Understanding 3D Structured Light
To Assess Corrosion Defects

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ABSTRACT

Phase Measurement Profilometry or 3D Structured Light is not a new technology, but it is new to the pipeline industry. This paper will provide an overview of how 3D structured light technology works (process time, error, analysis, impact on corrosion analysis) and how it is now being used as a new method for gathering pipeline feature or defect measurements. Hazardous liquid and gas pipeline operators are tasked with the responsibility of complying with regulatory requirements to ensure that field data gathered of pipe and corrosion defects are assessed properly after in-line inspection runs, direct assessment or other maintenance activities. Yet too often, the focus has been to hire field personnel that are qualified in some tasks, but not experienced in all phases of direct examination of corrosion, gouges, dents, weld defects, cracks, wrinkle bends, SCC, construction defects, etc.

KEYWORDS

Phase Measurement Profilometry (PMP), 3D Structured Light, API[1] RP579/ASME[2] Fitness for Service (FFS), Remaining Strength of Corroded Pipe (RSTRENG), ASME B31.G, MAOP, High Consequence Area (HCA), Stress Strain Calculations.

INTRODUCTION

Even though oil and gas pipelines and their related facilities are the safest for people and the environment rather than other means of transportation, occasional leaks and failures due to corrosion and other defects have become an issue in maintaining pipeline integrity. A number of solutions have been

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[1] American Petroleum Institute (API) 1220 L St. Washington, DC 20005
[2] American Society of Mechanical Engineers (ASME), Three Park Ave. NY, NY 10016

developed for the assessment of remaining strength of corroded pipelines. There is a need in the pipeline industry to assess the severity of a particular feature (dent, gouge, corrosion pit, etc.) in a pipe or structure as to whether or not repair or removal is required. This process is now called Fitness for Service (FFS). It is a process to evaluate features that may impact a pipeline or other structure for serviceability. One tool that will make this a true reality is called Phase Measurement Profilometry (PMP), also better known as 3D Structured Light. This advanced technology will facilitate the repair and determination of repair and prioritization of defects to make remaining-life assessments of pipeline segments to meet today's stringent industry and regulatory requirements.

This paper will provide the pipeline industry with an understanding of the differences between "screening tools" and "prove up tools" as well as the benefits of the 3D structured light technology (accuracy, repeatability, reliability and cost) to meet API 579/ASME FFS-1 standards and PHMSA[3] regulations.

KNOWLEDGE, VERIFICATION/PROVE UP OF THE PIPELINE

Fitness for service has been used in the oil and gas industry since the early 1980's. On the petroleum industry side, it was always known as FFS, while on the gas pipeline side, it was known as ASME B31.G. In 2007 the American Petroleum Institute (API) and American Society of Mechanical Engineers (ASME) published a joint document as API RP 579-1/ASME FFS-1. This recommended practice (RP) consists of the following three levels for assessing corrosion:

1. Level 1 – Quick evaluation with the minimum number of measurements (maximum depth and length) with a built in large safety factor (ASME B31.G and Modified B31.G).
2. Level 2 – Additional measurements and more in-depth analysis to establish a remaining strength of corroded pipe (RSTRENG).
3. Level 3 – Intensive measurements using tools such as the 3D Toolbox - Phase Measurement Profilometry (PMP), loading, stresses, stress strain and material understanding to conduct a finite element analysis (FEA).

Because of the errors in the past using mechanical instrumentation (pit gauges) used in the past, rarely was a Level 3 analysis conducted. The field data was too inconsistent or too difficult to measure due to the complexity of the defects and features.

Factors for selecting a Level for analysis of a corroded area include:

- Quantity of data available with which to perform an evaluation
- Quality of the data
- Degree of significance of the analysis to the pipeline operations
- Degree of significance of a specific corroded area in the remedial plan for all anomalies in a line section being investigated

[3] Pipeline Hazardous Materials Safety Administration, 1200 New Jersey Ave. SE, East Building 2nd Floor Washington, DC 20590

Level 1 – ASME B31.G and Modified ASME B31.G

Metal loss on pipe or vessels due to corrosion can be evaluated by taking the deepest point and longest length of a corrosion pit or patch (corroded area). This procedure required a pit gauge, straight edge and a calculator. However, when assessments of remaining strength were performed in the early 1970's, a set of tables and a flat stainless steel pit gauge were provided to the technician or field engineer and a flat stainless steel pit gauge. An engineering decision was made based on this information. However, it was more of go-no-go type decision with a huge safety margin built in to the tables. Because these pit evaluation tables were very conservative, many unnecessary steel repairs and cut-outs were made due to the unknowns in field data. If repairs were made, they were limited either to steel Type A or B sleeves. Unfortunately, these types of pit gauges are still in use today. They should be limited only for screening purposes; whereas, advanced tools with more accurate and *repeatable* measurements are required.

