Futuristic Scanning Plan -Automatic Ultrasonic Testing Systems For Oil And Gas Pipeline Industry

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Futuristic Scanning Plan - Automatic Ultrasonic Testing Systems For Oil And Gas Pipeline Industry

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ABSTRACT

Ultrasonic testing is essential for ensuring the safety and reliability of pipelines used for transporting H2, CO2, crude oil, and natural gas. Automated ultrasonic testing systems, employing arrays of transducers/probes arranged in fixed patterns such as X, I, K, on-bead, or wheel probes, are commonly used by manufacturers to detect both longitudinal and transverse defects in various types of pipes, including L-SAW, H-SAW, ERW, or seamless pipes. However, the challenge lies in detecting defects that can occur in any direction, necessitating the use of multiple transducers.

While phased array probes are available, they still send ultrasound in a single direction with varying angles. In this study, I investigate the feasibility of using a single transducer/probe with multiple crystals mounted at different angles or a rotating transducer/probe which can scan in different directions to detect defects oriented in different directions. This approach leverages the law of reflection to maximize defect detection while minimizing the number of transducers/probes required, thus potentially enhancing both efficiency and cost-effectiveness in pipeline inspection processes.

Keywords: Phased Array, Multi Directional Transducer, Ultrasonic Testing, Steel pipe, calibration

1. INTRODUCTION

In pipeline inspection, standards like API 5L and CSA, along with European standards, guide the calibration of ultrasonic systems. This involves using drilled holes, longitudinal, and transverse notches as reflectors. However, recent IOGP standards have introduced a new requirement for detecting oblique defects like FBH (flat-bottom holes). This means that excluding the IOGP requirement may lead to missing defects oriented at different angles.

IOGP standards necessitate the use of numerous transducers to meet the requirements. This raises concerns about the practicality and efficiency of inspection methods. Therefore, there is a need to explore alternative approaches to ensure comprehensive defect detection while minimizing equipment and resource requirements.

By current practices, calibration pipes manufactured according to API 5L (or similar standards) are used for ultrasonic testing. During calibration, a 1/16 inch through drilled hole (TDH) is introduced into the calibration pipe to serve as a sensitivity check. Additionally, N5 notches are machined into the pipe (weld toe) to verify that the ultrasonic waves are perpendicular to the weld seam. This perpendicular orientation is crucial for ensuring accurate and reliable detection of defects during pipeline inspections.

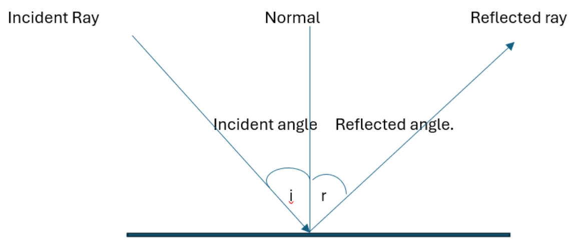
1.1 HISTORY

Ensuring the quality of oil and gas pipelines is crucial, and ultrasonic testing (UT) is a preferred method for doing this. UT uses sound waves to detect defects like cracks, porosity, slag, LOP, LOF, etc in welds, which are a major concern. Unlike other methods, UT is good at finding these flaws, especially linear defects. To speed things up and avoid human mistakes, automated UT is often used. This system uses multiple probes to ensure all types of defects are caught, keeping pipelines safe and reliable**.**

1.2 LAW OF REFLECTION (BASIS OF ULTRASONIC TESTING)

In ultrasonic testing, the law of reflection governs how sound waves interact with materials. This law states that when a sound wave strikes a boundary between two dissimilar materials, the angle of reflection will be equal to the angle of incidence. In other words, the sound wave bounces off at the same angle it hits the boundary.

This principle is crucial for ultrasonic testing because it can affect how easily defects are detected. When a sound wave hits a defect nearly head-on (approximately 90 degrees), it reflects towards the transducer/probe with minimal energy loss. This is the ideal situation to detect a defect, but if the incident angle is not 90 degrees, then energy losses will be high and can make the defect difficult to identify as the returning signal might be weak.



i=r

Figure (1)-Laws Of reflection (basic of ultrasonic testing)

Figure (1) used to show that according to laws of reflection incident angle is always equal to reflection angle

2. CURRENT INSPECTION PROCESS (PROBES ARRANGEMENT) AND LIMITATIONS

In manual ultrasonic testing, a single probe can be manually rotated to examine material for defects in different directions. This approach offers flexibility for inspectors. However, automating UT with multiple transducers to achieve the same level of omnidirectional inspection remains a challenge. In automatic systems, probes are situated in a fixed direction.

