Application of Flexible PAUT probes for small diameter Flow Assisted Corrosion elbow inspection II

Vajira JAYASINGHE, Chris EATON, Brian MILLEJOURS

1 IMS Development Lab, 1910 Clements Rd, Pickering ON
Phone: 905-427-4010; E-mail: vajira.jayasinghe@opg.com, chris.eaton@opg.com, brian.millejours@opg.com

Abstract
This paper presents an update to the application of newer flexible Phased Array UT (PAUT) probes that can be contoured to the surface of the component to be inspected. Development was based on introducing PAUT in lieu of Radiography (RT) as part of the FAC inspection program.

Currently for piping elbows of NPS 4” and less, there are limited PAUT solutions available. Most scanners cannot traverse elbows, or are not configured for smaller pipe diameters at all. The goal with application of a flexible array probe was to eliminate the need for multiple probes/wedge combinations and utilize a single design over a range of elbow diameters to determine wall loss.

After successful field trials, use of the flexible probes was expanded to actively replace RT in the plant FAC inspection program for butt-welded joints. Capabilities with C-scan mapping and post-processing to allow PAUT data mapping on 3D components were explored, with goal to provide visualization of the identified defects to facilitate replacement

Keywords: PAUT, FAC, pipe elbows, ultrasonics, flexible probe, Phased Array

1. Introduction

Ontario Power Generation’s (OPG’s) plants are in the process of replacing radiography testing (RT) with Phased Array Ultrasonic Testing (PAUT) on smaller diameter piping as part of the Flow Assisted Corrosion (FAC) program. It is preferable to use phased array ultrasonic testing in lieu of radiography for inspection accuracy, reducing manpower, and minimizing safety risk. However a significant drawback still remains with regard to the visual representation of the data.

This paper continues from where the previous entry left off. That paper summarized the creation of applicable test pieces which incorporated typical Flow Assisted Corrosion patches, followed by applying several different flexible probe sets to determine limitations. Linear and sectorial scan parameters were manipulated for each probe on the test blocks with an end goal of determining measurement accuracies, elements in contact, and optimal PAUT settings. Since that point in time, further development has continued with a focus on the potential to introduce encoded data scanners, mapping the acquired PAUT data onto a representative 3D model, and streamlining the process for simplified field application.

2. Background

The previous paper presented application of newer flexible PAUT probes which can be contoured to the surface of the component being inspected. The use of this type of probe was predicated by a need to inspect piping elbows of nominal pipe size (NPS) 4” and less for which there are limited PAUT scanner solutions available. Most scanners cannot traverse elbows, or are not configured for smaller pipe diameters. The application of a flexible array probe over more traditional manual PAUT probes was undertaken to eliminate the need for
multiple probe/wedge combinations and simplifying the inspection by utilizing a single design over a range of elbow diameters.

Following successful lab testing, the usage of flexible array probes as a potential replacement for RT was field tested at an OPG power plant in 2015. It has been introduced this year to replace radiography in several feed-water heater and boiler line locations. The implementation of this program is preferable due to several factors including lower manpower requirements, minimizing hazards/dose, and minimizing impact to other work groups. The primary drawback at this time is in the ultrasonic testing (UT) data presentation to the engineer. Currently, this inspection is taking place at one of our nuclear facilities with all of the special provisions working in such an environment entails. The procedure involves a relatively simple manual inspection using a 0° electronic scanning (E-scan) setup of a grid-mapped component. Encoded solutions are employed for larger diameter piping (>3”) inspections as necessary.

2.1 Test Pieces
Several piping elbow test pieces were developed based on FAC samples taken from the field. Based on a summary of affected components in the FAC program, both 90° and 45° elbows were created to cover a range of piping diameters (NPS ¾”, 1”, 1½”, 2”, 2½”, 3”, 4”). Three defects patches were machined into the components based on relevant FAC degradation mechanisms as outlined by Figure 1 [1].

These test pieces were used to develop the inspection and as such were designed to test the full capabilities of the probes under evaluation. Three FAC areas were machined into the test pieces using specially formed Electrical Discharge Machining (EDM) electrodes. Two patches mimic FAC at the midpoint of the elbow with 25% wall-loss and 50% wall-loss, and a third patch mimicking 40% loss following a weld. It is useful to note that the FAC pattern utilized is considerably more pronounced than typical FAC patches encountered in the field; this was done purposely in order to test the potential worst case scenario of a reflector with inadequate parallel surface, creating a loss of signal [1].

