ILI TOOL VALIDATION – FEATURE ASSESSMENT AND MAPPING

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Abstract

In-Line-Inspection reports are now forming the foundation of Integrity Management Plans. Reliance on these reports demands that tool data be verified and validated. This validation requirement, while technically prudent, will also be a recommended practice in new procedures being developed.

Tool validation is a difficult task requiring detailed field measurements of features in a format that can be compared directly to the ILI data. This paper presents an overview of the validation process and describes the development and testing of a new device for measuring, documenting and assessing external corrosion on steel pipelines.

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Introduction

A method for measuring external corrosion on steel pipelines has been developed and tested. The new method, developed by Southwest Research Institute, San Antonio, and Clock Spring Company, Houston, Texas, uses a flexible printed circuit board with pairs of sensing coils and electronic components which energize the coils and process their signals.

Software produces a contour map of the corrosion, which identifies the depth and location of the deepest pit, and calculates the maximum safe operating pressure.

Defect Assessment

Pipeline operators use both external and internal surveys to evaluate the condition of their pipelines. In-line inspection (ILI) tools are a common method to evaluate pipelines and pinpoint damage. ILI surveys can provide information on welds, branch connections, valves, wall thickness changes caused by corrosion, and other imperfections in the pipe.

Once features are identified, bell-hole excavations verify the quality of reported features. While verification serves many purposes, the primary one is to accurately quantify the extent of the features so that defect assessment and repair can be completed to ensure pipeline integrity is maintained cost effectively.

Secondary benefits include the recording of feature information for use on subsequent inspections to help calibrate and validate ILI performance.

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Defect assessment typically follows one of three industry-accepted methods. The most common is B31G (ASME B31G, Manual for Determining the Remaining Strength of Corroded Pipelines). This assessment technique requires only the length and maximum depth of a corrosion defect, which, with pipe material information, can be used to calculate a safe operating pressure for the defect. While this method is fast and easy, it is often too conservative and can lead to unnecessary repairs.

More-complex assessment methods can be used to minimize unnecessary repairs. Using slightly different material properties and a different shape factor, a modified assessment can be made that is less conservative than the original B31G. This is the 0.85 dt method. However, it still requires only defect length and maximum depth to calculate a safe operating pressure.

The assessment technique with the least variability is the exact or effective area technique. Instead of assuming a shape factor, this technique uses the exact cross-sectional area of the defect. The area is determined from a complex axial profile which uses the maximum corrosion depth at each axial measurement spacing.

Corrosion Measurement

Regardless of which assessment method is used, the input data are usually provided by local measurements on the outside of the pipe in the pipeline excavation (bell hole).

The simplest case is that of a single isolated pit. A scale measures the length of the corroded area. A dial extension gage (pit gage) is placed over the pit (assuming the base will span the pit) and the maximum depth read and recorded.

Slightly more complicated is the case of several overlapping pits or a small patch of corrosion. In this case, the length can still be read from a scale. An attachment, such as a bridging bar, often spans the entire defect, providing a reference surface from which to measure depth. It is not always possible to readily locate the deepest pit within the grouping from a visual examination, so several independent depth measurements must be taken.

When the corrosion is extensive and an exact area assessment is needed, it is essential that the defect be accurately mapped to form a contour plot.

In these cases, a rectangular grid is drawn or painted on the pipe surface, including the corroded area. Depth measurements are taken at each grid intersection.

From this array of measurements, either manual or computer-aided processing constructs a contour map. The contour map is then used to assess the defect and calculate a safe operating pressure.

All these manual methods are laborious, time-consuming, and error prone. It can take the better part of a day to make all the grid measurements on an extensive corrosion patch. Furthermore, the environment of the pipeline bell hole is not always user-friendly.

Rain, cold, and other inconveniences can take a toll on operator attention and, consequently, accuracy of measurement. This is particularly true if the corrosion patch is on the bottom of the pipe.

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The eddy current array, described here, promises a faster and more-reliable method of acquiring contour measurements.