2.1 EXPERIENCE

In my work examining weld defects, I utilized the on-bead +I+I mode inspection technique (L-Saw Pipe/H-Saw). This method excels at detecting defects that are parallel, perpendicular (90 degrees), or at a 45-degree angle to the weld seam. However, the echo amplitude, which indicates the severity of the defect, weakens for defects oriented at other angles.

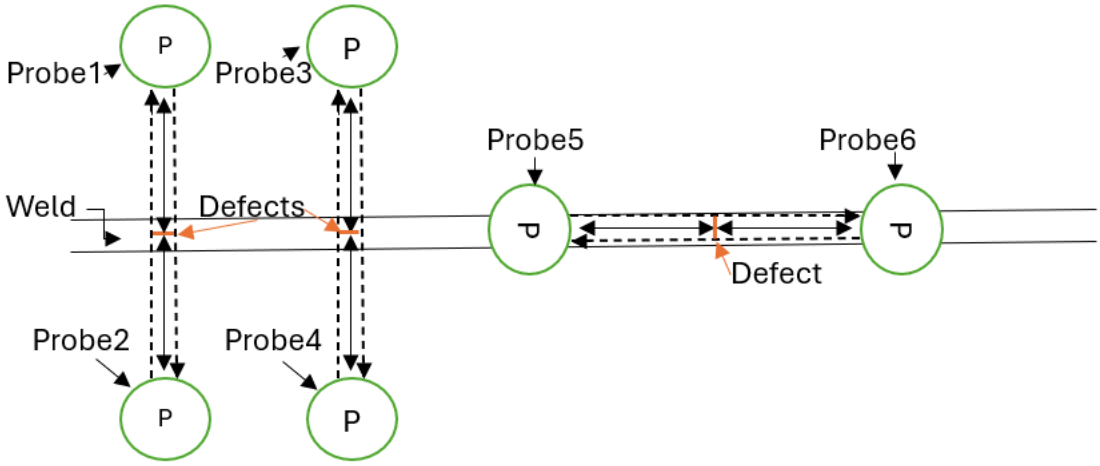


Figure (2)- Scanning Mode (Probes Arrangement in Automatic ultrasonic scanning system

Figure (2) showing the probe arrangement in I+I+ ON bead pattern to scan weld for longitudinal and transverse defects

⟷ This denotes that Probe is working in Pulse Echo mode for flaw detection.

- - - - - - -→ This denotes that Probe is working in Through Transmission mode for decoupling.

⟶ This denotes that Probe is working in Through Transmission mode for flaw detection.

Two “I” mode probe configurations are typically set to inner and outer zone longitudinal imperfections (from probe 1 to 4).
On-bead probe configuration is typically set to cover inner and outer zone transverse imperfections (from probe 5 to 6).

2.2 ULTRASONIC WELD INSPECTION WITH DIRECTIONAL SENSITIVITY

This example demonstrates how ultrasonic testing can be sensitive to the orientation of defects in welds. When the defect is parallel, perpendicular, or at a 45-degree angle to the weld path, the echo signal remains strong. However, defects oriented at other angles can cause a significant drop in echo amplitude. This drop will increase when the defect orientation angle and inspection set angle gap increase.

This highlights the importance of considering the potential impact of defect orientation when interpreting ultrasonic weld inspection results.

Figure (3)-volumetric defect (visual hole) on weld (ID)

Figure (3) showed a visual hole located on pipe ID and missed through the automated Ultrasonic Testing system.

