Field Experience and Best Practices for Laser Assessment of Pipeline Damage

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ABSTRACT

Laser surface scanning is an accurate and cost-effective solution to the challenge of assessing external pipeline damage. With automated interaction rules, the system can easily handle dozens or even hundreds of corrosion features at once and produce burst pressures based on ASME B31G code immediately on the job site. Laser scanning is also ideally suited to documenting and assessing mechanical damage such as dents and out-of-round features. As with corrosion, dent dimensional analysis can be carried out on the job site, or, alternatively, used offsite as input to finite element or strain analysis software. Laser scanning is a very reliable and repeatable method, but only in the hands of a qualified operator with appropriate procedures and quality controls. During the initial evaluation and approval process, it was recognized that the optically-based technology would be new and foreign to many NDT field technicians. There are also limitations with scanners, such as the ability to scan inside deep cracks, and limitations to analysis software, such as the effects of bends on results. This paper outlines pipeline applications of laser scanning and will discuss the quality program undertaken to verify the system, train technicians, develop procedures, and produce reliable results.

Keywords: laser, scanning, corrosion, pipeline, integrity.
INTRODUCTION

A laser scanner is an instrument that takes point measurements on the outside surface of an object and produces data that describes the object’s shape [1] (and sometimes other properties such as colour or texture). Specialized software can then be used to determine the object’s dimensions or to highlight deviations and imperfections. As such, laser scanners are well-suited to the job of evaluating corrosion and mechanical damage on pipelines – with the proper procedure, quality controls, and a good understanding of the strengths and limitations of the technology. Due to their precision and simplicity, the corrosion assessment methods prescribed in ASME B31G code [2] are well suited to both manual and automated analysis. An advantage of the laser scanning method is that it provides a fine mesh of data points in a format that can easily be processed by corrosion assessment algorithms [3, 4] or exported to finite element software for advanced analysis.

LASER SCANNING FOR PIPELINES

Advancements in commercially available computing power have improved the speed, accuracy, and viability of laser scanners [5], which has resulted in more productive and effective pipeline damage assessment. The simplest application for 3D scanning is the documentation and archival of the shape of a damaged part (Fig. 1). In nondestructive testing (NDT) a common application is laser scanning for inspection, in which the data is compared to a reference part or drawing to assess flaws or deviations (Fig. 2). Different analysis methods may be used, based on the results required. For example, an analysis based on a virtual pit gauge is effective for assessing corrosion or dents (Fig. 3L), and a deviation-from-cylinder analysis can be used also for dents and for other mechanical damage such as out-of-roundness (Figs. 3R, 4). Scanning in progress at various job sites is shown in Figs. 5 and 6. Scanning systems differ in three key aspects:

1. Their speed, portability, required clearance around the pipe, and ability to scan complex shapes.
2. Onsite analysis options such as burst pressure results for pipeline integrity work.
3. Offsite analysis capabilities such as bend compensation prior to corrosion assessment or analysis of complex shapes.

Fig. 1: Left: Burst pipe. Right: 3D image.
Fig. 2: An example of scanning for inspection. Left: Scanning an elbow with suspected freezing damage. Right: Deviation analysis showing a bulge.

Fig. 3: Example on-site results. Left: Corrosion burst pressure assessment. Right: Dent dimensional assessment.

Fig. 4: Example results. Left: Onsite 3D view showing dent (red) and adjacent bulging (blue). Right: The colour-scaled ‘whiskers’ in data from another pipe indicate deviation from round.
Fig. 5: Left: Scanning corrosion on a pipe suspended below a bridge. Right: Scanning and merging data from a large area with internal pitting.

Fig. 6: Left: Corrosion scanning in progress at a dig site. Right: Scanning defects for calibration of inline inspection tools.
RESEARCH AND DUE DILIGENCE

Since there are next to no international standards that apply to close-range scanning [7], let alone for pipeline damage assessment, a robust and auditable quality program, including training, qualifications, and examination procedures is essential. Laser scanners are often promoted as an ‘ultimate solution,’ however they can also be seen as just one more tool in the NDT box. As with any technology, it is important to verify its performance and to determine its strengths and limitations. Elements of our internal verification program include:

- Assessment of accuracy on simple machined flaws (Fig. 7).
- Assessment of scanner performance on a range of pit sizes (Fig. 8).
- Comparison of results from different technologies on complex corrosion features (Figs. 9, 10).

On the specific corrosion feature shown in Fig. 9, the range of effective area burst pressures produced by all the methods, including manual ultrasonic thickness measurement, was ±1.5%. (The automated ultrasonic scan was carried out from the inside of the pipe coupon, due to the difficulty of maintaining coupling on the corroded surface.) An example of a comparison of laser and manual pit gauge measurements is shown in Fig. 10. As can be seen in the figure, the river bottom produced by the laser provides finer detail – thus tending to produce more accurate burst pressure calculations. This is an advantage of laser scanning over manual measurements.

