Shaft inspection using Phased-Array compared to other techniques

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Abstract

With the petroleum boom in the western part of the country the Rail industries oil transportation sector has grown significantly in the last decades. The safety of that kind of transportation method has also took an important part of the public debate space lately. The Lac Mégantic tragedies and other derailment causing environmental causality in northern Ontario have contributed to that debate. Generally an accident is caused by one of the following reasons: a human mistake, rail failure or train mechanism/component failure.

According to Transport Canada, between 1997 and 2006, 28 train derailments occur because of an axle failure. Traditionally, Axles were inspected using typical surface techniques such as MT, PT and UT at the extremity. A typical train axle would normally be solicited in all the possible stress orientation such as bending, compression, traction, torsion, and shear. This phenomena make it unlikely to predict the orientation of an induced fatigue Crack. This paper is going to demonstrate that a multi-orientated Phased Array inspection approach could increase the probability of detection, the interpretation capability and the productivity compared to conventional technologies.

Introduction

Train axle is a component among other that could beneficiate of a new shaft inspection approach. The main purpose of this article is to suggest a new multi-orientated Phased Array (PA) inspection, which could reduce the cleaning and disassembly of shaft assembly in general. The main idea is to replace the conventional surface technique inspection by an encoded circumferential PA inspection using the Curved Surface Correction (PA CSC) of the Veo+. This inspection combined with a PA inspection at the extremity of a shaft would cover all the possible flaw orientation and hopefully increase the probability of detection, the interpretation capability and the productivity. Since the approach using Phased Array from the extremity of a Shaft is already well documented[i], the rest of this paper will focus on the circumferential outside surface (COD) (PA CSC) Flaw detection and technique limitation.

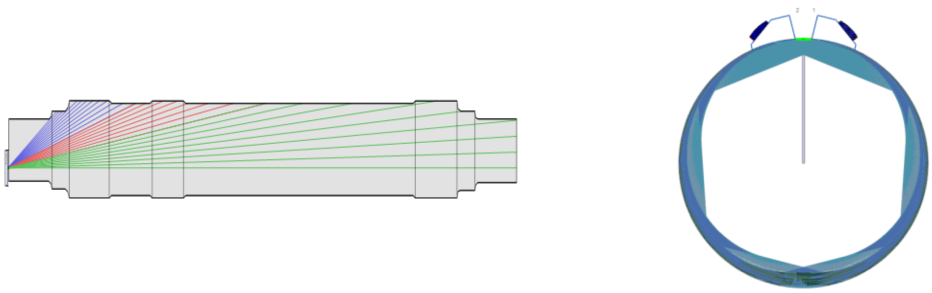

Figure 1 Combined technique (Axial+ CSC) inspection using Phased Array

1 Theory

1.1 Conventional Ultrasonic technique limitation

The CSC inspection with conventional probe comes with some limitations; these could explain the marginal use of this technique in the industry. The surface is being cover with only one angle at the time, which constrains the inspector to move the probe on the entire circumference to obtain 100% coverage. The localisation, visualisation and sizing of a flaw is quite challenging for most inspectors. Also, there is only one fix focal point and it cannot be adapted to increase beam density or spatial resolution.

Figure 2 Conventional inspection coverage of angle 70°, 60° and 45°

1.2 The Advantages of the PA CSC approach

Geometry effect

In a previous paper about the PA CSC, *"True Advancements for Longitudinal Weld Pipe Inspection"*[ii], the effect of the beam spread on the internal diameter (ID) reflections and our approach to counter that phenomena have been explained.

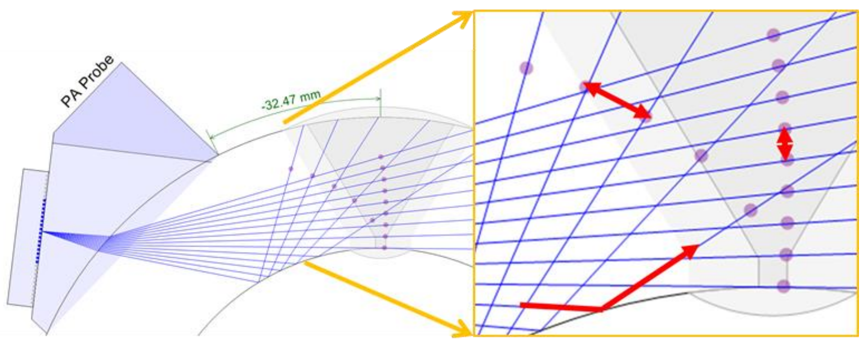

Fig. 3 Effect of ID reflections

In a similar way, the beam spread on the outside diameter (OD) reflections would decrease, hence increasing the angular resolution and spatial coverage. Moreover, the successive OD reflections would keep the beams energy density and help the flaw detection probability for that specific Area.

