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RUHR-UNIVERSITÄT BOCHUM



# ADVANCING MATERIAL CHARACTERIZATION DAMAGE WITH ULTRASONIC TESTING

BACHELOR THESIS

BINH DUONG 2023



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# *Advancing Material Characterization Damage with Ultrasonic Testing*

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## Abstract

Non-destructive testing (NDT) has become an essential tool in assessing materials and products without causing alterations. This thesis focuses on the challenges associated with utilizing ultrasonic testing on curved seamless steel pipes, particularly in detecting surface deflections. The research addresses the limitations of the fixed gate positioning method and proposes an innovative solution by utilizing the IF START function. Enhancing defect detection processes for industrial applications, ultimately increasing product quality and reducing rejection rates is this thesis's goal.

Examining the implications of varying pipe curvatures on gate positioning and the confusion between interface and deflect detecting gates forms a core aspect of this research. This study seeks to eliminate inaccurate results by exploring the potential of the IF START function to automatically align the deflect detecting gate with the interface gate automatically. Real-life experiments with curved steel pipes will be conducted to validate the proposed solution's effectiveness, aiming to optimize defect detection through gate adjustment based on the interface echo's position.



In conclusion, this bachelor thesis bridges the gap in non-destructive testing for curved steel pipes by proposing the IF START function as a solution to improve gate positioning accuracy. Through empirical validation and a formula development process, the research aims to enhance product quality and production efficiency, highlighting the pivotal role of skilled NDT specialists in achieving reliable results. The study contributes to the field's understanding of effective defect detection and gate setting, addressing a critical concern in industrial quality assurance.

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# List of Abbreviation

*Table 1: List of Abbreviation*

<b>Acronyms</b>	<b>Meaning</b>
<b>NDT</b>	Non-destructive Testing
<b>NDE</b>	Non-destructive Evaluation
<b>NDI</b>	Non-destructive Inspection
<b>NDE</b>	Non-destructive Examination
<b>VT</b>	Visual Testing
<b>ECT</b>	Eddy Current Testing
<b>UT</b>	Ultrasonic Testing
<b>TOFD</b>	Time of Flight Diffraction
<b>LF</b>	Longitudinal Flaws
<b>TF</b>	Transverse Flaws
<b>RPM</b>	Round per minute