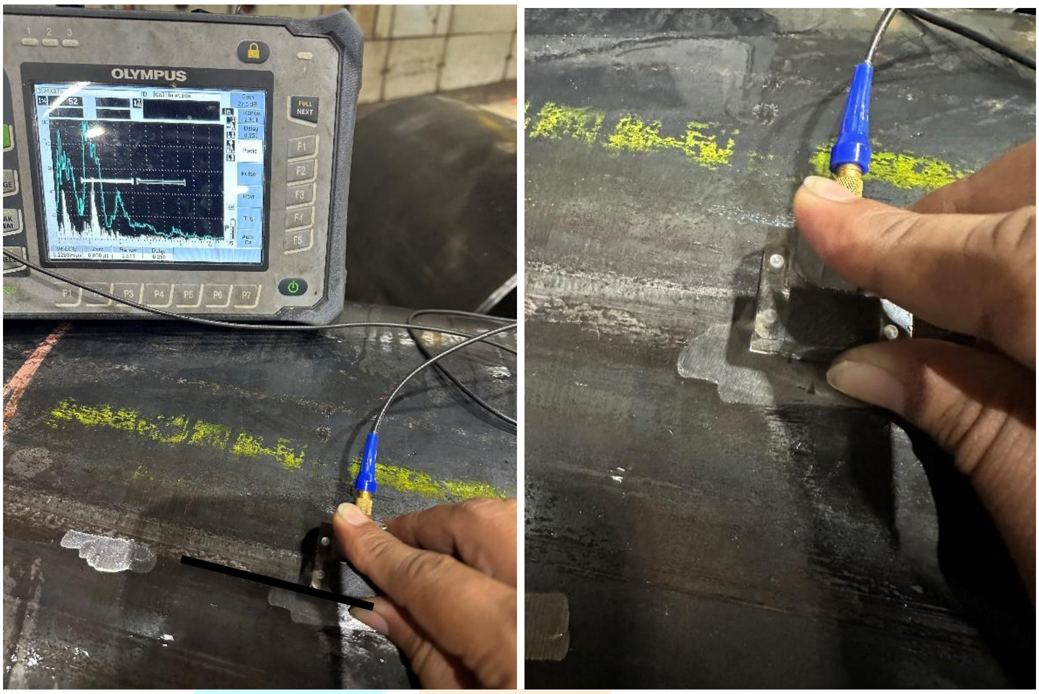


Figure (4)-Probe position and Manual handheld machine screen on job

Figure (4) showing Probe position and Manual handheld machine screen while probe position is like that ultrasonic rays' perpendicular to weld and also showing reflection from the defects dropped below threshold level for defect showing in figure (3)

