

True Advancements for Longitudinal Seam Weld Inspection in Phased Array

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Phased Array inspection of curved parts brings some real technical challenges. Evaluation of seam welds on small diameter and heavy wall pipes are difficult to accomplish using actual tools that, most of the time, are based on a flat surface model. This often leads to erroneous and imprecise flaw location and sizes. Furthermore, interpretation of the S-Scans becomes difficult in these circumstances because trying to take into consideration the effect of the convex surface reflections is something the current instrument imagery is not taking into account. The typical tools like presenting a flat overlay of the weld just can't be used in a practical way when it is a question of a curved part.

This paper presents a new approach of inspecting seam welds and more generally curved parts, the Phased Array - Curved Surface Correction (PA-CSC). This novel method rethinks almost all aspects of the traditional implementation. Starting from an original beam forming that allows the technician to inspect with a constant resolution in the zone of interest of the weld. As well, this paper describes how the data is represented in a live 3D scan plan in order to facilitate interpretation and identification of flaws. Corrected A-Scan views are also produced, allowing to perform accurate depth and surface measurements.



1 Introduction

Longitudinal welded pipes are manufactured according to different specifications and with various wall thicknesses. These products are utilized in a number of diverse industries and are quite frequently used, for example in power plant construction, water supply, natural gas and petroleum transport.

As for other welded parts, these pipes need to be inspected for defects, both at the time of manufacturing and for maintenance purposes. Using phased array (PAUT) for flaw detection poses numerous problems, as the contact surface is curved. Moreover, not only the outside diameter (OD) causes some difficulties for the interface, the inside diameter (ID) will reflect each beam of the S-Scan at changing angles, as the reflection comes from a convex surface.

From our experimentation, we were able to conclude that the usual PAUT imaging was a less appropriate model to use in the case of curved surfaces because of beam divergence. This beam spread is obviously due to the curved OD interface but mostly to the convex ID reflection. To the end, this namely influences:

- The spatial coverage or acoustic density in the zone of interest
- The precision of the beam focusing
- The interpretation of data and imaging in S-Scans and A-Scans
- The measurements accuracy
- The calibration methods

2 Theory

2.1 Geometry Challenges

Nowadays, displaying a PAUT S-Scan with an overlay representing the weld is common, broadly used and widely accepted. This is a great aid in order to locate echoes produced by the part geometry itself or by potential flaws. This approach is simple and easy to understand because the reflections are coming from a flat surface, hence producing a perfect reflection as the one produced by a flat mirror. In the case of flat surfaces, the skips of the sound path are dealt with by representing the weld overlay as a series of folded images. In the case of a curved surface, this method is more challenging to use, as the reflected image formed by the convex surface is distorted. An alternate representation would instead use the profile of the part, and draw folded beams, taking into account the specific reflection angle of each beam. Figure 1 visually shows these expected behaviours.