Eddy Current Liftoff Measurement

Eddy current liftoff is the method of pit depth measurement used by the conformable array.

If an alternating electrical current flows in a coil of conductive material (Fig. 1), a magnetic field is created about the coil. If the coil is placed near an electrically conductive material (Fig. 2), the magnetic field penetrates the material and causes reaction currents to flow in the material.

The effect of these reaction currents is to change the electrical impedance of the coil. The amount of change depends, among other things, on the spacing between the coil and the material, as indicated by the arrows in Fig. 3.

If two coils are closely adjacent each other, as is the case with the conformable array, and one coil is an "exciter" and the other a "receiver," the electromagnetic coupling between the coils is a function of the distance to the conductive material.

If the coil pair is placed on a smooth surface and then moved over a corroded area, the metal loss at the corrosion represents an increase in the distance from coil pair to conductive material, leading to coil coupling changes that may be detected as a measure of pit depth.

Eddy current measurement using alternating current excitation creates reaction currents only in the near surface of the conductive material with the depth of penetration depending on the excitation frequency and the properties of the conductive material.

The conformable array uses a frequency that penetrates much less than 1 mm into the pipeline steel, making the measurement independent of the pipe wall thickness. As a result, the system cannot determine remaining wall thickness without using an assumed nominal wall thickness or by an auxiliary wall measurement in the vicinity of the corrosion.

When these measurements are acquired, they are input to the conformable array analysis software to produce an accurate defect assessment.

Conformable Array Design

Since eddy current coils can be fabricated on flexible printed circuit boards, a flexible board was outfitted with multiple eddy current coil pairs and wrapped over corrosion to produce a rapid mapping of the corrosion, including depth.

This system offered the potential for a fast, relatively low-cost measurement system, usable with minimal support equipment and minimal training (Fig. 4).

Original experiments with the eddy current array used a flexible printed circuit array with 64 coil pairs, each one 4 mm in diameter. The engineering prototype board and the commercial system expanded the size to 256 coil pairs, with coil pairs being 9.5 mm apart. Besides the 6-inch (152 mm) square array, the printed circuit board also included rigid portions for mounting circuit components (Fig. 5).

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The flexible portion of the board is made in several layers to provide for the intricate interconnections between coils and the interface circuitry at the board's edge. The production version of the array includes a conformal coating over the circuitry boards for environmental protection.

Testing the Conformable Array

Two sets of proving tests were conducted once the prototype board was built and checked out: The first test was carried out on a natural corrosion specimen at SwRI and the other on a section of pipe with extensive corrosion at the RTD Quality Services Houston facility.

The testing at the RTD facility had two advantages over the SwRI test. First, the corrosion patch was large, providing a chance to use the stitching algorithm that created a large color-depth map from several (in this case, eight) separate scanning positions.

Second, the test pipe had previously been scanned by a laser scanner, giving a comparison of performance with the industry "standard of excellence" in accuracy and resolution.

The results of the laser scan and the eddy current scan are shown in Fig. 6. The eddy current scan (top image) was plotted in Microsoft Excel and the contour colours chosen to match the laser scan (bottom image) colours.

Comparison of these images indicates the laser has a higher resolution, based on the many smaller spotted (red) indications shown between the larger (multicoloured) indications. Significant features—those representing least-remaining wall thickness (multicoloured indications)—match between the two scans.

Fig. 6 (top image) shows the 12-inch (305 mm) by 24-inch (610 mm) corrosion patch with the eight contiguous 6-inch (152 mm) square measurement areas. To create a file of baseline data, the array was first used to scan a clean area on the test pipe. The array was then positioned on the large corroded area in eight setups guided by register marks placed on the pipe.

The operating software accepts inputs of the number of setups in the horizontal and vertical directions and prompts the user to move to the next position. Each scan takes only seconds.

The calculations of pit depth are made almost instantly after the data are collected, and the data are written out to a file that may be displayed with graphing software such as Microsoft Excel. Comparison of the plot and the photograph of the corrosion indicate excellent correlation.