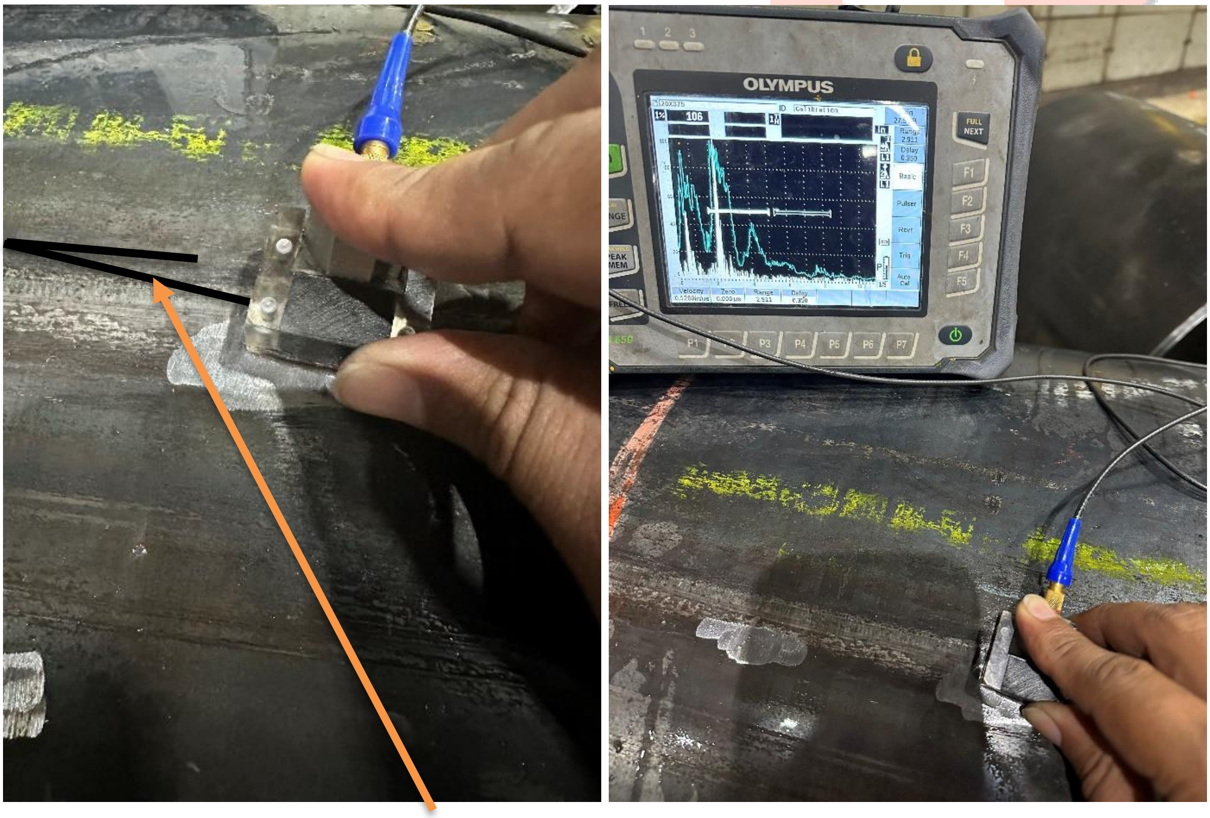


Figure (5)-Probe position and Manual handheld machine screen when got maximum reflection from the defects showing in figure 3

Figure (5) showing Probe position and Manual handheld machine screen when probe position is like that (twisted) to get maximum reflection from the defects showing in figure (3)

By above defect its prove that defects can be missed in current scanning plan because it's not covered all orientations and that's why we need to think differently to catch this type of defects.

INSIGHT:

My study revealed a concerning trend. The echo amplitude reduction becomes more pronounced for defects with orientations between:

- 0 to 45 degrees in the longitudinal direction (along the weld)
- 90 to 45 degrees in the transverse direction (across the weld)

This effect reaches a maximum at:

- 22.5 degrees in the longitudinal direction
- 112.5 degrees in the transverse direction

At these specific angles, the echo amplitude can drop significantly, potentially falling below the detection threshold and causing these defects to be missed entirely.

The Sensitivity of other inspection methods, like On-Bead and roller probe techniques, is even more dependent on defect orientation. These probe arrangements can only reliably detect transverse defects (cracks running perpendicular to the weld) at 90 degrees. My research indicates that even a 15-degree variation in the orientation of a transverse defect (like an N5 notch) can make it undetectable with current probe configurations. Increasing the gain can slightly improve detection, but this unfortunately leads to a higher noise ratio and an increase in false positives. This approach also has limited effectiveness as the variation angle increases.

Similar limitations apply to longitudinal defects (cracks running along the weld). Deviations exceeding 15 degrees from the ideal orientation become undetectable with current longitudinal probes.

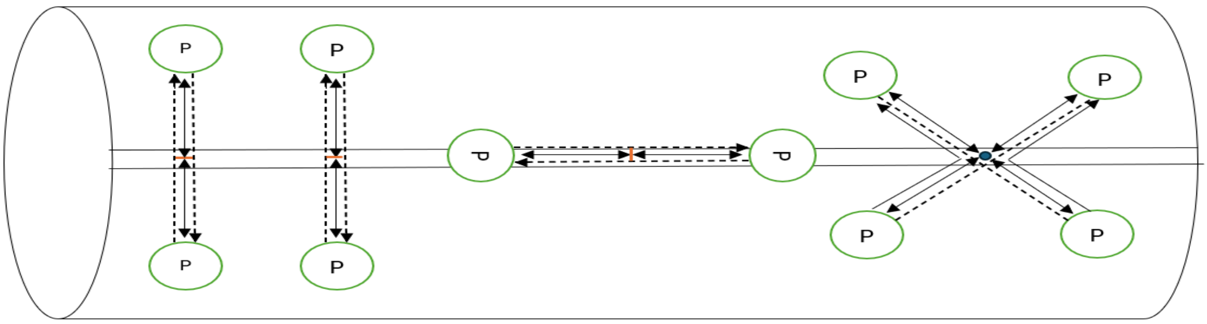


Figure (6)-I+I (for Longitudinal defects) + On- bead (For transverse defects) Arrangement+ X (for transverse defects)

Figure (6) showing the probe arrangement in I+I+ ON bead + X pattern to scan weld for longitudinal and transverse defects

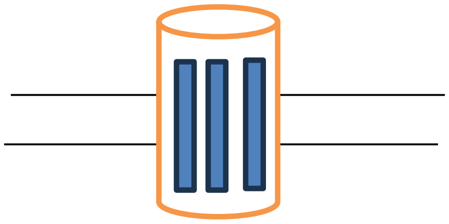


Figure (7)-Wheel type probe arrangement for transverse defects oriented at 90 degrees to weld.
Figure (7) showing a wheel probe on top of weld to scan transverse defects in weld.

