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# True advancements for longitudinal weld pipe inspection in PA

## Prawdziwy postęp w inspekcji spoin wzdłużnych wykonanych w pozycji PA na rurach

### ABSTRACT

Phased Array inspection of curved parts brings some real technical challenges. Evaluation of seam welds on small diameter and heavy wall pipes is 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 very difficult in these circumstances. Trying to take into consideration the effect of the convex surface reflection is something the current instrument imagery is not taking into account and is very difficult for the operators to correct themselves. The typical tools like presenting an overlay of the weld just can't be used in a practical way. This paper presents a totally new approach of inspecting seam welds and more generally curved parts. The novel method rethinks almost all aspects of the traditional implementation. Starting from an original focalisation of beams that allows the technician to define specific focal points in a zone of interest. As well, we describe how the live data is represented in a 3D scan plan in order to facilitate interpretation and identification of flaws. Corrected A-Scan views are also produced, allowing to perform accurate measurements. We finally touch on how to calibrate the instrument prior to performing these inspections on curved surfaces.

**Keywords:** Longitudinal Seam Weld, Phased Array, Curvature Correction, Pipeline, Weld

### 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, would it be for power plant construction, water supply, nature 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. In the end, this namely influences:

- the spatial coverage or acoustic density in the zone of

### STRESZCZENIE

Badania metodą Phased Array elementów zakrzywionych stanowią techniczne wyzwanie. Ocena wzdłużnych połączeń spawanych rur o małych średnicach oraz o dużych grubościach ścianki jest trudna do zrealizowania za pomocą aktualnie popularnych narzędzi, ponieważ są one dedykowane głównie do powierzchni płaskich. To często prowadzi do błędnej oceny lokalizacji i rozmiaru wad. Ponadto w tych warunkach prawidłowa interpretacja S-skanów jest bardzo trudna. Próby brania pod uwagę korekty efektu odbicia od wypukłej powierzchni nie są zazwyczaj skuteczne i trudne do stosowania przez operatorów. Typowe narzędzia pozwalające nakładanie na ekran szkicu przekroju złącza są zupełnie niepraktyczne.

Ten artykuł przedstawia zupełnie nowe podejście do badania szwów na rurach lub bardziej ogólnie na elementach zakrzywionych. Ta nowa metoda zmienia wszystkie aspekty tradycyjnego wdrożenia. Począwszy od ogniskowania wiązki, które pozwala inspektorowi definiować szczególne punkty w obszarach istotnych ze względu na cel badania. W dalszej kolejności pokazuje plan skanowania w 3D wraz z rzeczywistymi i chwilowymi wskazaniami (live data) w celu interpretacji i identyfikacji wad. Generowane są również obrazy A-skan, które umożliwiają ocenę i dokładne pomiary. Trzeba podkreślić, że końcowy wynik inspekcji zależy od prawidłowego skalowania i dlatego ten problem jest zauważony i realizowany również przez oprogramowanie aparatu.

**Słowa Kluczowe:** spoina wzdłużna, Phased Array, korekta krzywizny, rurociąg

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.

### 1. Theory

#### 1.1 Geometry Challenge

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.

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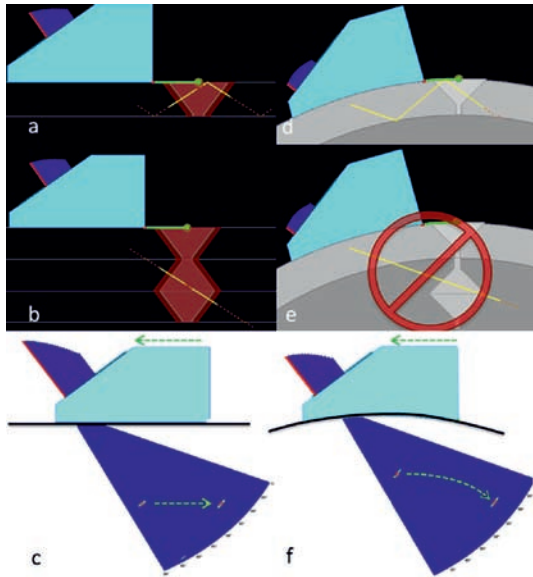