Indeed, when compared to the direct measurement laser scan data for this same corrosion patch, the conformable array showed similar pit depths, shapes, and positions (Fig. 6) with visible representation accuracy notably greater than that of in-line inspection.

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Analysis Software, Data Display

The conformable array software was written with ease of use for both acquisition and analysis in mind, thereby allowing a trained user to scan a pitted corrosion area and make pipeline repair or replacement decisions in minutes rather than days.

Conventional wall-thickness measurements require bulky instruments or imprecise and time-consuming hand measurements. The conformable array software handles both acquisition and analysis in real time.

Data scans of the pipe are first acquired by the operator in the 6-in. square sections; corrosion areas larger than this require multiple scans, with the results being stitched together in software.

These data are then scaled, using known scans from un-corroded pipe wall and air (100% corrosion). The user receives a surface map of calibrated wall loss. Using industry guidelines for interacting pits, the data are "auto-boxed" or, more simply, interacting pits are automatically discovered in software, and groups of such pits are reported to the user.

Initial versions of the software reported only two defect groups, the largest axial length group and the deepest pit group; however, early tests showed that this method would fail to report the correct group when a group displayed a combination of features. New versions of the software default to the group with the lowest maximum allowable operating pressure.

If the pipeline parameters have been entered by the operator, then B31G, modified B31G, and effective area calculations are performed and displayed in real time. If a pipeline is shown to be operating outside of allowed specification or a new maximum operating pressure has been determined, then a warning is issued to the user and the pipeline operator can take the appropriate preventive measures.

A future version of the code may also interface with an ultrasonic transducer to check the actual wall thickness and GPS transceiver to record a corrosion patch location.

ILI Tool Validation

In addition to assessing corrosion defects, ILI tool performance must be validated. ILI technology has matured to the point where tools can now report feature geometry information.

These tools also report thousands or even tens of thousands of features. The inspection report now forms the foundation for an integrity management plan. This requires that the ILI data be confirmed and the ILI report validated.

This requires accurately mapping defects for comparison to the reported feature geometry. The conformable array can perform this secondary task with no additional labour. The electronic file can be stored for record keeping and reviewed on subsequent inspections to validate tool performance.

It was a design goal of the conformable array system that the system relieves the operator of making any manual calculations of safe operating pressure; therefore, the system software performs the assessment calculations automatically.

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Individual pits are tested for proximity to all surrounding pits to determine interaction. The system then performs a “boxing” function to place pits critical to the pipe safe operation within a calculation box.

The eddy current data are converted to pit depths by using a conversion curve. Since the spacing between coil pairs is fixed and known, X-Y dimensions can also be determined. The depth and profile data are applied to B31G and other assessment algorithms and the results displayed on the laptop screen. In addition to the numerical data, graphs of acceptable combinations of defect depth and length are displayed along with local corrosion parameters.

Figure 7 show a sample of the type of data presented. The software allows the user to specify the number of scans to be taken in both the axial and circumferential directions. Pipe properties are input via the Pipeline Data screen. When a scan is completed using the New Scan screen an analysis can be done using the Defect Analysis screen.

A feature previously assessed can be reviewed using the Load Scan screen.

Application

The conformable array has three unique applications; defect profiling to help inspection vendors calibrate inspection runs, record keeping to meet regulatory requirements and to qualify future inspections and defect assessment in a timely fashion.

Before rehabilitation or defect assessment can take place, the pipeline must be inspected to determine its condition. The most common technology used for the inspection task is Magnetic Flux Leakage. This is a robust and complex technology. Defect profiles are not directly measured but must rather be deduced from a detailed analysis of the magnetic data. The magnetic data is not only influenced by the defect in the pipe wall but also by the material properties of the pipe and the operating conditions of the tool. When errors occur they can be corrected or minimized with additional calibration information. For this calibration information to be useful, it must accurately reflect the physical properties of the defect. The conformable array will be able to provide accurate calibration information in a convenient digital format to the inspection vendor such that an inspection can be graded more accurately. This alone can save large amounts of money for the operator.