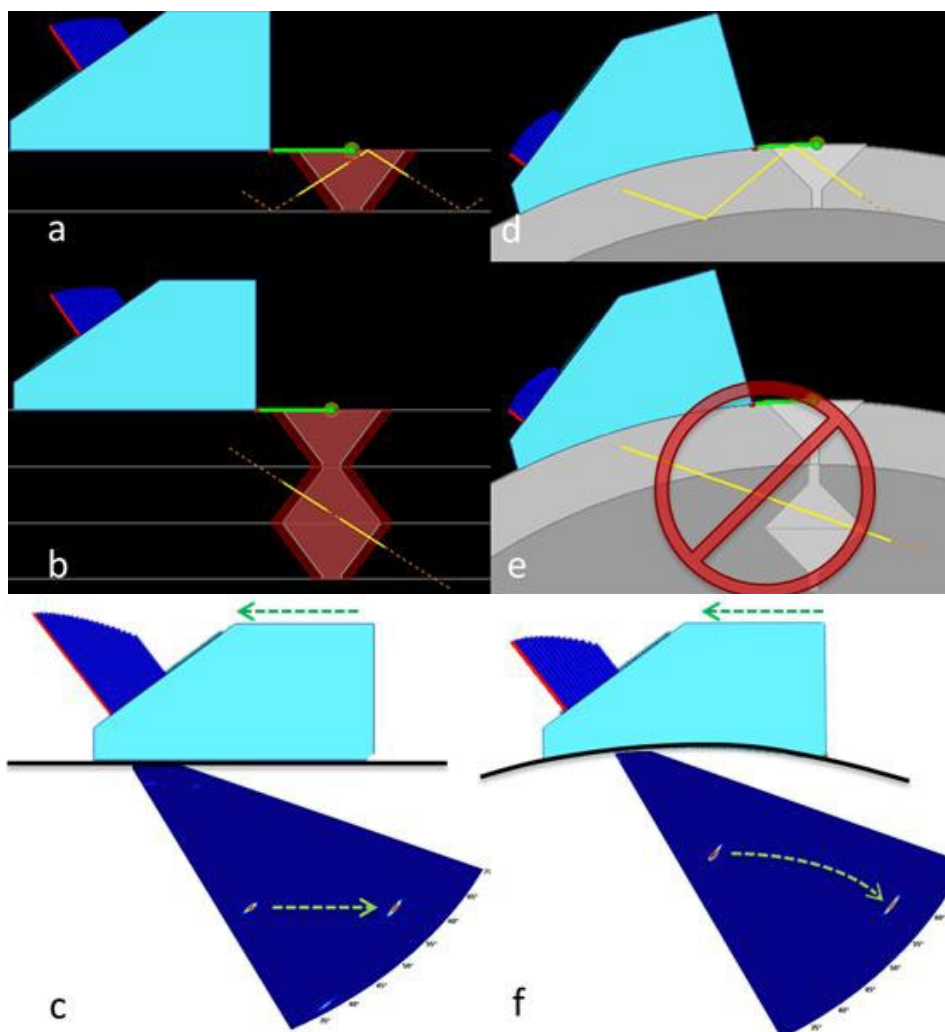


Figure 1. Showing important differences between curved and flat surfaces imaging

Legend of figure 1:

- a) Real sound path in the flat part
- b) Unfolded representation of the sound path (same as image 1a – as usually represented on instruments)
- c) The way an indication will “travel” in the S-Scan when the probe is moved backwards on a flat part
- d) Real sound path in the curved part
- e) Invalid representation of the sound path when using an unfolded overlay on a curved part
- f) The way an indication will “travel” in the S-Scan when the probe is moved backwards on a curved part

2.2 Beam Resolution versus Convex Surface

It shall also be understood that the beam spread, and hence the angular resolution, will greatly vary depending on the diameter of the part. For a reduced diameter pipe, the angular resolution in the second leg is significantly and unevenly reduced, lowering the spatial coverage, which may result in poor probability of detection. The smaller the diameter of the pipe, the larger the inter-beam distance in the second leg. Moreover, after the first reflection, the beams' energy density is also decreased due to this convex lens effect. For the same reasons, when producing focal laws using the traditional constant path focus method, the focusing points are affected, decreasing the image sharpness.