3. CURRENT VALIDATION PROCESS AND LIMITATIONS

3.1 CURRENT LIMITATIONS OF ARTIFICIAL REFLECTORS IN AUT CALIBRATION:

- Limited defect orientations: API 5L specifications primarily utilize notches oriented at 90 degrees (transverse) and parallel (longitudinal) to the weld. However, real defects can exist in various orientations.
- Isotropy of drilled holes: Through-drilled holes used as calibration reflectors provide a consistent response regardless of the probe direction. This doesn't reflect the behaviour of defects like cracks.
- IOGP specifications address some limitations by incorporating flat bottom holes at specific angles for calibrating probes in transverse and longitudinal configurations. However, this still doesn't cover all possible defect orientations.

3.2 CHALLENGES ARISING FROM THESE LIMITATIONS:

- False sense of security: Passing a calibration test with current reflectors doesn't guarantee 100% defect detection. Defects with orientations outside the calibration range might be missed.

Below are some calibration specimens used to calibrate automated Ultrasonic systems for weld defects (H-SAW, L-SAW, ERW, and seamless pipes)

3.3 CALIBRATION AS PER API 5L

Figure (8)- Calibration pipe drawing as per API 5L
Figure (8) showing calibration pipe to standardized auto ultrasonic testing machine as per API 5l guideline and with details below

1, 2: Longitudinal N5 notch on left and right side of weld edge of seam on ID
4, 5: Longitudinal N5 notch on left and right side of weld edge of seam on OD
3, 6: Transverse notches on weld on ID, OD
7: 1.6 mm (1/16”) TDH at Middle of weld

<u>Notches:</u>
−Depth: 5 %t; not necessarily less than 0.3 mm, maximum 2.0 mm; tolerance ±15 % of depth or ±0.05 mm, whichever is greater.
− Length (longitudinal): maximum 25 mm, Length (Transverse): Equal to weld width

− Width: maximum 1 mm
− Position of weld edge notches: Starts from at least 1.6mm away from weld edge

3.3.1 CALIBRATION AS PER IOGP SPECIFICATION

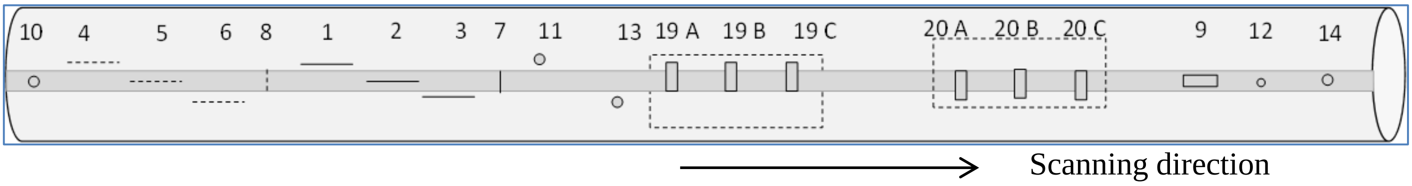


Figure (9)-Calibration pipe drawing as per IOGP specification
Figure (9) showing calibration pipe to standardized auto ultrasonic testing machine as per IOGP Specification guideline and with details below

10,14: 3.2 mm RDH on weld canter at 250 mm from each end
12: 1.6 mm RDH on weld canter for transverse scan
2, 5: Longitudinal N5 notch on weld canter on OD, ID
1, 4: Longitudinal N5 notch on left side weld edge of seam on OD, ID
6, 3: Longitudinal N5 notch on right side weld edge of seam on ID, OD
7, 8: Transverse notches on weld on OD, ID
13, 11: 3.2mm RDH on weld toes on the right and left side of weld for gate setting (assuring coverage)
19A, 20A: 3.2 mm FBHs on OD bevel face at depth 25 % of wall thickness on right and left
19B, 20B: 3.2 mm FBHs on root face at depth 50 % of wall thickness on right and left.
19C, 20C: 3.2 mm FBHs on root face at depth 75 % of wall thickness on right and left.
9: SDH 3.2 mm diameter, longitudinal, located at mid wall weld centreline drilled parallel to the weld axis