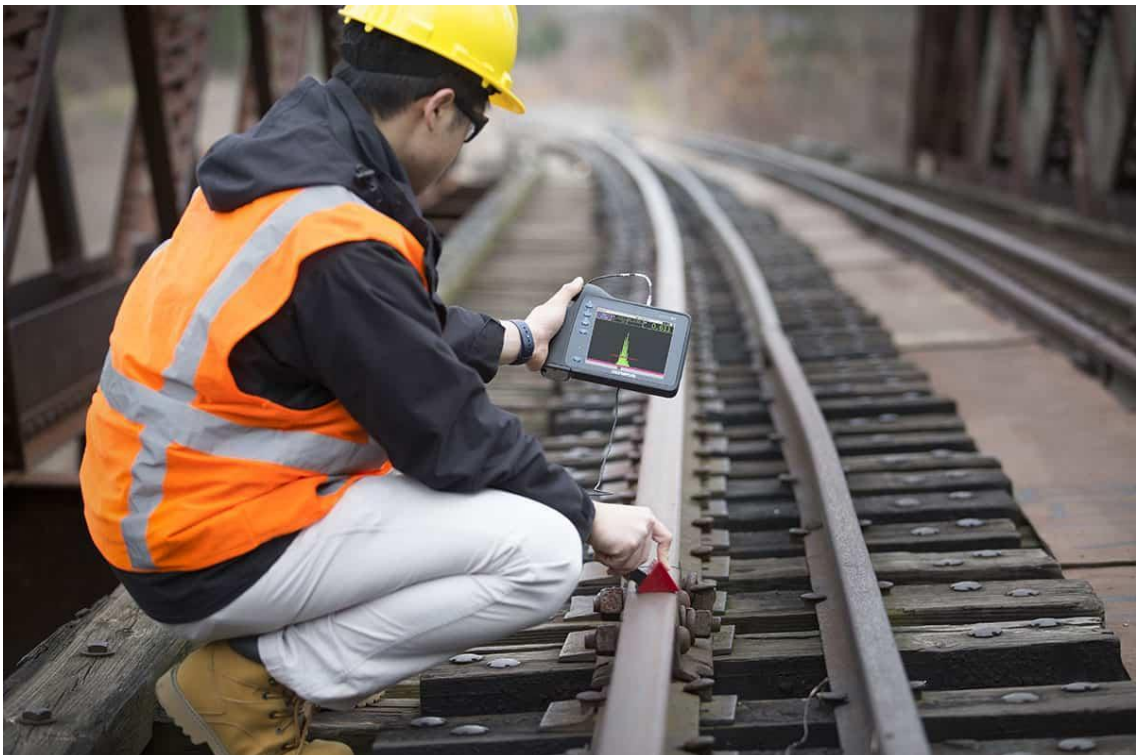
# Chapter 1: Introduction

## *1.1 What is Non-Destructive Testing (NDT)*

Non-destructive testing (NDT) is a process that involves inspecting objects without causing any alterations to them. Its primary objective is to identify any conditions or discontinuities that might affect the object's usability or functionality while maintaining its state. NDT also encompasses measuring characteristics such as size, composition, hardness, and grain size of the object under examination. Essentially, NDT entails examining objects of types, sizes, shapes, and materials to detect flaws or assess material properties. In the realm of technology, NDT is also referred to as non-destructive examination (NDE), non-destructive inspection (NDI), or non-destructive evaluation (NDE)[1]. Despite being employed for years now, NDT remains unfamiliar to the average person who often takes things like building integrity, aircraft safety, and product reliability for granted[2]. Although NDT cannot completely prevent failures from occurring, it significantly helps minimize their likelihood. However, it's important to note that failures can still happen even if NDT is implemented correctly due to factors such as design issues or improper application.



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*Figure 1: NDT engineer applying ultrasonic testing on railways [3]*

Over the 25 years, there have been remarkable advancements and breakthroughs in the field of NDT, making it one of the rapidly evolving technologies known for its innovative approaches and distinctive characteristics[4]. Due to the recent improvements in equipment along with an understanding of materials, a wide range of available products and systems have all contributed significantly towards popularizing this technology across various industries today[5]. Recognizing the significance of non-destructive testing (NDT) in our everyday lives is essential, as its influence on safety goes beyond even the work of medical professionals. It is truly remarkable to contemplate the multitude of accidents and unforeseen malfunctions that would transpire in the absence of non-destructive testing techniques being employed.

Non-destructive testing (NDT) has become a part of various industrial processes, where the failure of a product could potentially result in accidents or harm[6]. In fact, NDT is relied upon to an extent in almost every major industry today; interestingly, many individuals perform NDT without realizing it. For instance, when we insert a coin into a vending machine and select a product, that coin undergoes a series of tests that do not cause any damage to it, swiftly evaluating its size, weight, shape and metallurgical properties[7]. If the coin successfully passes all these tests, we are rewarded with our chosen product.



*Figure 2: Applying ultrasonic testing on material surface [8]*

It's worth noting that the human body itself can be considered one of the most remarkable instruments for non-destructive testing ever created[9]. Normally, we rely on our sense of sight to assess characteristics such as color, shape, movement, and distance for identification purposes. These instances align with the definition of non-destructive testing since they involve evaluating objects without altering them in any way. We can gather information about the object without visual observation through senses like touch and hearing alone. For instance, by relying on our sense of touch, we can determine roughness and configuration or estimate the size and shape of objects. Our ability to hear allows us to analyze sounds and make judgments about their source, like being able to recognize the approach of a truck before crossing the street. However, among all our senses, sense of sight provides a versatile approach to non-destructive testing[10].