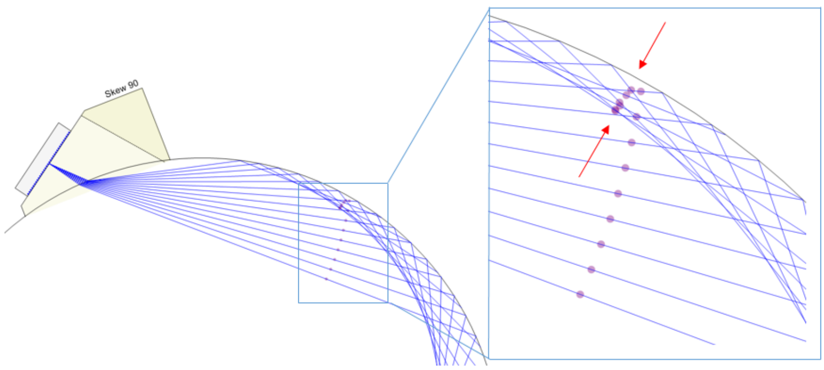

Figure 4 Effect of OD on reflections

Constant Resolution Focusing

The Constant resolution focalisation has two main advantages compared to the traditional constant path focalisation. The first one is the ability to focus directly on the outside diameter of a surface before the reflection. Those Focal points would maximize the beam energy before the natural focus effect generated by the cylindrical geometry and enhance the beam sharpness for that area. The second benefit is the maximum value of the scan resolution, which is no longer driven by the angular resolution of the scan but can be calculated according to the wanted resolution and distance.

As an example, let’s consider two identical inspection configurations covering the 60□ and 80□ angle. The maximum resolution for traditional focalisation method would be the beam quantity, at the maximum value of the angle resolution parameter, which is about 201 Beams. With the constant resolution focalisation mode, the system could generated up to 928 beams at his maximum focal resolution value. This is four times more than the traditional method. If we push it to the limits, the new scan resolution limitation using this focalisation method is the number of beam handled by the Veo+ electronic which would be 1024 per probe.

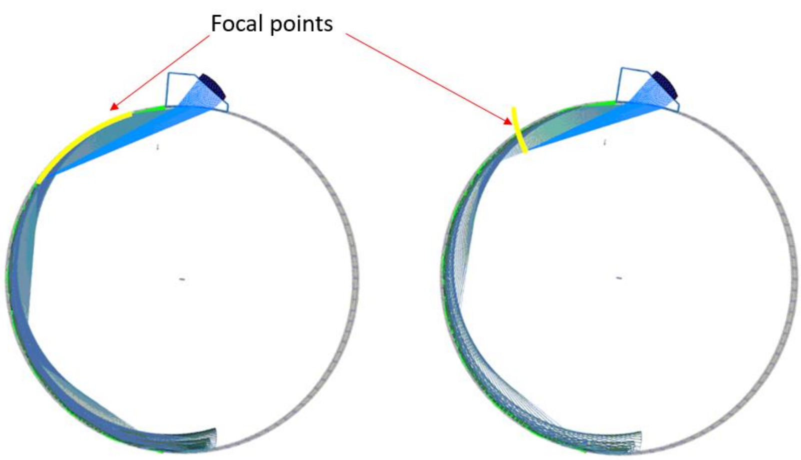

Figure 5 Constant resolution (Right) against Constant path Focalisation (Left)

The 3D View Representation

Localisation of flaws for circumferential inspection is really challenging. Indeed, the trigonometry behind the flaw position changes for every angle and after every rebound. To help the inspector to fully assess the coverage of his inspection requirement, a 3D view with a ray tracer have been added to the inspection layout as well as a dotted line in the S-scan view indicating rebounds in the sound path.

