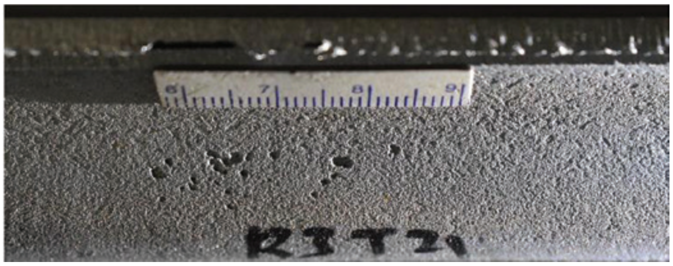


Figure 10. Tube after media blasting. Note the pits are narrow and isolated.

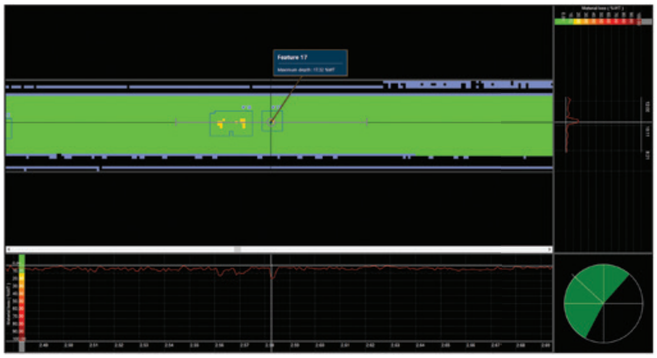


Figure 11. A laser scan of the pits shown in Figure 10.

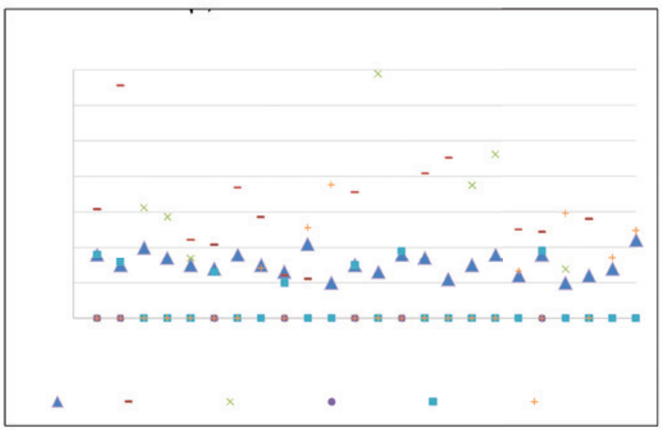


Figure 12. Laser versus Vendor RFT Calls

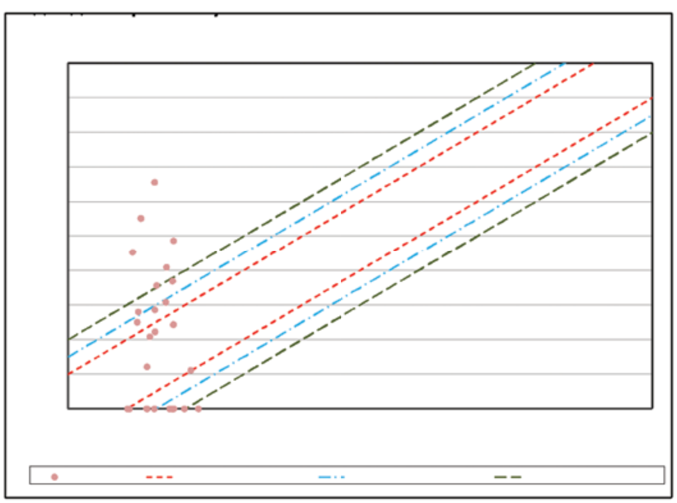


Figure 13. The RFT wall thickness values plotted versus the laser data.

measures needed. The fifth assessed 16% losses and recommended monitoring. How can one proceed based on this conflicting data and quantify the damage reliably?

The owner of the heat exchangers requested visual examinations and laser scans of split tubes—they needed to determine what kind of damage was occurring in the tubes. The 20-foot-long by 0.083-inch-thick tubes, which were all removed and split, had narrow and isolated pits. See **Figure 10**. The manual pit gauge tips were too wide to fit into certain pits. Also, measuring thickness values reliably in the small tube surfaces was challenging. However, the laser software pit gauges can be adjusted to various diameters for repeatable and accurate results. Also, data such as the axial length, circumferential width, axial position, pit diameter, and pit depth are mapped, as shown in **Figures 11** and **12**.

For example, the data from one of the vendors is discussed in detail. The RFT wall thickness values were plotted versus the laser data. See **Figure 13**. The X-axis shows many internal pits the laser identified that the RFT did not detect. Also, RFT identified many pits as deeper than 20%, whereas the laser only identified pits shallower than 23%. Based on the RFT data, many tubes would have required plugging, reducing the exchanger's efficiency; however, laser data found plugging not to be required on many of the tubes.

Statistical analyses of the probability of sizing (POS) and probability of detection (POD) were performed to compare the vendors. Most vendors had trade-offs between POD and POS. For example, Vendor 4 could assess the size of eight features within ± 3%WT but did not detect the remaining 18 features. There was no clear winner regarding which vendor was the most accurate.