Other issues that a technician/field engineer experienced using flat type gauges:

- Accuracy is approximately plus or minus 10%
- Scaling on flat pit gauge is typically at plus or minus 0.0254 mm (10 mils)
- Flat pit gauge length could not bridge longer patches of corrosion which could result in errors
- Flat pit gauge tip is too large to find deepest pit
- If the flat pit gauge tip is worn, accuracy was affected in determining the deepest pit
- If the flat pit gauge was not at 90 degrees from surface, readings varied as angle changed

Below in Figure 1 is a photo of a stainless type pit gauge that exhibits some of the issues mentioned above such as bridging, tip size, scaling, angle, etc.

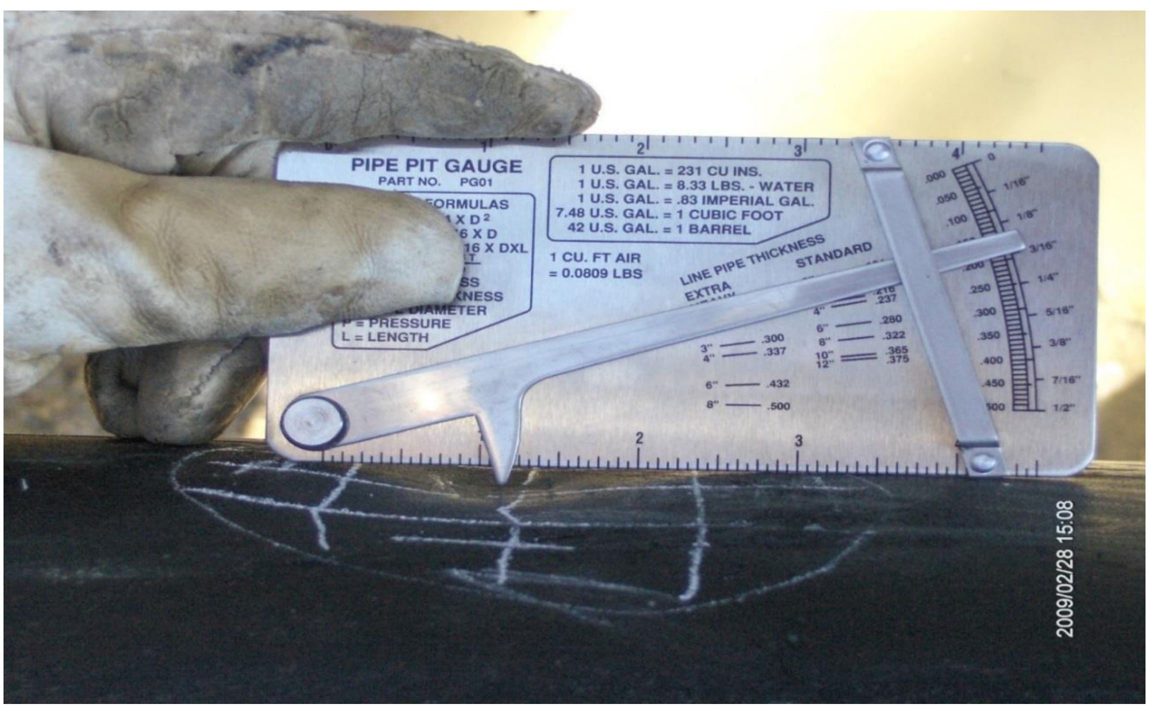

Figure 1: Stainless Flat Pit Gage

Level 2 –RSTRENG

As in-line-inspection, pressure testing and Direct Assessment have become the standard methods in the integrity process to assess pipelines, the methods of prove up for defects has been limited to the conventional mechanical type pit gauges. The most common pit gauge used in industry is the spanning or bridging type gauge. It is used to measure corrosion pitting, gouges, dents and combinations of these features. However, like the flat pit gauge, the bridging/spanning pit gauge has limitation such as:

- Accuracy is approximately plus or minus 5%
- Scaling on the bridging pit gauge is plus or minus 0.1542 (6 mils) depending on the dial indicator
- Bridging pit gauges can only span a limited length of pitting and if no parent metal exists then it approaches the same accuracy as the flat pit gauge
- Bridging pit gauges can find the deepest pits in a grid but it must constantly be realigned
- If a flat pit gauge is not mounted on a flat surface, readings vary as the pit gauge rocks sideways
- Process of grid measurement is extremely slow and tedious and subject to multiple errors

Below in Figure 2 is a photo of a typical type bridging/spanning pit gauge exhibits some of the issues mentioned above such as accuracy, requires parent metal for stability, constant alignment, etc.