Notches:

−Depth: 5 %t; not necessarily less than 0.3 mm, maximum 2.0 mm; tolerance ±15 % of depth or ±0.05 mm, whichever is greater.
− Length (longitudinal and transverse): maximum 25 mm
− Width: maximum 1 mm
− Position of the weld edge notches: Starts from at least 3 mm away from weld edge

RDHs:

1.6 mm diameter (12) at weld canter and 3.2 mm diameter (10, 14) at weld canter.
3.2 mm (11, 13) starts from at least 3 mm away from the weld edge for setting defect gate lengths/assuring coverage.

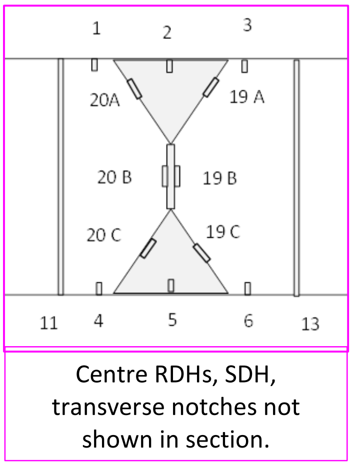
SDH:

3.2 mm diameter with a length of 40 mm maximum.

FBHs:

All 3.2 mm diameter drilled perpendicular to the fusion face, end faces parallel to and at the fusion face; one of each pair facing clockwise, one of each pair facing counterclockwise.

Side view



← Centre RDHs, SDH, and transverse notches are not shown in the section.

Figure (10)-Side view of defect in calibration pipe (As per IOGP Specification)

Figure (10) showing side view of defects which is discussed in calibration pipe showed under Figure (9)

3.4 EXPERIMENT AND EXPERIMENTAL DATA

3.4.1 My experiment investigated the effect of notch orientation on ultrasonic calibration accuracy. I utilized an N5 notch in both the longitudinal (parallel to the weld) and transverse (perpendicular to the weld) directions under ideal conditions. Calibration of the automated system was performed using probes arranged in an "I" pattern for the longitudinal direction and "X" and "on-bead" patterns for the transverse direction.

3.4.2 In the subsequent step, the N5 notch was intentionally misaligned by 10 degrees. Following this misalignment, a re-evaluation of the calibration revealed a decrease in the echo signal from the notch.

3.4.3 Further misalignment was introduced by tilting the N5 notch by an additional 15 degrees from the ideal position (5 degrees more from the above step or 3.4.2). At this point, the calibration began to exhibit signs of failure.
3.4.4 Finally, the notch was misaligned by a total of 20 degrees (5 degrees more than the above step or 3.4.3), resulting in a complete failure of the calibration.

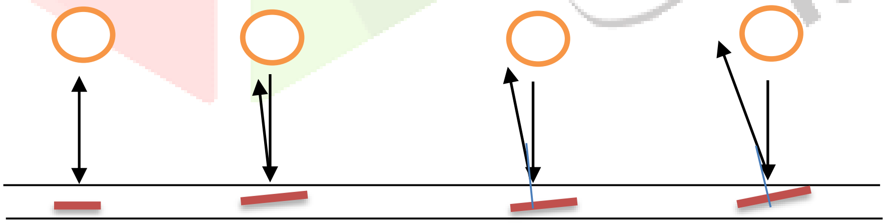


Figure (11)-Example of probe set for longitudinal defects.

Figure (11)- Figure 8 Showing the effect of energy back from a notch located at different angles

In manual ultrasonic testing (UT), displacing the N5 notch does not affect the test result as it is easier and standard practice to manually rotate the probe. Angulation allows a stronger signal (echo) to be obtained during scanning. In my experiment I used a manual UT probe and scanned the coupon and got all the N5 notches that were displaced in different directions.