In addition to providing calibration information, the conformable array will provide a convenient method of record keeping that will satisfy the regulators and provide a rich source of defect information that can be used to assess and qualify subsequent inspections. If a defect is measured and repaired with a technology that does not affect the magnetic properties of the pipe then that measurement information can be used on subsequent inspection to help calibrate the inspection. This data can also be used to ensure that the inspection company has complied with detection and sizing specifications outlined in the contract. It can qualify a tool run. This qualification aspect will become more important as inspection is imposed on the industry.

The main purpose of the array, however, is to measure defects for repair assessment. In the coming months, U.S. Pipeline operators will be completing plans to comply with the U.S. Department of Transportation’s Research and Special Programs Administration (RSPA) mandatory Integrity Management Program, also known as the IMP rule. These new regulations will spur a significant increase in pipeline maintenance activities. Mergers, acquisitions and consolidation of energy resources involving the transfer of assets will also impose tighter schedules on maintenance activities. In this process, operators will have to assess defects detected by inspection tools, select repair alternatives and develop maintenance procedure to ensure an effective and timely response.

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The conformable array is the tool needed to make fast accurate defect assessments in the field so that repair decisions can be made on site and repairs completed while the defect is initially exposed. This tool will not be designed to compete with the accuracy of a laser scanner but will be capable of providing the information needed to assess repair requirements and alternatives.

Conclusions

Tighter schedule imposed on operators and the increasing need to qualify pipe inspections demands new technology. The conformable array will be one of the tools that can gather defect information to assess defects, calibrate inspection equipment and qualify inspection results.

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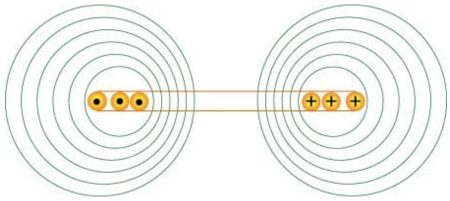

Figure 1. Magnetic Field created by a coil in air

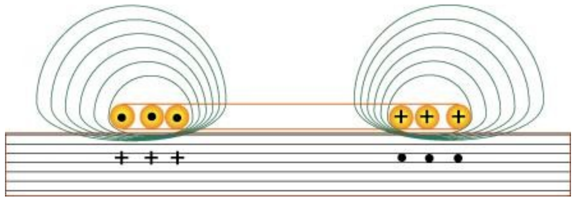

Figure 2. Magnetic field created by eddy current coil near a metallic surface

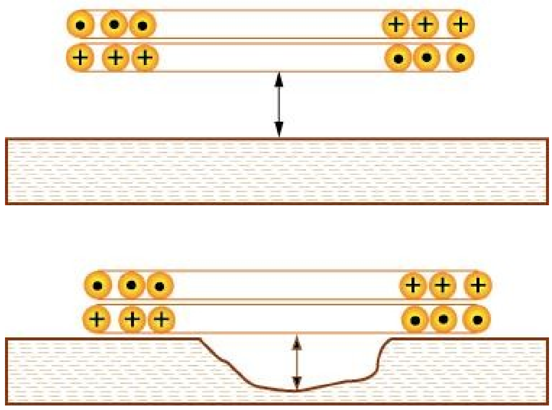

Figure 3. Liftoff distance measured by eddy current coil pair.