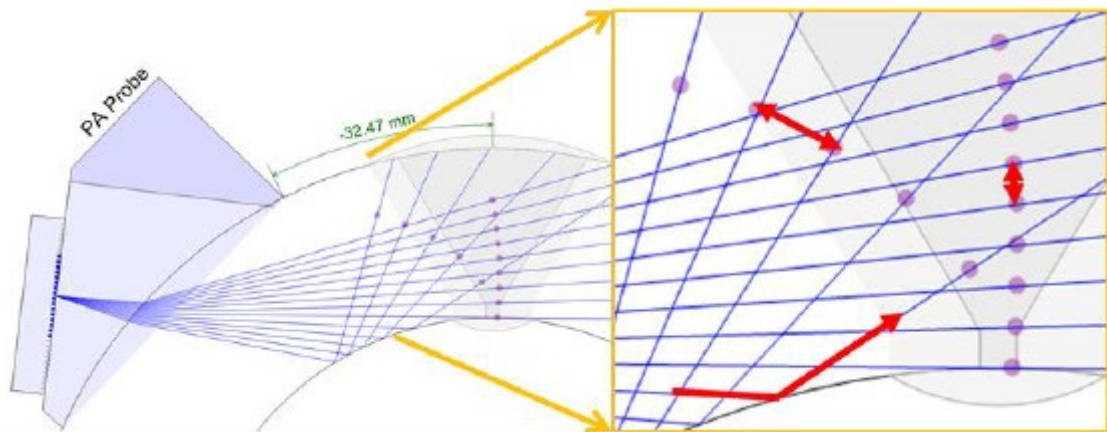


Figure 2. Effect of ID reflections

3 BEAM FORMING NEW APPROACH

Phased Array Curved Surface Correction (PA-CSC)

3.1 Using the Part's True Representation

The PA-CSC new approach uses a true representation of the curved part. By using the main characteristics of the pipe, a precise illustration of the part's profile is drawn. Then, employing a ray tracer, a correct illustration of the beams is achieved, both in the first and consecutive skips, taking into account a different reflection angle for each beam. The above tools allow the technician to assess full coverage of the zone of interest is achieved. By offering these tools directly on the instrument, the inspection's configuration and required adjustments can be performed live, as needed.

3.2 Constant Resolution New Focal Mode

As mentioned above, the convex nature of the part causes the S-Scan beams to diverge, reducing the beams' spatial density in the second leg. Of course, this can be compensated by increasing the angular resolution of the S-Scan. Yet, this does not guarantee a known spatial resolution in the zone of interest, most often the weld itself.

Available with the new PA-CSC, the constant resolution new focal mode offers a better methodology by defining a fix beam spatial resolution in the region of interest. It then uses this parameter as a key input for the focal law calculator to generate UT beams at specific angles to ensure proper coverage of the weld, taking into account the curvature effects of the ID and OD walls.

Interestingly enough, the constant resolution new focal mode method would be applicable in all circumstances. For example, for a flat specimen, in the case of longer sound path, the exact beam density might be difficult to figure out or calculate. By defining focus points with a specific spatial resolution, the focal law engine automatically provides effective coverage and beam density, as shown in figure 3. Here again, all tools required to define the spatial resolution, specify the focus points and calculate all resulting focal laws are embedded in the instrument for maximum flexibility.

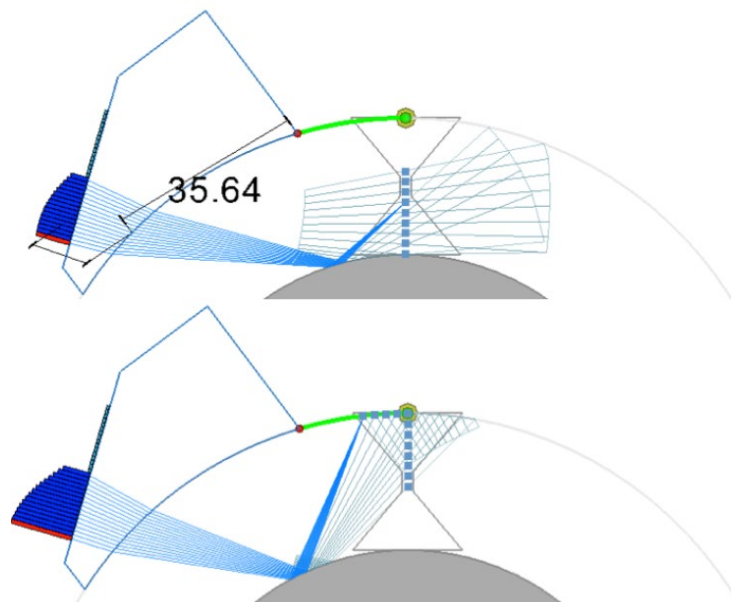


Figure 3. The complete S-Scan is made of 2 parts: direct and reflected beams. Note that the angular resolution of both has to be different in order to produce a 1mm constant resolution pattern.