Figure 2: Bridging or Spanning Pit Gage

Level 3 – Intensive Measurements and Statistical Analysis

As discussed, corrosion is one of the major factors causing pipeline leaks. However, the tools to measure this type of defect have failed the industry when using the Level 1 and 2 approaches. *Industry studies have shown that more than 80% of pipeline cut outs could have been avoided.* Why did these unnecessary cut outs occur? The technology to measure corrosion pitting with confidence was never in place. As one pipeline and plant manager stated, "I just didn't trust the present measurement equipment or the people using this equipment to conduct a comprehensive field assessment of these corrosion defects." However, with the advances in Phase Measurement Profilometry (PMP), also known as 3D Structured Light this has changed the dynamics of the industry. Combining this technology with advanced software using statistical analysis has produced better pipeline integrity predictions to meet the demands of safely transporting today's energy products. Because of the limitations of the other pitting tools and methods, the 3D structured light approach offers the following benefits:

- Meets IP67 requirements (Can be dropped on concrete and or submerged/used underwater)
- Repeatability (Measure of performance each time)
- Speed - Takes photos similar to a 2D camera in less than 80 milliseconds (mS)
- Visual and digital records are produced immediately for assessment to meet regulatory requirements
- Immediate data is made available for assessments using ASME B31G, Modified ASME B31G, RSTRENG©, API 579/ASME FFS-1, statistical calculations and stress strain calculations for dents
- Internal error checking - on every pixel
- Accuracy - within < 0.1 millimeters (3 mils)
- Lower cost - compared to laser technology (Higher compared to mechanical pit gauges)

UNDERSTANDING 3D STRUCTURED LIGHT

3D structured light is a scanning process of projecting a series of patterns such that, when viewed from an angle, a camera is able to extract range information. Resolution in depth is controlled by the number of patterns projected, which, in turn, increases the total time that the target object must remain still. By adding a second camera sensor, it becomes possible to not only achieve wrap around scanning but it also reduces the number of patterns needed to achieve a certain degree of depth resolution. In addition, a second camera also makes it possible to reconstruct 3-D surfaces through stereo-vision techniques and triangulation between the cameras instead of between the cameras and the projectors[3].

For both of these two tasks, correspondence between points from two cameras is essential as shown in Figure 3.

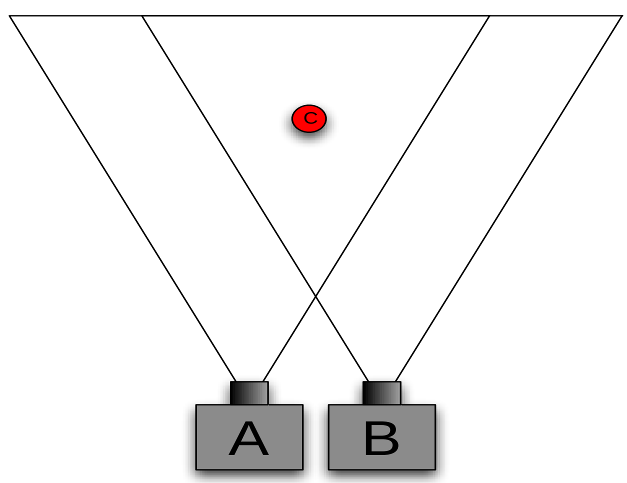

Figure 3: 3D Cameras

HOW TO USE 3D STRUCTURED LIGHT TECHNOLOGY

The 3D structured light technology procedure is the same as that used in the examination of the pipe using conventional pit gauge inspection of the coating and pipe in accordance to NACE ECDA Standards and ASME B38S. The procedure includes:

1. Inspecting coating/pipe for holidays and other features
2. Removing all coating in area of concern
3. Preparing pipe for inspection
    a. Clean pipe to remove old coating and debris

b. Remove all scale to a minimum of a NACE No. 2 abrasive blast or other approved method

4. Visually inspecting pipe for features
    a. Note areas of concern
        i. Pitting
        ii. Dents
        iii. Gouges
        iv. Wrinkle or Ripple Bends
        v. Arc Burns
        vi. Other Features

Note: This is where the 3D Pit Gauge becomes a tool that records, measures, calculates and allows the technician or engineer to make an engineering decision based on the type of mitigation or repair required. No gridlines or dots are required. However, marking references to areas of concern are recommended. The marked areas can be viewed in the 3D scans.

Shown in Figure 4 below is the 3D camera and in Figure 5 the field computer with accessories.

Figure 4: Camera

Figure 5: 3D System

Accessories are as follows:

1. 3D Camera
2. 12 VDC power supply for Camera
3. 12 VDC cable w/plug for vehicle
4. 12 meter cable for communication link between 3D camera and computer
5. 15.5 VDC power supply for computer or (Ruggedized System Controller (RSC)
6. Lap top computer or RSC
7. Monopod

Taking a 3D image is similar to capturing an image with a 2D camera. Point the camera, click using the computer, and take a 3D scan. It takes approximately 20 mS for each 3D scan. There is some sight preparation required if the corrosion has any length or width to it. However, it consists of marking the pipe or steel surface with a red pen to ensure proper overlap (25%) and sequence numbering for stitching the collage of scans together. Under typical conditions, it takes approximately 30 to 45 seconds to stitch each scan together.