Many facilities discard bundles or plug tubes based solely on the RFT. However, this case illustrates that validations are useful. This data should also be shared with the RFT vendors to benefit from the knowledge gained. Ultimately, this type of corrosion is difficult to detect and size accurately, and the RFT results should only be treated as a screening tool. A subsample must be verified to ensure that the results are accurate. This information should also be shared with the NDT service provider to ensure that they have an opportunity to improve their reliability.

Example 7: Identifying Piping with Erosion Losses

This application is still in development. A customer inquired about a more economical process for inspecting their urethane/rubber-lined piping. Heavy erosion from the oil sands resulted in a "dished area" downstream of the flange connections; the losses mainly resulted from misalignment during fit-up. There is currently no inspection technique to quantify the remaining internal liner thickness from the exterior, so the lined spools had to be disconnected and lowered to the ground for inspection. Considerable pipe handling was required, often leading this to be the critical path in turnarounds. A robotic technology that can navigate the piping, locate the dished areas, and quantify the remaining wall thickness would be beneficial.

A robotic technology that could navigate the piping internally and

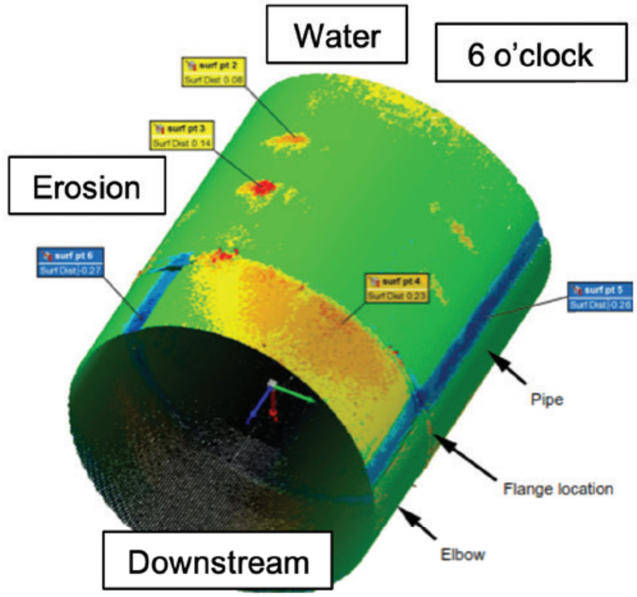


Figure 14. Lined piping is shown on the left. The image on the right represents the type of damage.

use a magnetic stand-off gauge to quantify the remaining wall thickness was initially tested. However, these wall thickness measurements were discrete and could only be taken in select areas. Visualizing the "dished areas" during the first trials was quite difficult. The damage was smooth erosion, which was difficult to identify visually. In another trial, laser scanning was adapted to the robotics system. The laser scans were used to identify areas needing further discrete measurements. The obvious question is, why are the laser scans not used for quantitative measurements?

The damage typically occurs at the 6 o'clock position of the pipe, as shown in **Figure 14**. However, to extend the piping life, the spools are often rotated. Consequently, the damage can be on any side, causing an unusable reference surface. Reminder: laser scanning is a line-of-sight-based technology that requires a reference surface. A reliable reference without losses is needed for laser scanning to obtain information. When the reference has been rotated several times, and the previous damage is unknown, a reference cannot be used. Therefore, the strategy remains to use laser scanning to determine if dished areas are present at a particular flange location. From there, quantitative, time-consuming measurements will be performed. The objective of the laser scan will be to ensure that dished areas are not missed. Unlike all the previous examples, the laser scan is not a quantitative tool in this case but rather a qualitative screening tool.

Concluding Remarks

Laser scanning is a powerful tool for asset integrity personnel to depend on for accurate and timely results during regular maintenance and turnaround applications. With valuable software additions, laser scans can now be considered a tool applicable to facility-based inspection. Many end users request that laser scanning be available during turnaround to help quantify as-found damage during the process. Laser scans improve the repeatability and accuracy of the inspection, giving them valuable information on time. ■

For more information on this subject or the author, please email us at inquiries@inspectioneering.com.

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Ana Benz, IRISNDT's Chief Engineer, has worked for IRISNDT for 26 years as a Corrosion, Failure, and Inspection Specialist. Ana worked extensively for Chemical, Petrochemical Plants, Fertilizer Plants, oil and gas, and refineries. She is a University Simon Bolivar Materials Engineer graduate and obtained a Master's degree in Materials Engineering from the University of British Columbia. She has a CGSB NDT certificate and CWB Level 3 and API 510 certifications. Ana was a member of the NACE Edmonton Executive and the Edmonton Chapter of the Canadian Welding Institute. She is also an IPEIA Special Sessions Committee member.

Laurence Kuan

Laurence Kuan has a Bachelor of Science degree in Mechanical Engineering from the University of Alberta. Having worked in the oil and gas industry for the last four years, Laurence focuses on maintaining asset integrity at all stages, from data collection to performing fitness-for-service. Laurence leverages inspection techniques to ascertain the condition of assets (pipelines, pressure vessels, tanks, etc.) and then evaluates and maintains their integrity.

Cameron Sjerve, P.Eng.

Cameron Sjerve has a Bachelor of Science degree in Mechanical Engineering from the University of Alberta. Over the years, Cameron has been involved in asset integrity engineering and performing NDT in the field, allowing him to better understand how good inspection data is crucial for supporting asset integrity programs. Cameron currently serves as an operations manager for the advanced NDT department, where he has developed a passion for leveraging new technology. He is responsible for implementing new technology focusing on advanced measurement methods, robotic technologies, digital NDT workflows, and 3D scanning.