4 PA-CSC & DATA INTERPRETATION

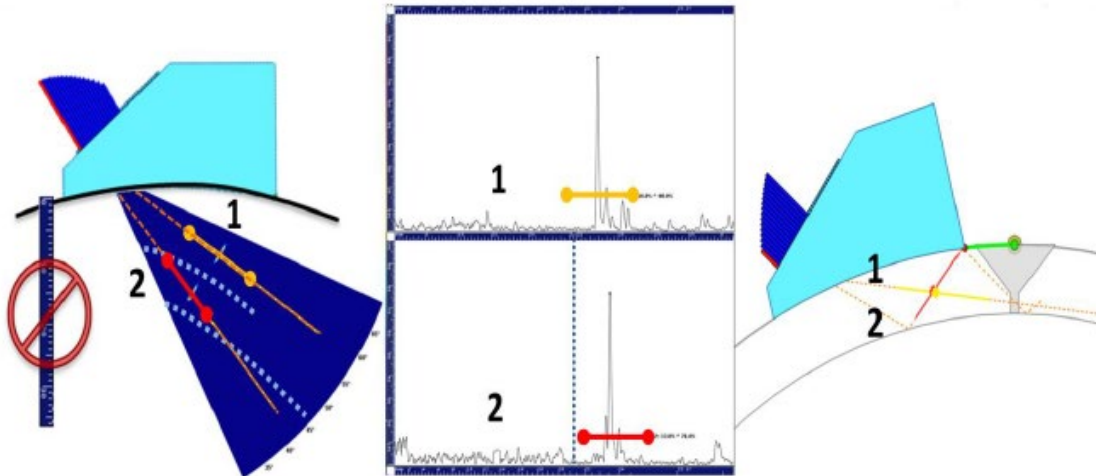


Figure 4. PA-CSC Sectorial Scan, A-Scan and 3D Live Views inter-relations

4.1 S-Scan View & Curved Part Overlay

The sectorial scan will remain similar to a standard one, however when using the standard sectorial scan on curved surfaces, it is also more challenging to interpret the position of the echoes that are revealed. The analogy of the distorted image produce by a convex (or concave, as a matter of fact) mirror applies. As displayed in figure 4, the PA-CSC solution includes specially developed curved part overlays that help the technician to correctly interpret the echo position in the sectorial scan taking onto account the effect of the curved ID and OD part reflections.

Moreover, it shall be noted that the depth scale of a sectorial scan (usually the vertical scale) is different because first it is not linear, and second it has a different scale for each beam of the scan. Again, this is a result of the curvature of the part.

4.2 A-Scan View & True Depth / Surface Gate Measurements

Since in depth mode the ruler's scale is specific to each A-Scan (beam), the ruler need be adjusted according to the true depth of the defect. Additionally, the surface distance needs be calculated properly, taking into account the circumference. This allows to physically spot the indication properly using gate sizing standard methodology over the echo. Referring to figure 4 above, it can also be noted that the different legs in the A-scan view are separated by a vertical dashed line.

4.3 Live 3D View Visual Support

As a complement to the A-scan, the 3D view renders the specimen. It also shows the beam extractor(s) from the sectorial scan. That is, the selected beams are represented in the part using the embedded ray tracer. The ray tracing also highlights the gates defined in the A-Scan, displaying these at the proper distance(s) in the sound path. The triggering point's exact position is also rendered and appears at the correct location in the part's model. Hence, by establishing a direct link between the sectorial scan, A-Scan and the live 3D view, the instrument provides invaluable help to the technician. Echoes, and namely flaws, could be located much more easily and with confidence. An example of the 3D view is presented in figure 4.

5 RESULTS PRESENTATION

5.1 Constant Resolution New Focal Mode

The experimentations conducted showed that the traditional focusing method (constant path) was perfectly usable and not greatly affected by the curved ID. This is mainly related to the fact that the limited number of active elements provide a much greater depth of field. On the other hand, additional results confirmed that a focusing degradation was noticeable using more than 22 elements.