3. Scanner Evaluation
One of the main improvements identified during the replacement of RT was to provide the engineer a better visualization of any identified defects. This immediately lent itself to an encoded scan that could be mapped either to CAD models or utilized in a .csv file for export. The primary purpose for the scanner was to enhance accuracy over a time-based scan mapped over a grid system and also to facilitate mapping of the PAUT data onto 3D components.

Different scanner options were evaluated on the test pieces mimicking FAC corrosion patches at different elbow diameters. The preferred solution for both cost and convenience was a ready-made off the shelf item. To that end, both the JIREH based low profile encoded scanners (Cobra and Circ-it) were looked at initially, but their design did not lend itself well to traversing an elbow. A wheel probe design was considered due to the inherent flexibility of the membrane, but unfortunately was not compatible once the piping diameter was less than 3”. Additional off-the-shelf scanners for small diameter piping were initially evaluated, and when it was evident that a suitable scanner could not be found the evaluation was expanded to custom solutions.

Ultimately several promising options were further assessed: a custom encoder housing for a flexible array probe, a repurposed flexible housing system, and a manual PAUT probe XY scanner.

3.1 Custom Flexible Probe Housing (e2sense probe)
A custom flexible array probe (10 MHz, 32 element 1.0 mm pitch) from e2sense was designed with a detachable housing mount which used different ‘pressure pads’ to control the flexibility of the probe around different diameter elbows (see Figure 2a). The pads would fit in between the housing shell and the probe to distribute the appropriate pressure to the probe to maintain coupling (see Figure 2b). This foam could be readily adjusted or switched out entirely for a different material. While the system worked well in principle there were difficulties maintaining uniform contact with the part surface. A gap tended to develop along the profile of the elbow creating contact issues as shown in Figure 2d).

3.2 Repurposed ECA Scanner (Olympus probe)
An Olympus designed 5 MHz, 64 element, 1.0 mm pitch flexible array probe did not come with any OEM encoding options for the probe. An updated design of the probe housing offered a potential option to attach the mini-wheel encoder, however this proved incompatible during actual testing on pipe elbows. An alternative option was proposed when observing the standard diameters covered in the Eddy-Current-Array (ECA) kit.
The ECA probe housing and encoder was removed and used in concert with the flexible array probe (see Figure 3). The Olympus PAUT probe is not as flexible as the ECA, so some care had to be used in how the probe was contoured to the scanner geometry. Also, the shape of the scanner created a cantilever on the elbow, affecting either probe contact or encoding quality as the scanner traversed the part. A sample set of results is shown in Figure 3c.

![Figure 3: Probe curving on NPS 2.5” pipe (a), side profile of probe combination (b), and sample E-scan file from acquisition (c).](image)

### 3.3 XY scanner (Imasonic probe)

The final scanner tested is a more traditional small footprint model, which was used in order to ensure a solution was available for deployment if an encoded solution was required for field execution. This design utilized a custom housing built to utilize manual PAUT probes with an encoder for the x-direction and indexer box for the y-direction (as shown in Figure 4). The encoder unit can be separated from the probe through a magnetic attachment, allowing a manual scan to be conducted and followed up with an encoded scan when recordable indications are observed. This results in a far more adaptable design, as a single line scanner can be prone to errors when axially scanning elbows. While the probe footprint is adequate to maintain contact from the elbow left cheek to right cheek, it cannot effectively be used on smaller elbow intrados. Additionally there is no practical method to avoid encoder slip during an axial scan, and a circumferential scan is impossible at the bend. Since it covers a distinctly smaller area, a gridding system is necessary on the pipe to ensure adequate coverage and that proper probe overlap is maintained during the scan.

Use of a manual PAUT probe allows more versatility in the system, which enables it to be deployed as a complementary technique should additional degradations mechanisms be discovered. The scanner’s usage is currently limited to piping elbows 3” and above. The probe holder is designed to accommodate the shoe for either axial or perpendicular scanning depending on the expected orientation of the defects.
4. 3D Visualization of Data

The primary goal of incorporated 3D visualization to inspection results is to simplify
presentation of the inspection data. A clearly outlined area can greatly enhance the
characterization of a defect, provide additional information when searching for potential
causes and aid in prioritizing repair/replacement efforts. A key caveat to these benefits is that
it needs to be balanced by the practicality of the inspection. The search for a perfect picture
should not significantly increase the complexity of the inspection. For that reason, more
advanced methods of data recording were not pursued. We want to create a streamlined
system that a technician can use to help the engineer/evaluator understand the significance of
the findings. This ideally is accomplished in a procedural manner, with minimal training
required, and without turning it into an exercise in graphical manipulation.