Fig. 1. Showing important differences between curved and flat surfaces imaging: a) real sound path in the flat part; b) unfolded representation of the sound path (same as image a) – as usually represented on instruments); c) the way an indication will “travel” in the S-Scan when the probe is moved backwards 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

Rys. 1. Ważne różnice w zobrazowaniu dla powierzchni zakrzywionych i płaskich: a) rzeczywista droga wiązki w elemencie płaskim; b) uproszczony przebieg wiązki (taki sam jak a), ale bez odbić – często pokazywany w aparatach); c) “przemieszczanie się” wskazania dla S-skanu podczas przesuwu głowicy do tyłu po płaskiej powierzchni; d) rzeczywista droga wiązki w elemencie zakrzywionym; e) nieprawidłowy obraz drogi wiązki z powodu nieaktualnego uproszczenia dla elementu zakrzywionego; f) “przemieszczanie się” wskazania dla S-skanu podczas przesuwu głowicy do tyłu po powierzchni zakrzywionej

### 1.2 Beam Resolution versus Convex Surface

It shall also be understood that the beam spread, and hence the angular resolution, will greatly vary depending of 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.

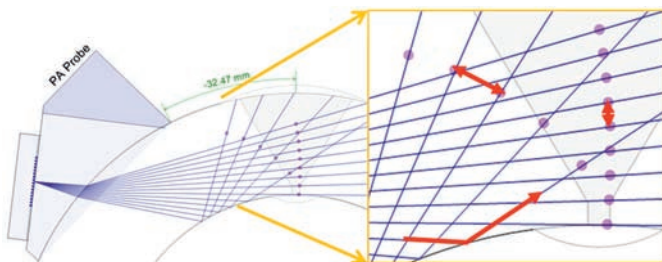


Fig. 2. Effect of ID reflections  
Rys. 2. Efekt odbicia od wewnętrznej średnicy rury

## 2. Proposed Approach

### 2.1 Using the Part’s True Representation

The 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.

### 2.2 Focal Law Calculations

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.

A better methodology would be to define the required spatial resolution of the beams in the region of interest, and use this parameter as a key input to the focal law calculator. It consequently ensures a proper coverage of the beams, with a known spatial resolution, totally independent of the curvature of the ID.

Interestingly enough, this 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.

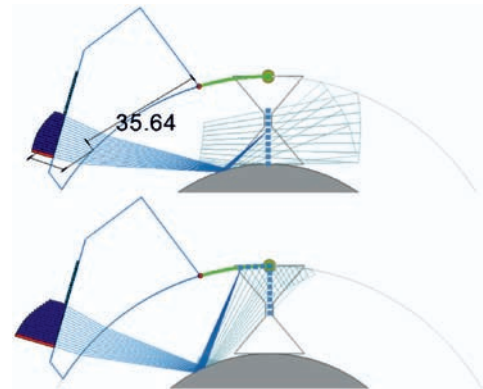


Fig. 3. The complete S-Scan is made of 2 parts: direct and reflected beams. Note that the angular resolution of both has to be different in order to produce a 1mm constant resolution pattern

Rys. 3. Całkowity S-skan składa się z 2 części: wiązki padającej bezpośrednio i po odbiciu. Trzeba zauważyć, że kątowna rozdzielczość będzie inna dla obu przypadków, ponieważ wybrano w programie stałą rozdzielczość 1mm

## 3. Data Interpretation

### 3.1 S-Scan

The basic sectorial scan will remain the same in the way it will be displayed. On the other hand, it shall be noted that the depth

scale (usually the vertical scale) cannot be shown since, above the fact it is not linear, it is different for each beam of the scan. Again, this is a result of the curvature of the part. As an example, figure 4 below shows that for beam number 2, the depth to path distance equation is non-linear.