*Figure 3: Visual Testing method[11]*

Visual observation offers a range of applications and provides valuable information, making visual testing (VT) one of the most commonly used non-destructive testing methods[12]. NDT has applications within various industries; it can be utilized to examine raw materials before they undergo processing. Additionally, it can be employed during the processing stage as a means of ensuring control over the manufacturing process. Non-destructive testing is also invaluable for inspecting finished products and assessing their quality; furthermore, it can be used to evaluate products and structures once they are in use[13]. Essentially, NDT serves as an extension of our senses, particularly when we utilize advanced electronic instruments and specialized equipment that enhance our ability to detect and analyze various properties of the objects being examined. However, it is crucial to acknowledge that incorrect application or misuse of non-destructive tests can have severe consequences. If tests are conducted incorrectly, or the

interpretation of results is flawed, it can lead to bigger problems. That is why it's crucial for technicians to use appropriate non-destructive testing methods and techniques to minimize such issues[14].

To sum up, non-destructive testing is a technology that offers insights into the condition of examined objects. However, it requires considering all elements following approved procedures and qualified personnel to ensure accurate results and prevent any negative consequences.

## ***1.2 Problem***

Ultrasonic testing plays a crucial role in evaluating steel pipelines without causing damage in detecting surface defects, like deflections on both the inner and outer surfaces[15]. This method involves using ultrasonic sound waves to travel through the material and analyzing the reflected echo to identify any defects[16]. However, there are challenges when it comes to curved steel pipes, due to the varying distance between the surface and the transducer caused by curvature. Consequently, the fixed position of the detection gate during testing often leads to fault results because the ultrasonic testing machine might confuse interface echo signals, with deflect echo signals.

One drawback of this testing approach is its inability to measure the product's curvature directly. Instead, it depends on identifying surface deflections using echo signals, which poses challenges when working with steel pipelines; positioning the gate accurately and precise curvature information is required[17]. Unfortunately, such data is not accessible, during the testing phase.

Currently, there are no examination techniques to detect deflections in curved steel pipes before conducting ultrasonic testing. The curvature information is only accessible after the straightening procedure, which happens before the test. This curvature data hampers the ability to set up the interface gate and trigger gates precisely.

In the A-scan, accurately determining the position of the interface echo is vital for setting up the detecting gate. However, when dealing with curved sections, the distance from the transducer to the outer surfaces of the pipe varies due to its curvature. As a result, the position of the interface echo is not fixed, causing confusion for the detecting gate as it interprets echoes at points along the pipe[18].

To perform testing effectively, a rotating probe machine is used to scan every part of the pipe's surface[19]. However, because of variations in product curvature



and probe positioning, there are discrepancies in distances between transducers and outer surfaces. These differences in distance lead to the detection of deflections and inaccurate identification of interface echo.

In order to ensure quality, the customer allows a curve of less than 1mm per 1m length and 3mm per individual piece. The standard sample used for experiments usually has no curvature. However, due to limitations at the working station, the standard sample may exhibit a curve during testing at the NDT station leading to small errors. Additionally, the actual products will have allowable curvature, which can result in more noticeable differences between interface and deflect echoes. Mistakenly detecting defects when there are none can lead to rejecting products that are defect-free, causing a large number of final products to be rejected during the evaluation process (figure 5). This high rejection rate greatly impacts production efficiency and results in costs.