![Fig. 7: Left: Machined coupon for verification of burst pressure calculations. Right: Scanning coupon in lab.](image)

![Fig. 8: Coupon to determine capability for pit depth measurement. Left: Excerpt from drawing. Right: machined coupon, with targets applied for scanning.](image)
**Fig. 9**: Comparison of corrosion assessment results from different technologies.
STRENGTHS AND LIMITATIONS

Although laser scanning is a leap forward in technology, the strengths and limitations of the complete system – including the scanner and analysis software – need to be considered and understood. While scanning accuracy in itself may be impressive, there remain other key questions such as what surfaces and profiles can be scanned and what variance is introduced by post-processing. For example, current scanners cannot see to the bottom of cracks and sharp-bottomed flaws, such as the preferential corrosion in Fig. 11 (and in fact ASME B31G [2] does not apply to such flaws). Most scanners also have difficulty acquiring data from matte black areas such as those created by black-on-white magnetic particle testing. Field technicians must be able to determine whether a complex feature can be assessed by the laser system or if a manual method might be more appropriate. Elongated corrosion on a bend, for example, is a challenge when there is minimal uncorroded surface for reference. Although a competent analyst with advanced software can estimate the corrosion depth profile on such a bend, there is always some sacrifice in accuracy. Because of the many variables that contribute to overall performance, systems are best evaluated by the end user on real samples.

Fig. 10: Example of comparison of river bottoms from manual pit gauge (blue) and laser virtual pit gauge (red).

Fig. 11: Preferential corrosion on a weld seam is sharp-bottomed and hidden from view (occluded), and is thus not suitable for assessment by laser scanner.
TECHNICIAN TRAINING

The American Society for Nondestructive Testing (ASNT) recognizes the method of Laser Profilometry in their qualification and training guides [8, 9]. In fact in ASNT’s 1995 handbook, the application of interest for Laser Profilometry is measurement of corrosion on the inside diameter of boiler tubes [10], which can be seen as a precursor to scanning for pipelines. Whereas a profilometer is usually moved in a straight path over a surface, a scanner is used at multiple viewing angles to produce a 3D image. Since the two technologies are closely related, standardized training materials for profilometry can be expanded to laser scanning. The application of laser scanning to pipelines requires an interesting combination of different fields. Technicians should have a good knowledge of pipeline damage mechanisms and manual assessment techniques, combined with an understanding of scanning, the optical properties of surfaces, and 3D analysis. ‘Point and shoot’ analysis can be dangerous: a well-defined training course with hands-on exercises on corroded samples is essential to produce reliable results and to avoid quality lapses in the field.

PROCEDURE

As with most NDT procedures, the first, essential step is to verify that the system has an up to date (typically annual) manufacturer’s calibration, has an up to the minute field calibration at ambient temperature, and is functioning correctly. Scanner manufacturers should certify calibration to a national or international standard for optical measurement such as ISO 10360-7 [11], which was developed for coordinate measuring machines with laser probes and is often applied to other types of laser scanner. For a system check in the field, a verification coupon (Fig. 12) was developed. The flaws in the coupon are calibrated to a known burst pressure and is also used to demonstrate correct application of interaction rules by the software. The coupon is scanned at the beginning and end of each shift to provide evidence of correct functioning.

The procedure requires a pre-scan visual inspection to ensure that the feature is suitable for scanning, to check for bends or out-of-roundness, and to remove problems such as pits filled with ultrasonic couplant. Where there is any doubt, manual ultrasonic or pit gauge readings should be taken at selected points to verify the accuracy of laser results. The surface is usually prepared by applying light-coloured matte coating to shiny or dark areas. Sandblasted or lightly rusted surfaces can be scanned without preparation. The most common error is not recording position reference information: the scan position should be entered into software so that all features can be located with reference to the required girth weld or feature.

The surface is scanned, and the data is checked for quality, for example by verifying that there are no missing areas in the scan. The results are compared with manual readings: discrepancies indicate that there may be unobserved sources of error such as debris creating a high point in the data. The burst pressure results are generated on site – preferably in the ditch – and are then communicated to the client. Final reports are issued after review by the regional engineering office. The procedure also specifies the essential contents of the report such as equipment serial numbers, scanning conditions, pipeline material parameters, and settings used for analysis. Lastly, laser scan data is backed up to at least one additional location before the technicians leave the job site.
CONCLUSION

In the absence of international standards for 3D imaging, an in-depth quality program has been created and implemented with the following objectives:

- Compile evidence verifying the performance and accuracy of the system (instrument and software).
- Investigate the strengths and limitations of the system, specifically when it is suitable for use and when other, conventional methods might be more appropriate.
- Develop a technician training program based on an internally-reviewed curriculum and specified hours for training and job experience.
- Develop a procedure that guides technicians to produce reliable results.
- Communicate these objectives to pipeline owners to allow effective implementation.

It is hoped that this paper will be useful for the application of laser scanning to pipeline damage assessment and might also be a starting point for development of standard practices.
REFERENCES


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