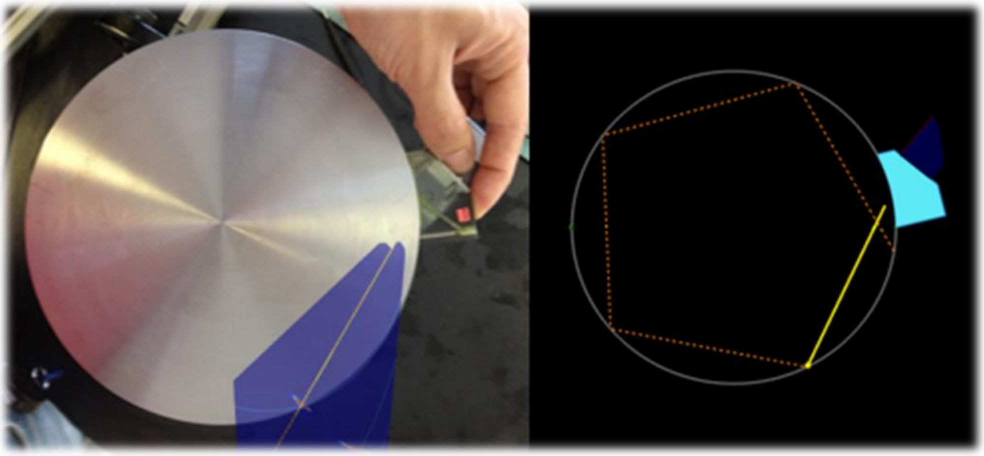

Figure 6 3D view and S-scan on a real component

The ray tracer takes into account all the different reflections angle for each beam.

The One Contact Inspection Possibility

With an appropriate scanner, all the data could be encoded and stored in time. Also, according to the inspection limitation, it is likely possible to inspect 100% of a shaft surface with only one contact point, without skew or circumferential scanning being required.

2 Proposed approached

2.1 Ultrasonic limitation

The sensibility and resolution of this approach is still limited by the physics of ultrasound. The smallest detectable flaw will always be define by the probe frequency, beam energy, density and diffraction, wave mode (Longitudinal or Shear), material attenuation, focal laws and surface quality. On top of that, for the high steered angles, there is a possibility to generate mode conversion into surface wave. For those reason, the overall beam attenuation is hard to evaluate theoretically. In order to validate the detection capability of such inspection the experimental approach has been chosen instead of the simulation approach.

2.2 Sample and Flaw detection probability

A shaft sample has been manufactured in order to assess the detection capability of this approach. The 8'' diameter shaft has 6 notches at different depths, spread equally on his length. The depth of the notches are between 0.5 mm and 3 mm, with 0.5 mm increments. Few sets of data have been taken in order to demonstrate the detection capability and the sizing advantage of this approach. For this paper, the tests have been conducted with only one 5 MHz probe, nevertheless the use of several probes and frequencies to enhance the detection capability according to the shaft size dimension could also be considered.

2.3 Calibrations

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

To counter the beam attenuation, a constant TCG curve of 0.08dB/mm has been applied on the signal. The attenuation in the material is not linear, hence the signal response of the notches were not uniform. For better result a TCG Curve with reference geometry is recommended.

Afterward, the sensitivity of the inspection should be set with the smallest wanted detectable flaw at the farthest distance from the probe, in our case the notch of 0.5 mm deep at a 595mm path distance

3 Results

3.1 Effects of Focusing Method

In a range path within the nearfield distance, the constant resolution focalisation effect compared to other focalisation mode has major effects. Indeed the focal points are located on the surface of the outside diameter of the component. This disposition ensure a maximum energy distribution for this area and an optimised representation of all surface reflector as illustrated in the **Figure 7.**