Assessing Defects/Features

The types of defects that are typically encountered on pipelines are as follows:

- Corrosion
  - Internal
  - External
- Gouges
- Arc Burns
- Dents
  - Smooth
  - Combination with gouges and other defects
  - Kinked
- Cracking
  - SCC
  - HIC
- Manufacturing defects in the pipe body
  - Hard Spots
  - Hook Cracks
- Weld defects
  - Girth
  - Long Seam

3D structured light can assess most type defect types if they can be observed with the naked eye. The old adage of "What You See is What You Get" (WYSIWG) applies to this technology. However, different type of 3D cameras may be needed to observe SCC and other forms of cracking.

CORROSION AND DEFECT ASSESSMENT

Example - Using the 3D structured light camera a scan was taken approximately 381 mm (15 inches) from this heavily corroded pipe. The dimensions were as follows: 254 (10 inch) inside Diameter, 12.7 mm (0.500 inches) wall thickness, 2897 bar (42,000 psi) SMYS.

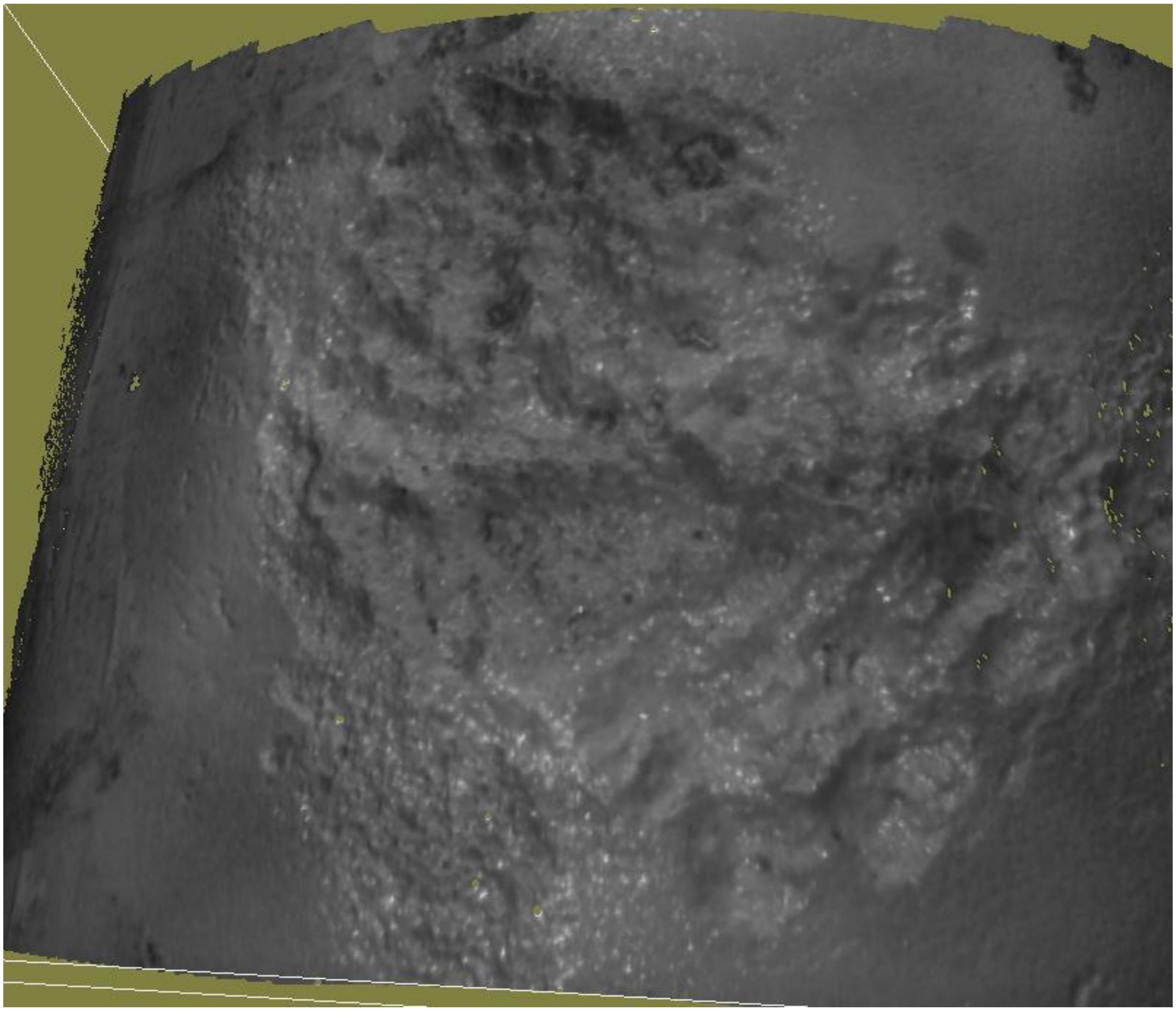

Figure 6: 3D Scan of Corroded Pipe

Approximately 300,000 pixels are in each photo, which give an excellent resolution for RSTRENG or finite element analysis (FEA). File size is approximately 7 Meg per shot. 3D scans can be easily stitched together for longer or wider lengths of corrosion. Scan time is typically at 20 milliseconds (mS).