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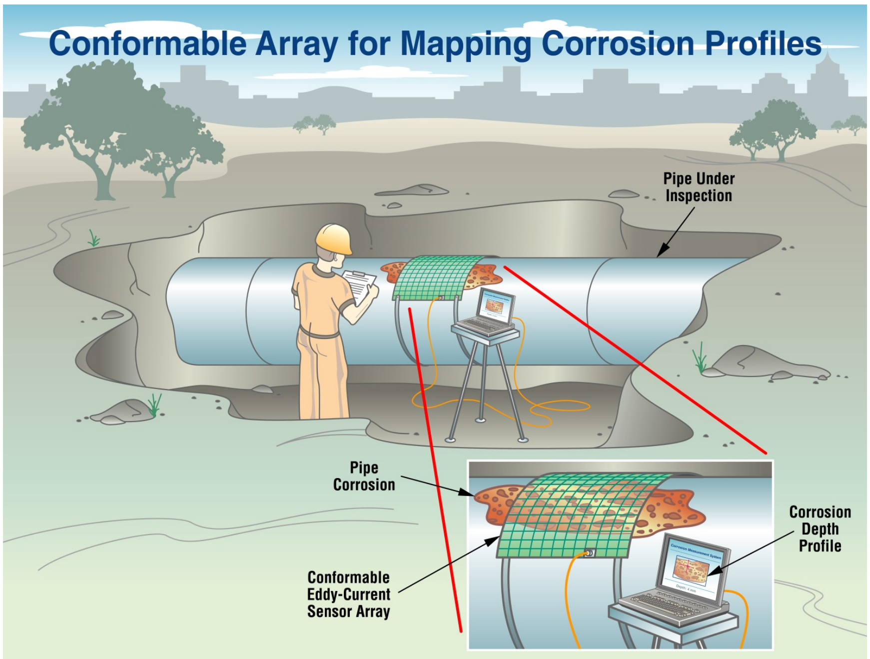

Figure 4. Flexible array concept

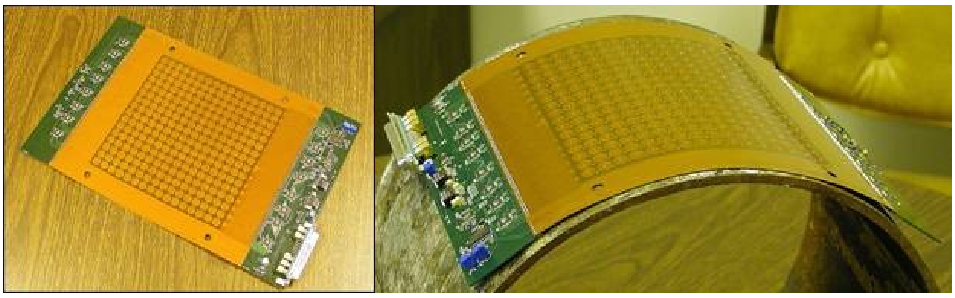

Figure 5. Conformable EC Array

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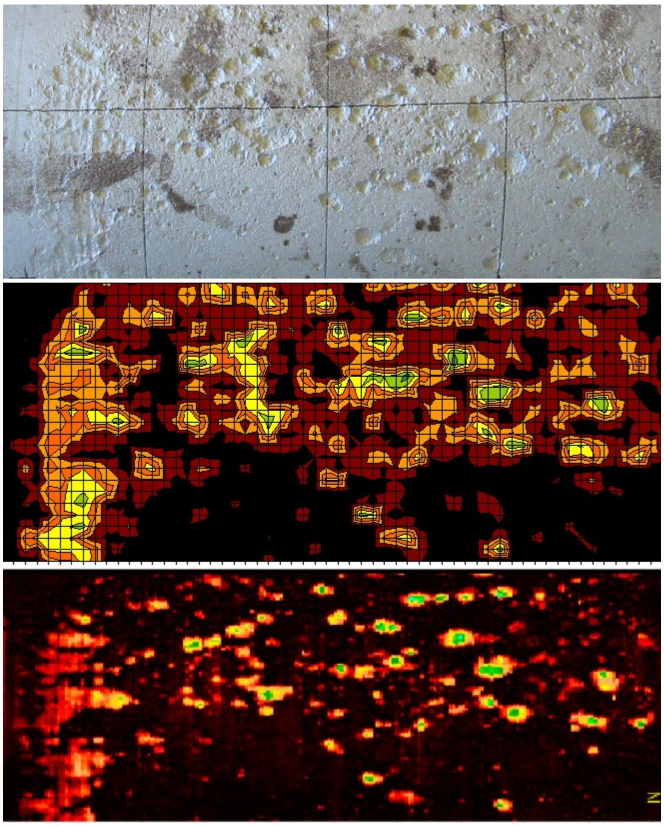