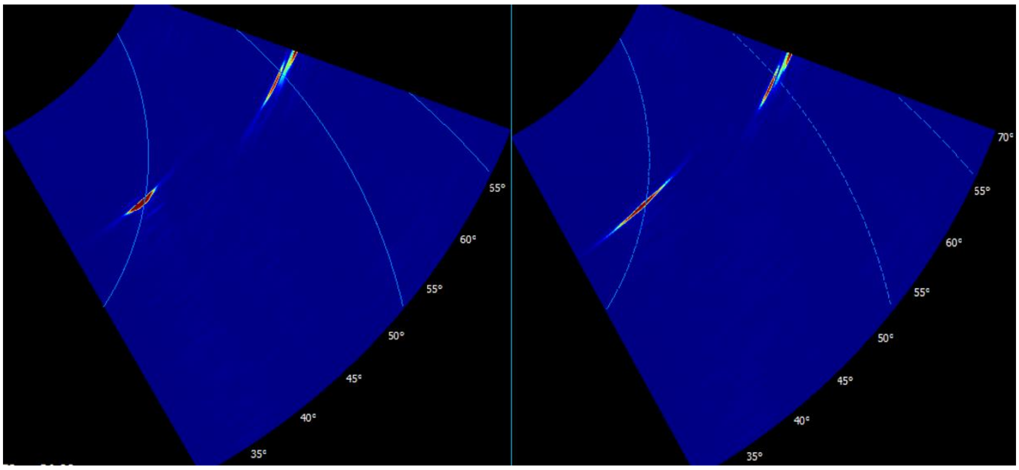

Figure 7 Constant Resolution (Right) against Constant path (Right)

The other advantage of this focalisation type is that the scan resolution can be increase regardless of the sound path distance. This feature is specifically useful when the inspection requires a big sound path with a distant region of interest. A higher resolution would counter the resolution lost by the beam diffraction.

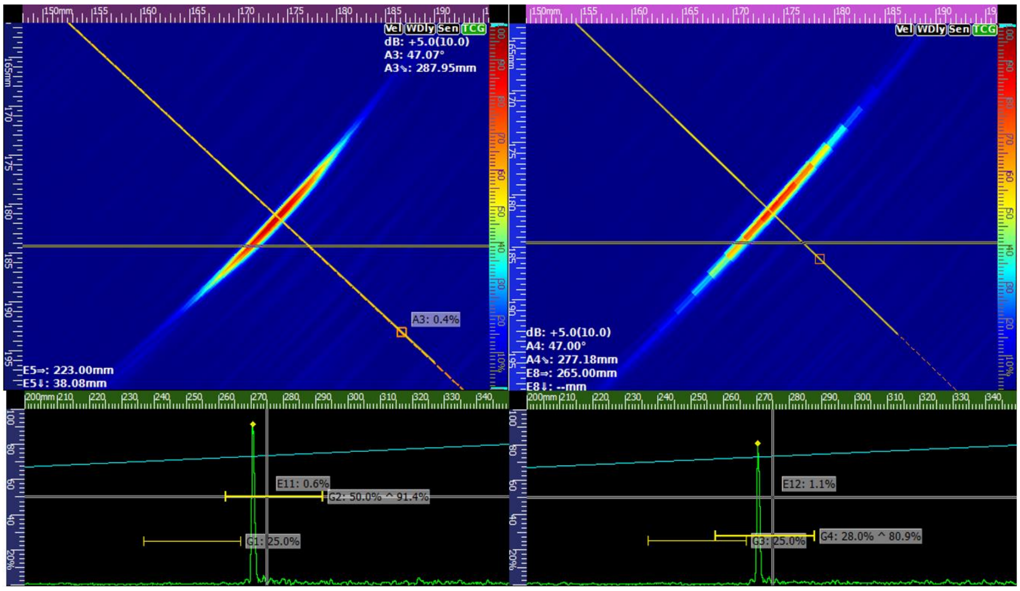

Figure 8 High constant resolution effect

3.2 Technique Performance

From a sizing and characterisation perspective, focalisation effects are only effective within the Nearfield distance. As a reference for future user, the Signal Attenuation & Sound Path relation have been drawn for the main angle in order to evaluate the Nearfield dimension per angle. This could be used as a guideline to assess the number of probe required or the angle to prioritise in pursuance of the desired sizing capability. The Figure 9 reveal that the lower angles have the longer Nearfield, hence more focusing capability than the higher angles.