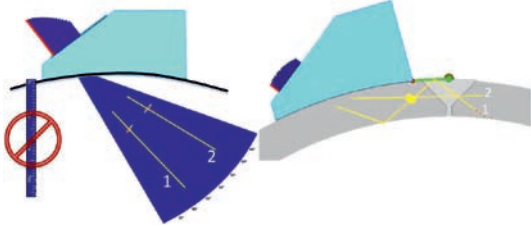


Fig. 4. Sectorial Scan view showing depth ruler not applicable  
Rys. 4. Obraz skanu sektorowego (S-skan) pokazuje nieaktualną linijkę głębokości

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 produced by a convex (or concave, as a matter of fact) mirror applies. For one to be able to correctly interpret positions in the S-Scan taking into account the effect of the convex bottom of the part would require remarkable cognitive abilities.

### 3.2 A-Scan

In the case of the A-Scan, the rulers need be adjusted. In depth mode, the ruler's scale is specific to each A-Scan. Of course, the sound path ruler remains standard. Additionally, the surface distance needs be calculated properly, taking into account the circumference. This allows to physically spot the indication properly. Refer to figure 5, below. Note that the different legs in the A-scan view are separated by a vertical dashed line.

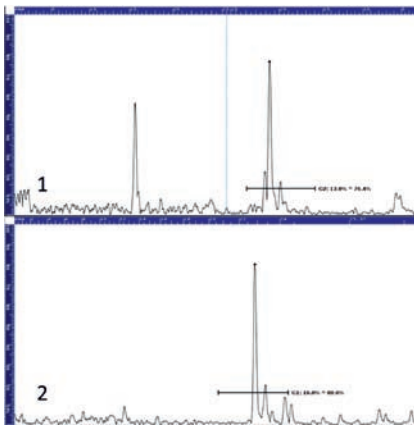


Fig. 5. A-scan #1 refers to beam #1 in figure 4 and A-Scan #2 to beam #2  
Rys. 5. Obraz 1 typu A odpowiada wiązce 1, a obraz 2 wiązce 2 z rys. 4

### 3.3 3D View with Ray Tracing

As a complement to the A-scan, the 3D view renders the specimen. It also shows the beam extractor(s) from the S-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 S-scan and the 3D view, the instrument provides invaluable help to the user. Echoes, and namely flaws, could be located much more easily and with confidence. An example of the 3D view is presented in figure 6.

## 4. Results Presentation

### 4.1 Effect of Focusing Method

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, we providing poor image quality. In that case, the advantage of the new focusing method presented earlier is obvious. Figure 6 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.

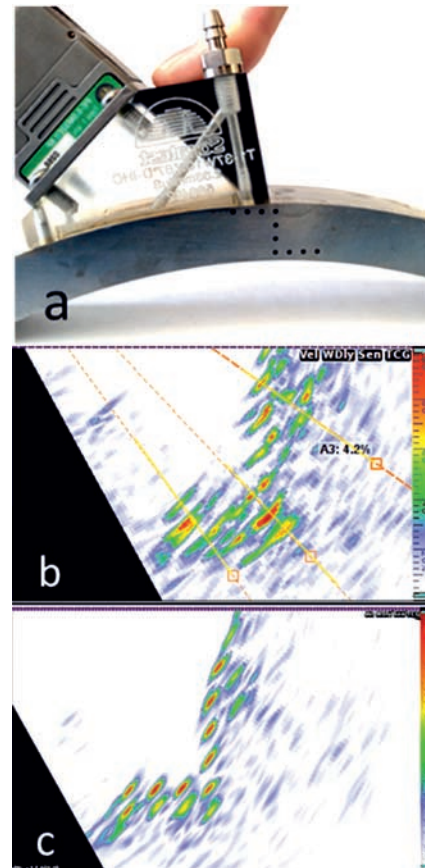


Fig. 6. Comparison of conventional method of focusing and new method proposed. Using 32 active elements: a) demo block used; b) constant path focusing pattern; c) constant resolution focusing  
Rys. 6. Porównanie konwencjonalnej i proponowanej, nowej metody ogniskowania. Użyto 32 elementy aktywne: a) użyty wzorec demo; b) ogniskowanie dla stałej drogi wiązki; c) ogniskowanie dla stałej rozdzielczości