The next step is to conduct a full corrosion analysis of the pitting. Interaction rules are selected next, which are operator, company or country dependent. The software allows the user to select rules specific to the company or industry requirements for this pipe specimen.

Shown on the next page in Figure 7 is the pipeline corrosion analysis which takes less than 1 minute to load, select the interaction rules and run the calculations.

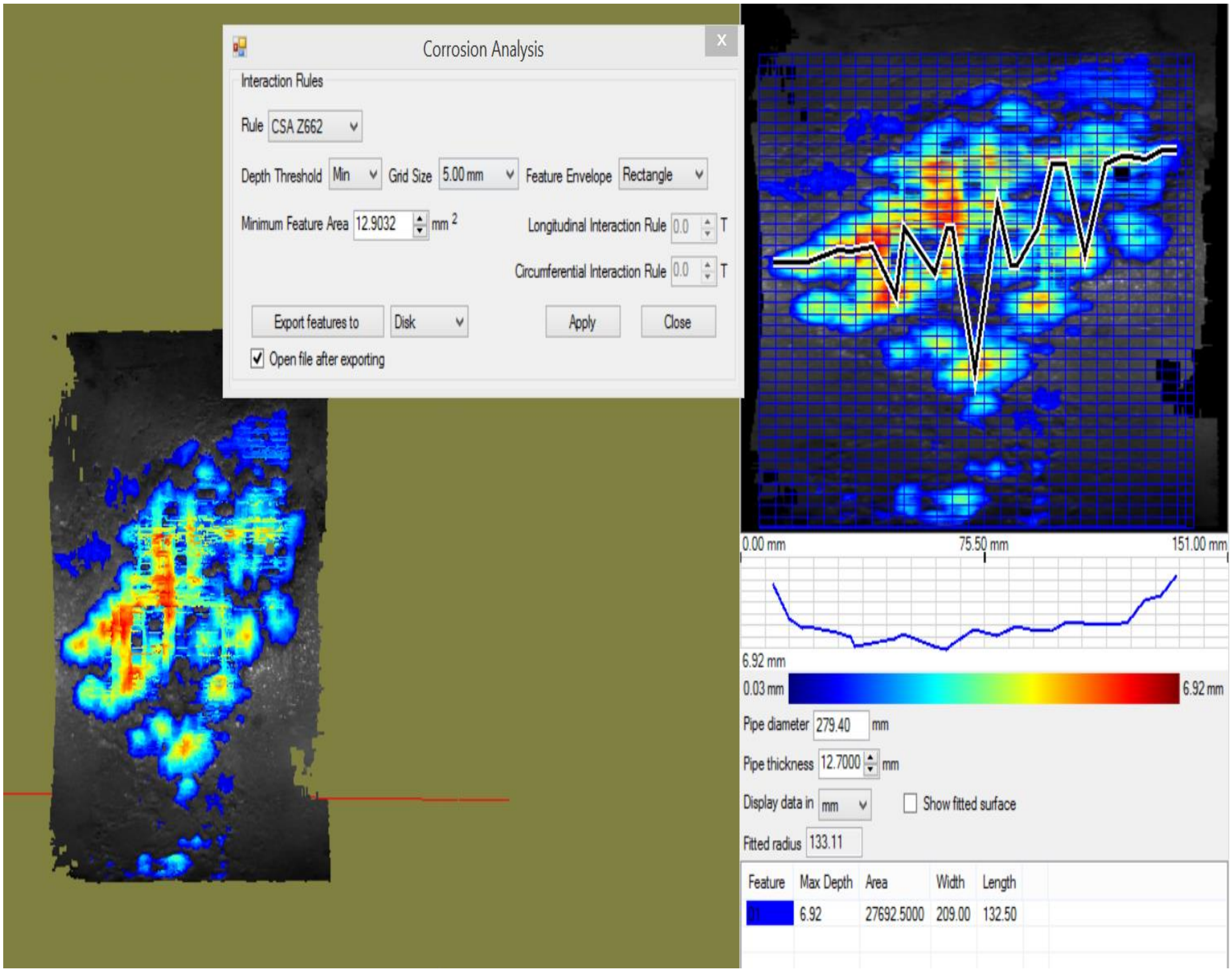

Figure 7: Corrosion Analysis of Corroded Pipe

Note: The 3D River Bottom Path is in the upper right corner of the graph. Below is the 2D Graph of the corrosion profile. The attribute data such as pipe diameter and pipe diameter is inputted by the user. The 3D camera and software measures the fitted radius of the pipe to determine if it is out of round or it can be used for determining pipe diameter. By selecting the interaction rules, the user defines the length of corrosion and how it interacts with each pit.