4.0 Proposed solution (Multi-directional Probe) with either multiple crystals mounted in a different direction or a rotating probe for multi-directional scanning.

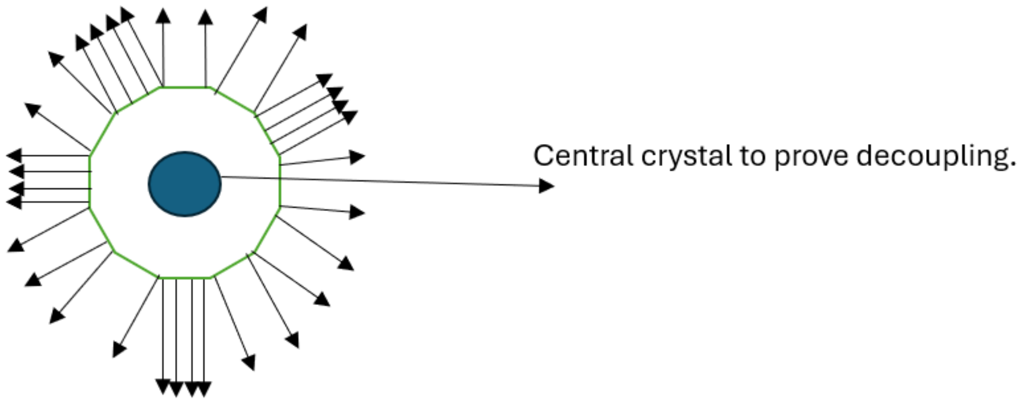


Figure (12)-multiple crystal mounted in different direction probe.

Figure (12) showing a proposed probe drawing to scan multiple direction which is discussed in this paper

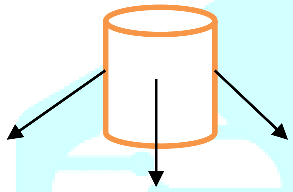


Figure (13)-Rotating probe to scan all directions.

Figure (13) shows a proposed probe drawing (Wheel type) to scan multiple directions which is discussed in this paper

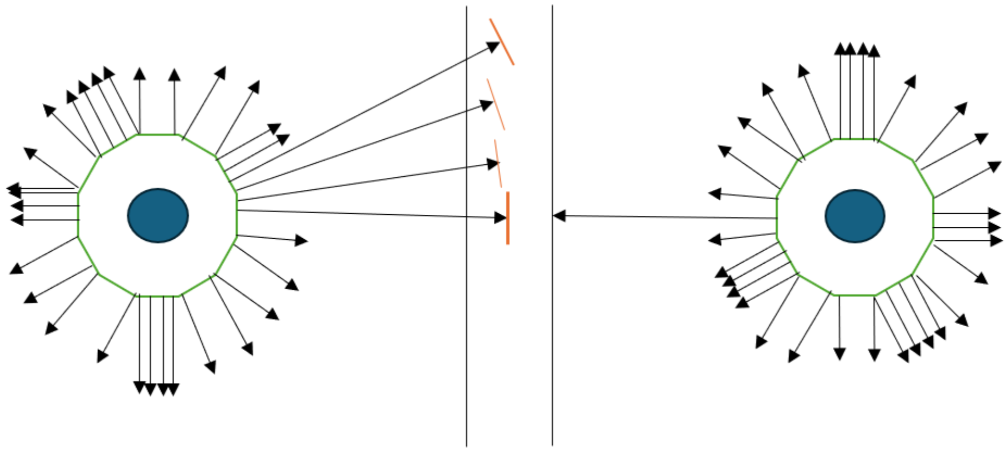


Figure (14)