As well, scans performed with 32 elements, producing a shallow depth of field, were providing poor image quality. In that case, the advantage of the new focusing method presented earlier is obvious. Figure 5 presents the results obtained.

On the other hand, it is sometimes desirable not to focus, namely in the case of huge volume inspection. This "steer only" scan guarantees a large depth of field and a constant energy distribution along the beam. This focusing method has also been implemented for completeness, as it addresses different needs.

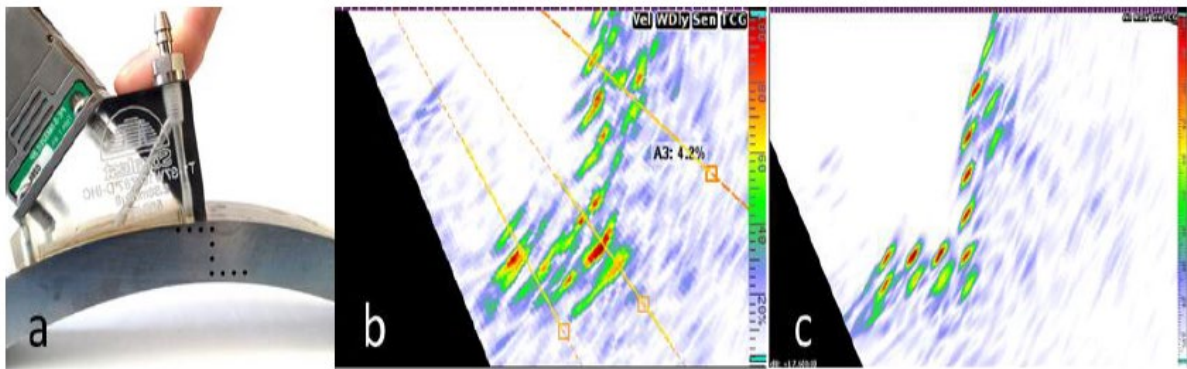


Figure 5. Comparison of conventional focusing vs. PA-CSC new method proposed (32 active elements). a) Demo block used; b) Standard constant path focusing; c) NEW constant resolution focusing

5.1 PA-CSC New Layout of Data

The acquisition layout implemented, as presented in figure 6, should ease the interpretation of the seam weld inspection data. The different views complement each other. The S-scan offers a general view of the data that is being recorded. The A-scan displays the amplitude at one specific angle and offers a depth ruler. Quick measurements such as percentage full screen height (%FSH), true depth, surface path, sound path are available. The 3D view gives the ray tracing corresponding to the extractors shown in the S-Scan. The S-Scan view is not folded into the part. The lines of the legs are drawn that bounds the surface. Hence, multiples reflections