Next step is to run B31.G, Modified B31G or RSTRENG calculations

Shown on the next page in Figure 8 is the output of the river bottom path corrosion profile. The results of this pitting cluster are on 5 mm grids for demonstration purposes which include increment length, depth, maximum pressure in bars and safety factor.

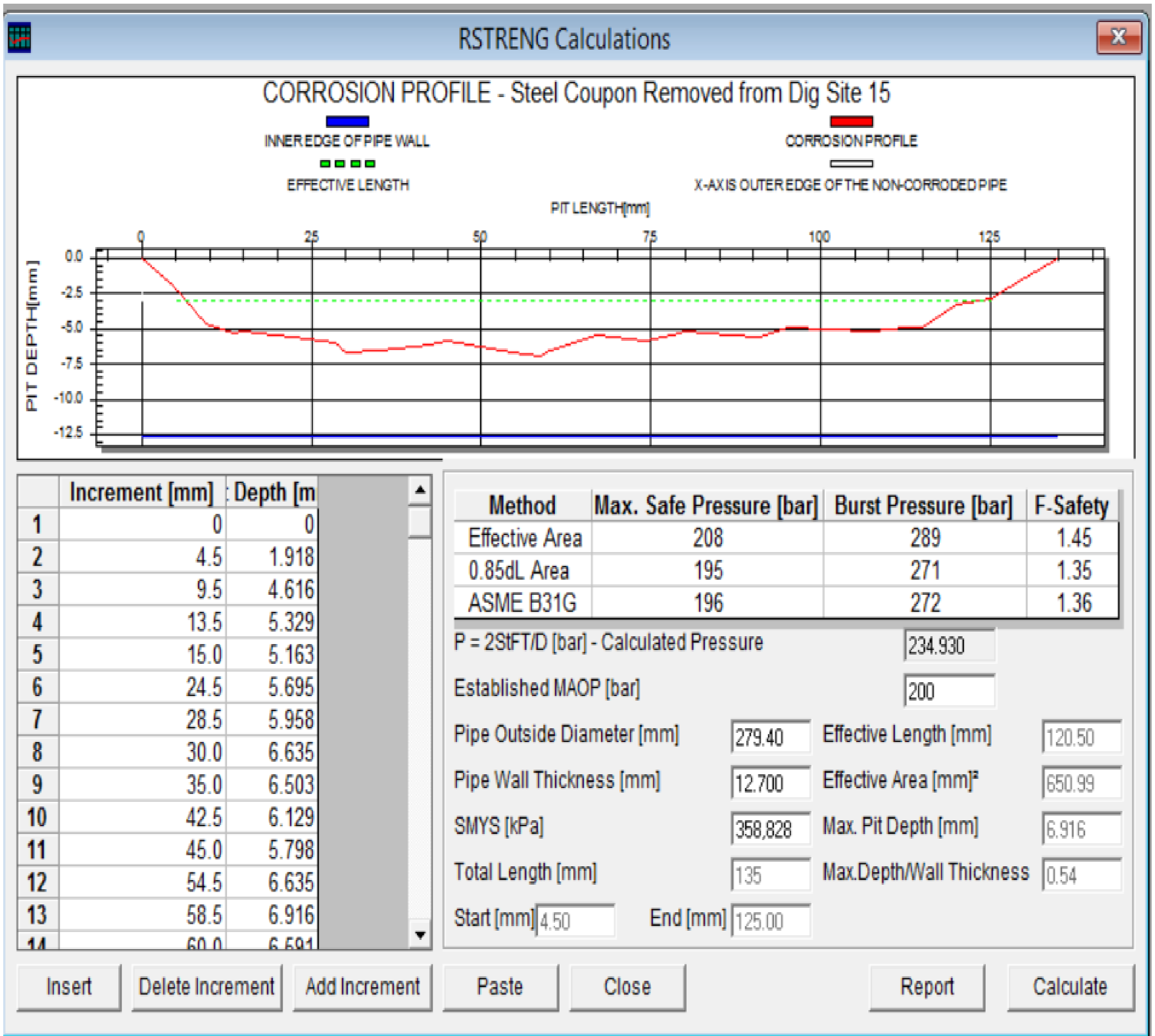

Figure 8: RSTRENG Analysis

If this were a Class 1 area rated at 72% SMYS for a natural gas pipeline, with a maximum operating pressure (MOP) of 100 bar (1450 psi), this corrosion patch as bad as it looks would only require an abrasive blast and recoat for mitigation. The maximum safe pressure and safety factor using the more conservative method of ASME B31.G would have passed at 196 bar with a 2.72 safety factor respectively. However, the Remaining Strength of Corroded Pipe (RSTRENG) would be 208 bar (3016 psi) with a 2.89 safety factor.