Figure 6. Corrosion, Conformable Array Scan, LASER Scan

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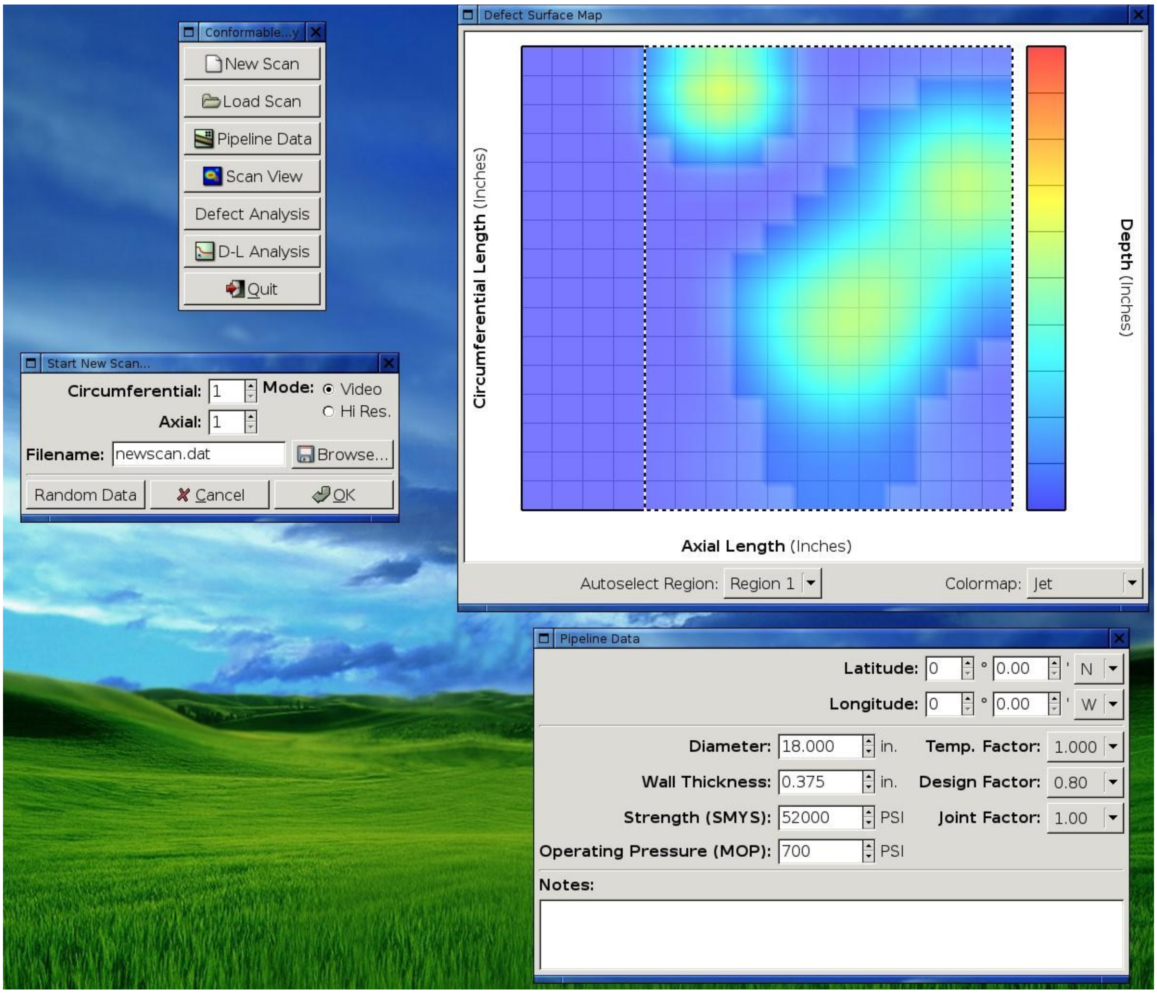

Figure 7. Sample of output data

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