These goals are aided somewhat by the simpler interpretation of UT thickness
measurements as opposed to weld inspection which would require accuracies of the weld
bevel prep to match up with the PAUT data, or turbine blades which have non-uniformities
across batches. However, an acknowledged challenge in the approach is manufacturing
tolerances with piping elbows and fittings which could still cause larger errors in mapping.

The process required use of either an MX-2 or Topaz, a 3D license of UltraVision 3.7
and a CAD model of the component inspected. An overview of the step by step process was
as follows:

1. Importing the data-file from either an MX-2 or a Topaz into UltraVision 3.7.
2. Import custom geometry as the specimen (in this case a pipe elbow).
3. Map the scan path of the probe over the same area inspected onto the CAD model.
4. Set up contours in UltraVision to adjust the volumetric merge parameters by boxing
   in the relevant data (ie. eliminate multiple backwalls, extraneous scan data).
5. Perform a volumetric merge.
6. Evaluate the alignment between D-scan, B-scan and the projection for accuracy and
   adjust the process from 3. as necessary.

For testing on a block with known defects, modelling was pursued with the actual CAD
model of the reference block to enhance the data visualization. As shown in Figure 5, a single

Figure 4: Scanner system traversing a 3” elbow (a), Scanner with probe and encoder detached (b), and a typical B-scans response (c).
line scan over the critical orientation of the defects can be merged with the CAD model to enhance them. These defects line up with the presentation in Figure 1, showing clear identification of each indication when compared to Figure 5d. The final presentation of the CAD model overlaid with the image is consistent with these identified thickness changes (see Figure 5a).

Subsequently, modelling using a standard CAD model was used as a comparison with a scan from a field sample (see Figure 6). In both cases, while the merge is consistent with the results, the overall presentation does not greatly aid in distinguishing thin areas.

Figure 5: Screenshot of UltraVision showing scan of test piece with data overlaid onto CAD model (a), E-scan of the test piece (b), Probe scan path on part (c), B-scan of the test piece (d).
4.1 3D laser mapping component

Creating a CAD model by laser mapping the inspected part either prior to or following the examination was considered as an additional step that could be undertaken for greater accuracy. A lab trial was conducted to determine the viability of such a solution in the field. Using a Creaform laser scanner, a field sample was dotted, scanned, and converted to a compatible CAD model (as shown in Figure 7). The subsequent model was imported into UltraVision and the same data mapping process as outlined before was repeated. It may also be possible to approach this process inversely through utilizing 3D laser mapping pipe-check software with the import of UT data as a CSV file. However this would directly result in a degradation of the data and it is unclear whether the elbow transition point can be accurately mapped in the software. This option was not explored in detail.

Overall, for the purposes of scanning piping elbows this process is somewhat laborious and the specific benefits are not necessarily realized for an FAC program. However, the process provides an ideal testing ground for the potential application to more complex surfaces such as nozzles or weldolets which may differ from patch to patch and possess significant variability.

Figure 6: Scan of a field sample, with data overlaid onto a generic CAD model of same dimension pipe elbow. Screenshot of UltraVision showing scan of a field sample, with data overlaid onto a generic CAD model of the same pipe dimension (a), E-scan of the test piece (b), RT shot of the same elbow (c), B-scan of the test piece (d).
5. Conclusion

An ideal encoding solution for this application has yet to be found. While several solutions exist to provide an adequate solution for the time being, new options will continue to be explored.

The process of matching a CAD component to a single-line encoder scan is relatively simple, and the key evolution for this would be in the ability to pre-configure setup files with CAD models and a scan plan uploaded. This capability would allow for the post-processing to be streamlined into a step by step boxing of the area of interest, followed by processing the merge which would not add significantly to off-line data analysis already used in such a situation.

6. References


2. J. Berlanger et al, Advanced 3D Visualization and Analysis of Phased Array UT Inspection Data, Quebec City, NDT.net, 2012