Double Dent with 7 Gouges Assessment

Example - Using the 3D structured light camera, a scan was taken approximately 15 inches from the surface on a small diameter pipe identified with two dents and 7 gouges. The dimensions were as follows: 101.6 mm (4 inch) inside Diameter, 6.35 mm (0.250 inch) wall thickness, 1655 bar (24,000 psi) SMYS.

Below in Figure 9 is a 3D raw photo of the double dented pipe with 7 gouges.

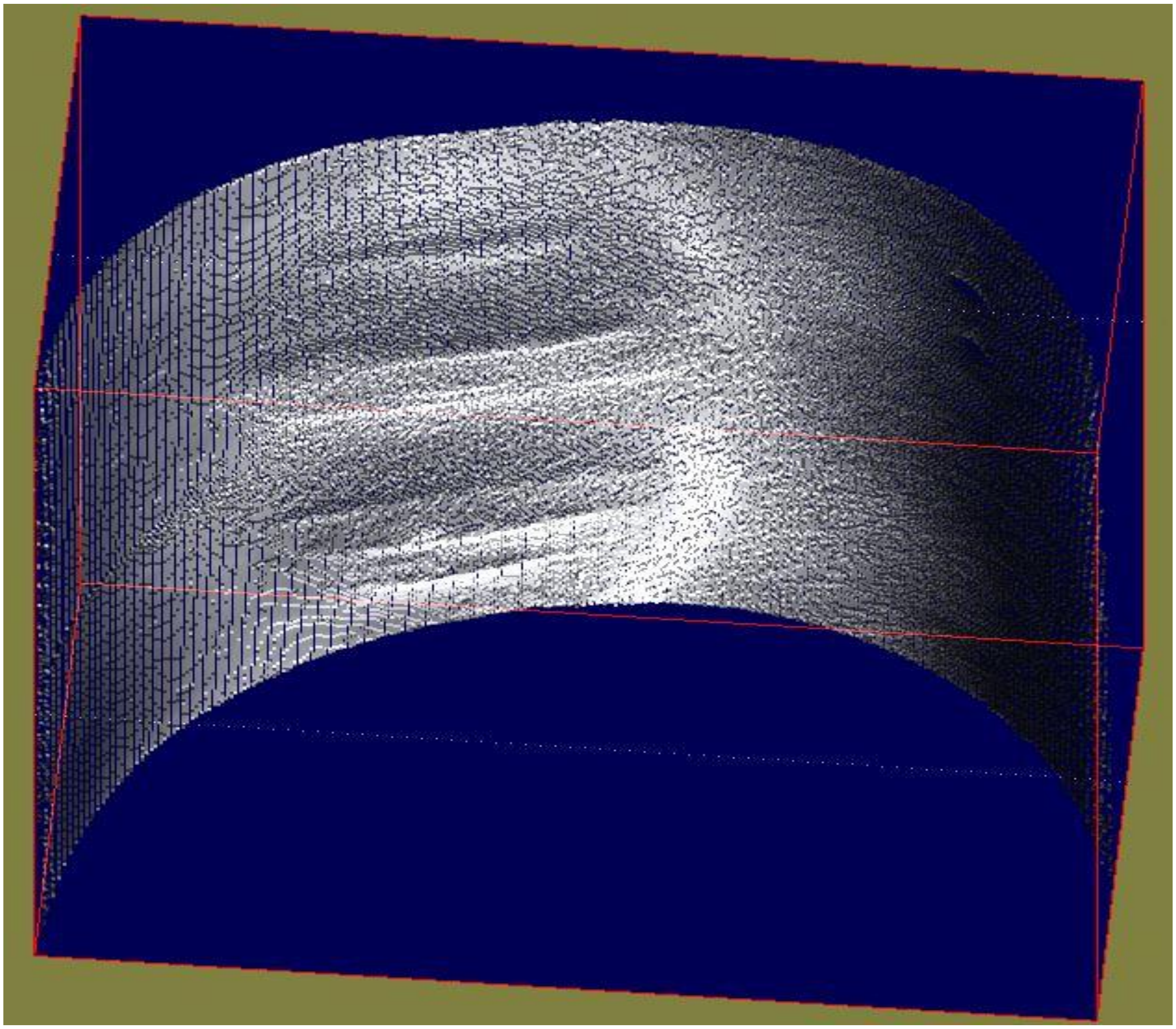

Figure 9: Double Dent with Gouges

As with the corrosion scan, there are approximately 300,000 pixels in each scan which allow allows excellent resolution for determining the radius curves of the gouges inside the dent for finite element analysis or stress strain calculations. File size is approximately 7 Megs per shot. 3D scans can be easily stitched together for longer or wider lengths of features. Scan time is approximately 20 milliseconds (mS), the same as used for corrosion determinations.

The next step is to conduct an assessment of the dents and/or gouges. Using dent analysis, this method depicts the steepest radius curves in the longitudinal and circumferential directions. In addition, the software allows the user to select and run the full family of longitudinal and circumferential curves, including the following:

- Degrees

- Down sample
- Average
- Delta Radius
- Radius

The next involves exporting data to spreadsheet for finite element analysis to determine the stress strain of the dent.