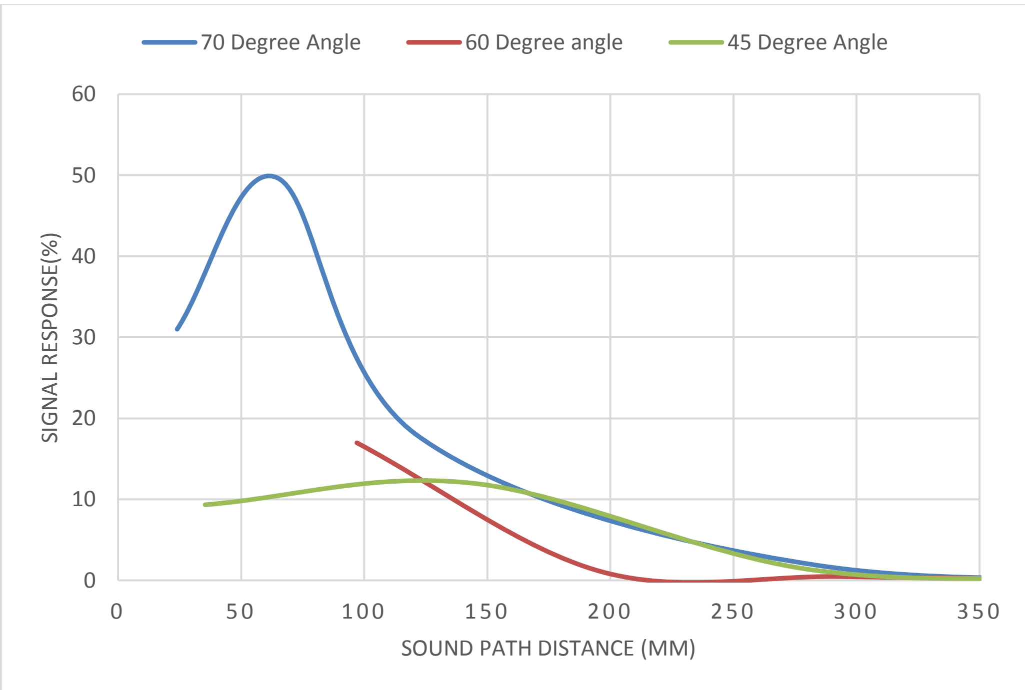

Figure 9 Signal Response per angle in function of sound path distance

From the Screening tool perspective, all the notches have been size and precisely located by only one probe. The first notch illustrated in the encoded view, is the 0.5mm deep and the last one is the 3mm deep. The first notch was physically behind the probe. The distance between the probe and the notch was 595 mm. The second signal response, which follows the 3 middle indications, confirms the presence of L wave mode conversion after a notch reflection.

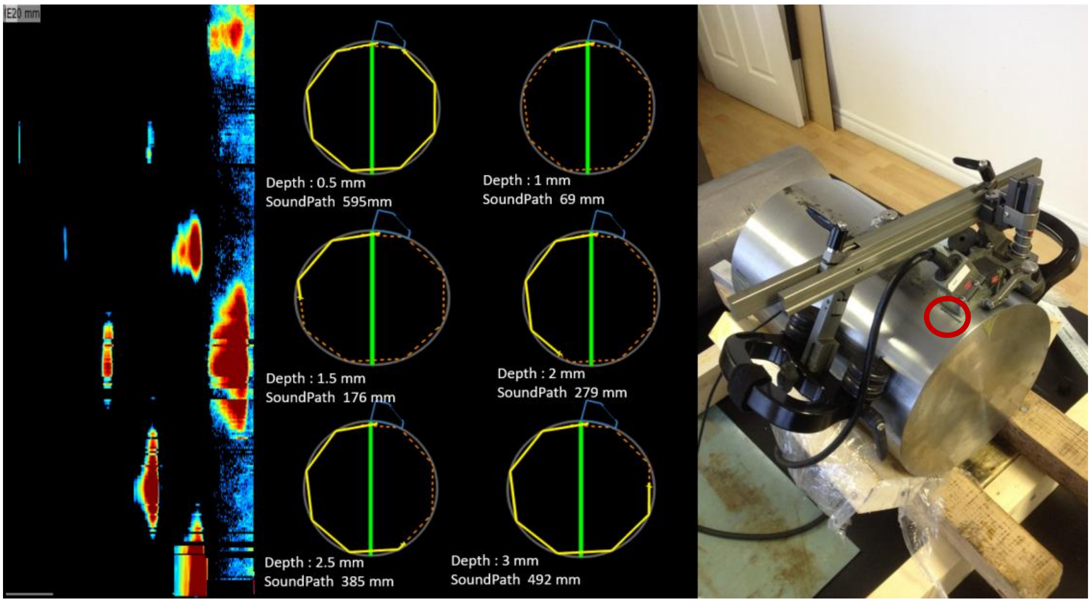

Figure 10 Encoded Data, the 3D view for each notch and the acquisition setup

The surface path and the sound path are calculated automatically by the software and are updated in real time in the 3D view representation as shown in the **Figure 10**. This provides an additional and valuable interpretation tool.