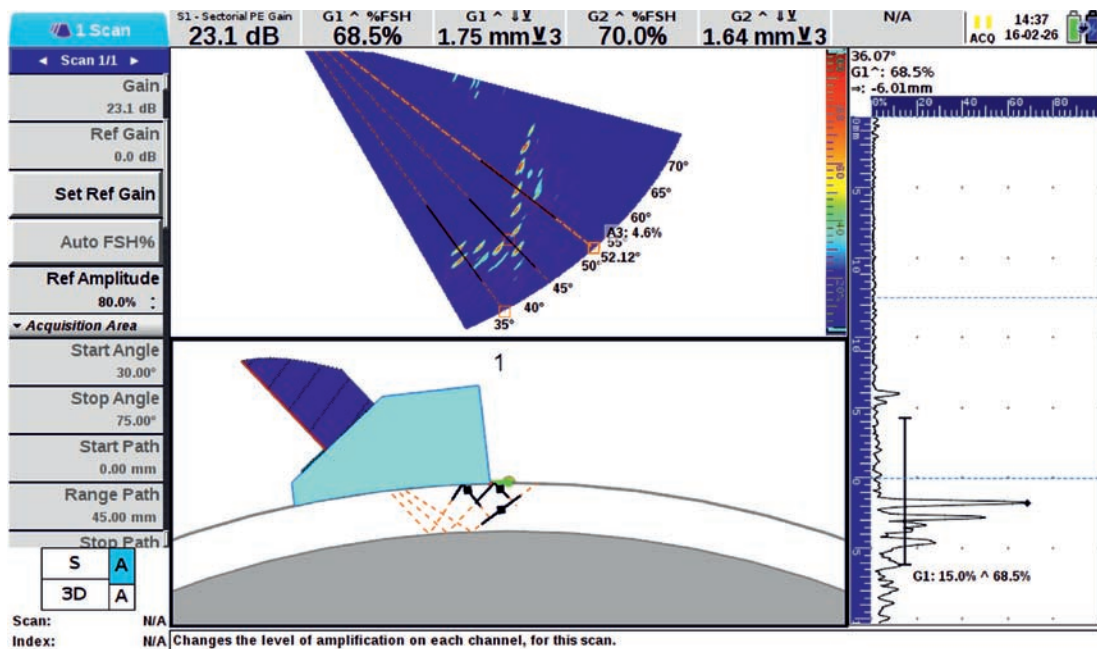


Fig. 7. Recommended Acquisition Layout; ID indication on the A-scan and Confirmed in the 3D View  
Rys. 7. Zalecany układ obrazowań podczas rejestracji; wskazanie na obrazie typu A i potwierdzenie w 3D

#### 4.2 Complete Layout of Data

The acquisition layout implemented, as presented in figure 7, 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.

#### 5. 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 reflexions. 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, a method to improve the PAUT inspection of seam welds was presented. This approach is in fact applicable more generally to any curved surface component. The proposed practise namely offers a proper coverage of the region of interest, by guarantying accurate focus at predefined points. Moreover, the distance between these defined positions define the beams' spread, insuring a sufficient beam density, hence providing a known spatial resolution.

As the interpretation of the S-Scan in the second and third leg proves to be quite challenging by the nature of the part producing a distorted reflection, it was also shown that by using a true representation not only helps define the coverage, but also can be used to visualize more easily the location of defects. By representing specific A-Scans associated to the S-Scan extractors, and by displaying the gates and gate trigger exact position, the 3D view provides an additional and valuable interpretation tool.

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 to begin and the final calibration strategy shall also be determined.

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

#### 7. References

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