Below in Figure 10 is the output dent analysis which takes less than a minute run.

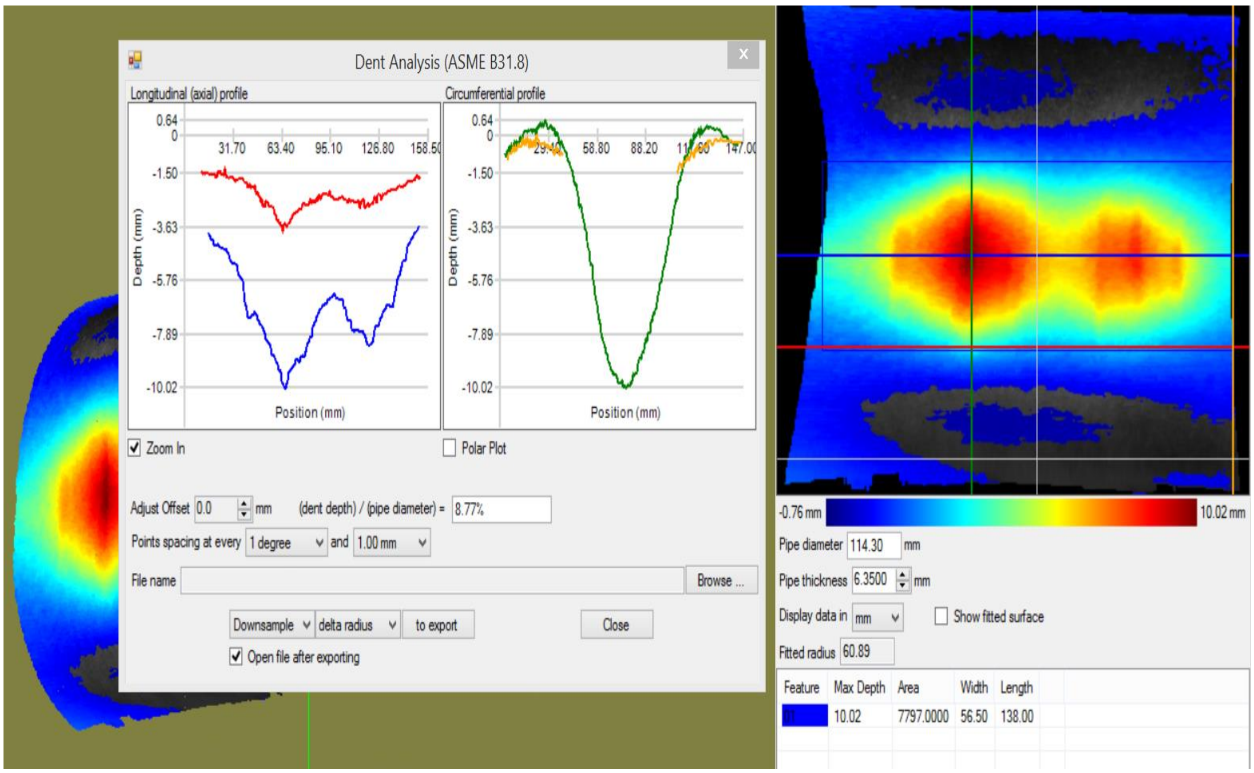

Figure 10: Dent Analysis

Note: The dent analysis show dent depth/pipe diameter to be 8.77%. This would be considered a significant dent which is combined with 7 gouges. These gouges can be seen in the longitudinal left side of the graph as tips project below the line. The shoulder of the dent can be seen in the circumferential side of the graph or green line which projects above the zero line. What is more interesting is that the dent projects out more longitudinally than the coupon. This phenomena has been observed by many others in scanning dent using this technology. We believe that additional study needs to be addressed in this area of these types of defects.

The above examples examine what can be accomplished with this type of technology and software. With 3D structured light technologies, the most stringent requirements of API RP 579/ASME FFS-1 Levels 1, 2 or 3 can be with the confidence to assess and determine pipeline or vessels remaining strength and stresses. In addition, the raw data and ensuring reports are now all digital. There is no need to write down readings in performing these types of assessments which can be done either in the field or in the office. Decisions can be made quickly to minimize contractor down-time while waiting for the various types of mitigation to be implemented.

CONCLUSIONS

Integrity management activities to ensure safety are paramount. Risk reduction can only be achieved by using tools that provide confidence though repeatability. These benefits include:

- Immediate analysis of data for assessment using ASME B31G, Modified ASME B31G, RSTRENG©, API 579/ASME FFS-1 and statistical calculations
- Repeatability each and every time
- Accuracy - within in several mils or < 0.1 millimeter
- Internal error checking - on every pixel
- Visual and digital records - produced immediately for assessment and regulatory requirements
- Achieve required documentation for regulatory requirements and continuous improvement

REFERENCES

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