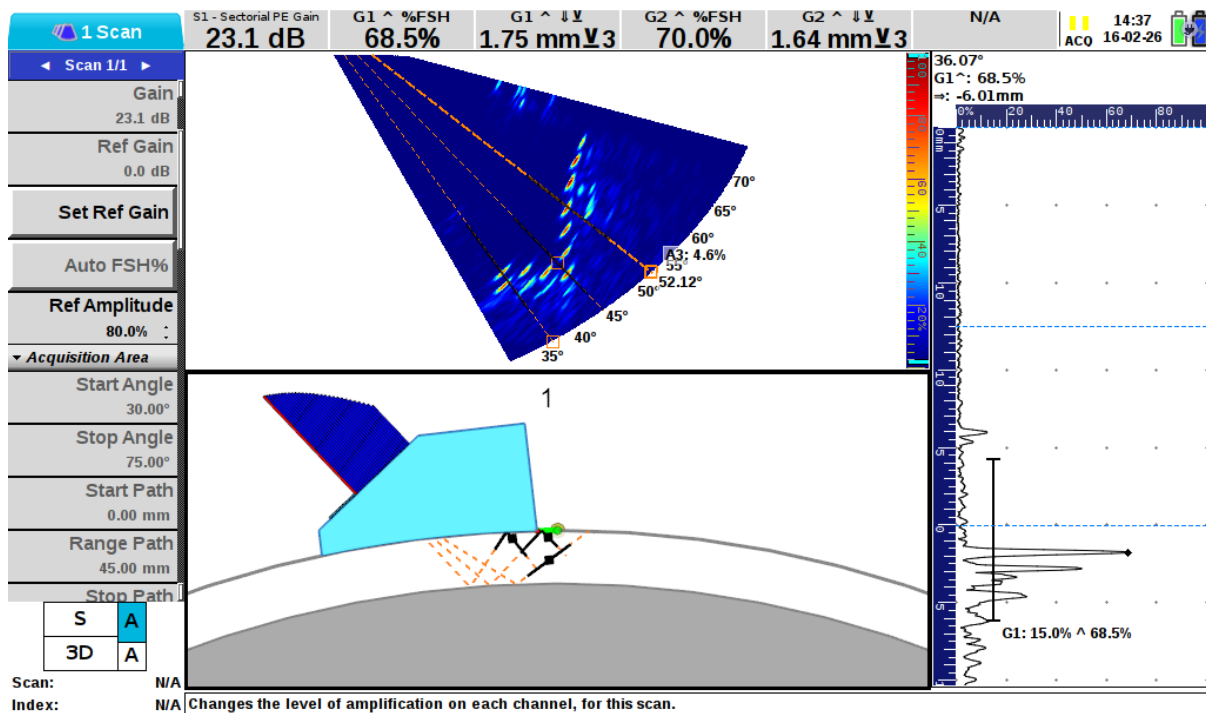


Figure 6. Recommended PA-CSC Acquisition Layout; ID indication sized on A-scan & Confirmed in Live 3D View

5.2 CALIBRATION METHOD

The usual techniques to calibrate velocities and delays remain the same. Calibration using a radius gives very accurate results. Notches and SDH calibration are nonetheless possible, yet not as good as the previous method.

It is actually a different story in the case of the DAC/TCG calibrations. The quality of the calibrated or corrected curves is improved when a curved version of Navships test block is used.



The number of points for each half skip makes the DAC more precise as this helps to better consider the curvature. The 3-point calibration using bottom and top notch in a pipe is the minimum acceptable in the industry. The closest sound path datum is direct, the second comes from the inner rebound, and the third is produced by both the inner and outer reflections. This means that to cover a full skip, up to 6 DAC/TCG points shall be obtained and recorded. Nine-point calibration shall be quite common, considering many of the pipes will present a limited thickness.

Please note that at the time of writing this paper, the exact and optimal calibration technique was not yet determined.

6 Conclusion

In this paper, the new Phased Array Curved Surface Correction (PA-CSC) method to improve the inspection of seam welds was presented. This approach is in fact applicable more generally to any curved surface component. With a new constant resolution focal mode, the proposed solution namely offers a novel way to cover the region of interest taking into account the curvature of the part. It ensure distance between beams to ensure a sufficient beam density at a known spatial resolution. Moreover the beam forming focusing is also corrected for improved inspection results.

As the interpretation of the sectorial scan in the second and third leg proves to be quite challenging by the nature of the part producing a distorted reflection, the implementation of curved part overlay is definitely a key asset of PA-CSC solution. It was also shown that by using a true representation not only helps define the coverage, but also helps to visualize more easily the location of defects in the part. The relation between a specific A-Scan, its gate, a sectorial scan extractor and the peak trigger point, the live 3D view provides an additional and valuable interpretation tool to a technician.

Experimental results have shown that the method provides accurate and precise measurements. These tests have been conducted on a number of parts with different diameters and wall thicknesses. At the time of writing, real life testing, in the field, is just about to begin and the final calibration strategy shall be completed.

Finally, as the concept shall also include the proper calibration methods, it is believed to comply with industry standards, like ASME V as an example.



7 REFERENCES

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