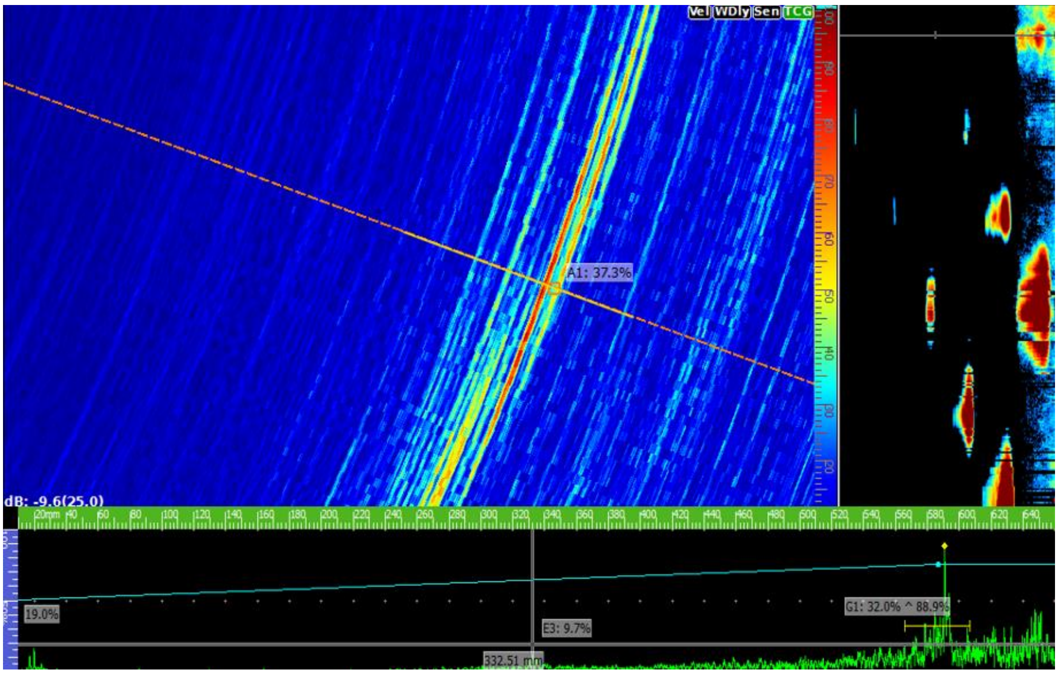

Figure 11 SNR of the 0.5mm notch at 595mm path distance

Finally, the Signal response of smallest notch was more than 4 time (12 Db) higher than the noise level, This Noise level is acceptable for a screening inspection.

4 Conclusion

The Train axle component has been selected as reference component in the abstract because the strain orientation sustain by its function could allow cracks propagation in every orientation. However, the proposed approach could easily be adapted to any cylindrical geometry such as a power shaft or forged billet.

The smallest notch has been detected at a path distance of 600 mm, with a signal to noise ratio higher than 4. This level of sensitivity is obtained, among other things, by the excellent signal noise ratio of the Veo+, definitely one of the best on the market. The sizing capability and signal resolution are superior because of the unique focalisation mode available. Finally, by representing specific A-Scans associated to the S-Scan extractors, and by displaying the gates and their triggers exact position, the 3D view provides an additional and valuable interpretation tool to the solution.

This trial was realised with notches and a similar setup should be able to detect any crack or other perpendicular flaws to the COD inspection. Further feasibility studies should be realised in order to define more precisely the detection limitations of other flaws geometries, such as corrosion, pitting and mechanical damage. Also, other applications could benefit from this approach, such as the detection and characterisation of HIC crack on piping and pressure vessel or the detection and characterisation of stress hydrogen cracking.

References

[i] Uwe VÖLZ [1], Peter HEILMANN [1], Henry SCHOLZ [2] New Generation of Test Benches for Ultrasonic Testing of Solid Axles, , Berlin, Germany, 2014

[ii] TURCOTTE Jonathan [1], RIOUX Philippe [1], CYR Philippe [2]True Advancements for Longitudinal Weld Pipe Inspection ¨,Québec, Canada,2016