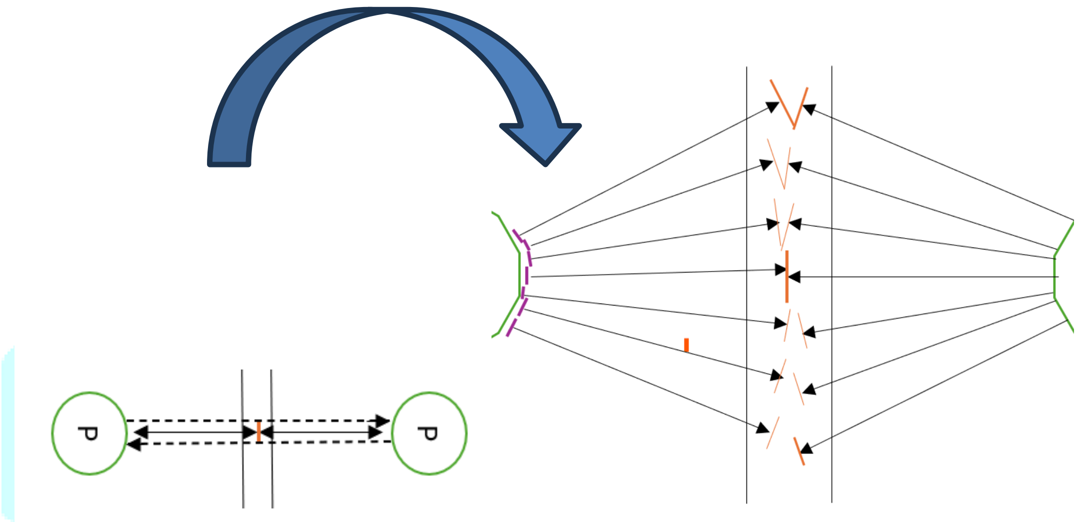
This novel ultrasound technology allows for the detection of defects in various orientations. This is achieved by transmitting ultrasound waves in multiple directions, rather than a single direction as in conventional methods.

Figure (14) showing a layout that how we can replace traditional I mode with our multiple direction probes.

Decoupling with separate probes: This decoupling can be set by using two separate probes in a crossed-talked pattern or by using a separate crystal in straight beam mode.

4.1 NEW TECHNOLOGY DETAILS:

New technology -Single probe with multiple crystals or rotating probe: This approach utilizes a single probe containing an array of crystals (20 to 30) in different directions. Each crystal transmits a beam in a specific direction, effectively covering a wide range of angles. Alternatively, a smaller number of crystals can be used in conjunction with a rotating mechanism to scan all directions. Another option is a "wheel-type" probe with crystals fixed at specific angles and rotated to capture all directions.



Current Technology Proposed Technology

Figure (15)-transformation from current to proposed technology

In figure 15 showing transformation from current scanning pattern to proposed scanning pattern

Purple colour Line showing crystal mounting in different directions.
The Red colour line shows defects in a different direction.
The Black colour line shows the ultrasonic direction.

Note- we can use the proposed technology in both directions, longitudinal as well and transverse direction (To replace the On-bead or wheel-type transducer)

The Proposed technology can be achieved either by a wheel type transducer with a mechanism to rotate the probe or by multiple crystals mounted in different directions.

4.2 NEW TECHNOLOGY ADVANTAGES

My proposed technology offers several key advantages:

- **Enhanced Detectability:** We can significantly improve the detection of defects regardless of their orientation. This ensures high-level quality.
- **Reduced Probe Complexity:** By merging the X+I pattern with a single I pattern, we can minimize the overall number of probes needed. This simplification can lead to cost savings and potentially improve the efficiency of the detection process.
- One additional advantage of the new technology is its ability to detect volumetric defects with increased accuracy.
- One additional advantage of this new technology is its ability to inspect the body of pipes (partially), beyond just welds, in multiple directions to identify potential defects.

4.3 LIMITATION

My proposed technology offers an advantage in detecting defects with various orientations. However, there's a limitation. Since all crystals are mounted in a single housing, we can't customize the "skip distance" for each crystal individually. This means when the direction of the UT beam changes, the skip distance might not be ideal for all diffraction patterns.

5.0 CONCLUSION:

This research explores the potential of a novel approach to ultrasonic testing utilizing a single transducer with multiple crystals at different directions or a rotating transducer for multi-directional scanning. Traditional methods face limitations in detecting defects oriented at angles outside the calibration range, leading to concerns about inspection efficiency and reliability. By leveraging the law of reflection and decoupling with separate probes, the proposed technology offers enhanced detectability of defects in various orientations while reducing probe complexity. Although there are limitations in customizing the skip distance for each crystal individually, the overall benefits of improved defect detection and simplified probe arrangements hold promise for enhancing inspection efficiency in pipeline integrity assessment. Further development and validation of this technology could lead to significant advancements in ensuring the safety and reliability of pipeline systems for transporting hazardous substances.

6.0 REFERENCE

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