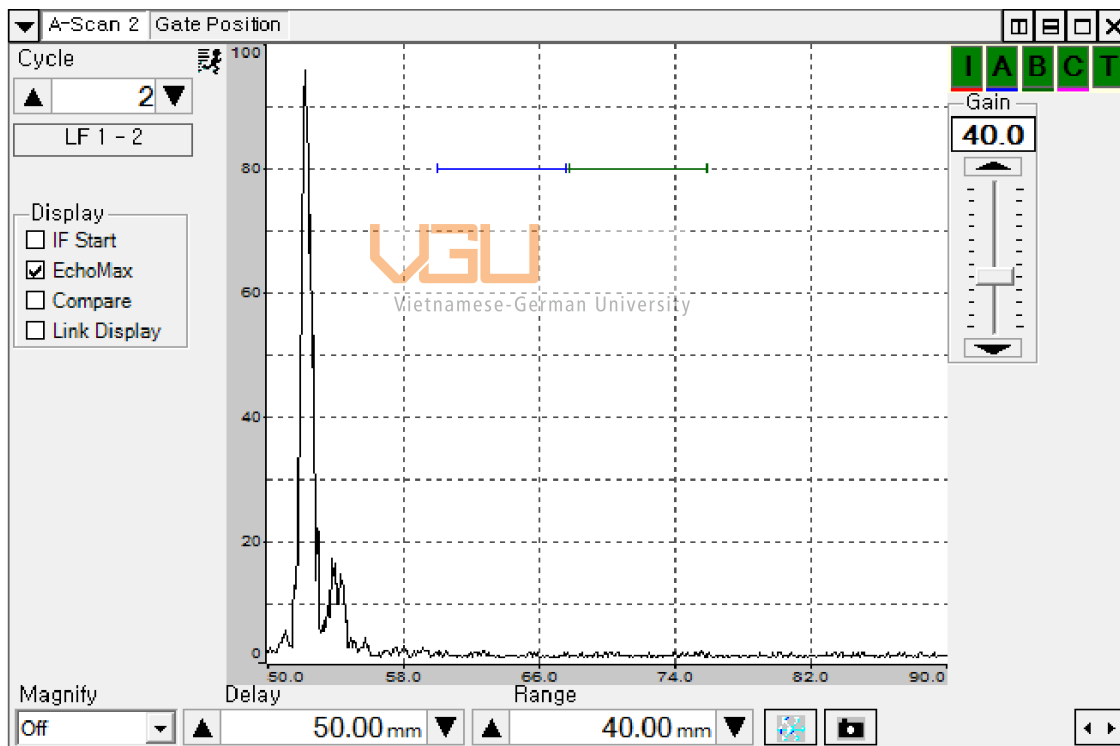
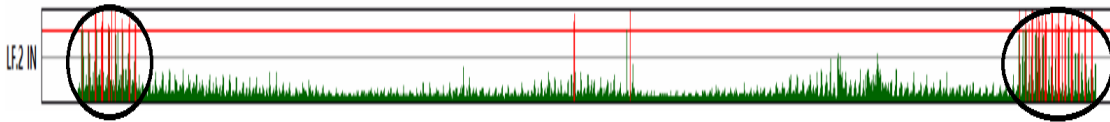


Figure 4: Normal A-scan

The A-scan display (figure 4) provides information about the position of the reflected waves. By using 45-degree probes, it becomes easier to identify outer and inner surface defects based on their location in relation to the wall thickness of the product. To solve the difficulties posed by varying curvature, one possible solution is to incorporate the IF START function into the machine[20]. This function ensures that the deflect-detecting gate aligns with the interface gate, automatically adjusting its position based on the interface echo. By configuring the detecting gate, we can prevent mistaking interface echo signals for deflecting echo signals[21].



*Figure 5: Interface echo hit defect gate, causing final result to fail*

It is important to have non-destructive testing experts utilize the IF START function and establish gate settings effectively. These specialists need a deep understanding of ultrasonic testing principles to ensure accurate and reliable results., improving product quality and minimizing incorrect evaluations[22]. Skilled NDT specialists are also essential for analyzing A-scan data and formulating a universal formula for gate positions, specifically for products with various sizes and curvatures[23]. Moreover, their expertise is invaluable, in tuning testing parameters to achieve precise defect detection while reducing false results.

Undoubtedly, incorporating the IF START function into testing systems has the potential to enhance production yield, minimize production delays and reduce costs associated with rejections. However, it's crucial to emphasize the importance of having personnel who understand and implement ultrasonic testing principles to ensure the effectiveness and reliability of this proposed solution[24].

The primary objective of this bachelor thesis is to explore the challenges related to testing curved steel pipes in detecting surface deflections. The study aims to address the limitations of the current fixed gate positioning method and proposes a solution by utilizing the IF START function. Additionally, it seeks to evaluate how effectively this solution can reduce discrepancies caused by varying curvatures.

To achieve these goals, we will undertake the following research tasks;

- Review literature on testing techniques and their applications in detection with a particular focus on seamless steel pipes.
- Examine how different pipe sizes impact gate positioning for detecting interfaces and deflections during testing.
- Thoroughly investigate the IF START function and its potential, for adjusting detecting gates based on interface echo positions.

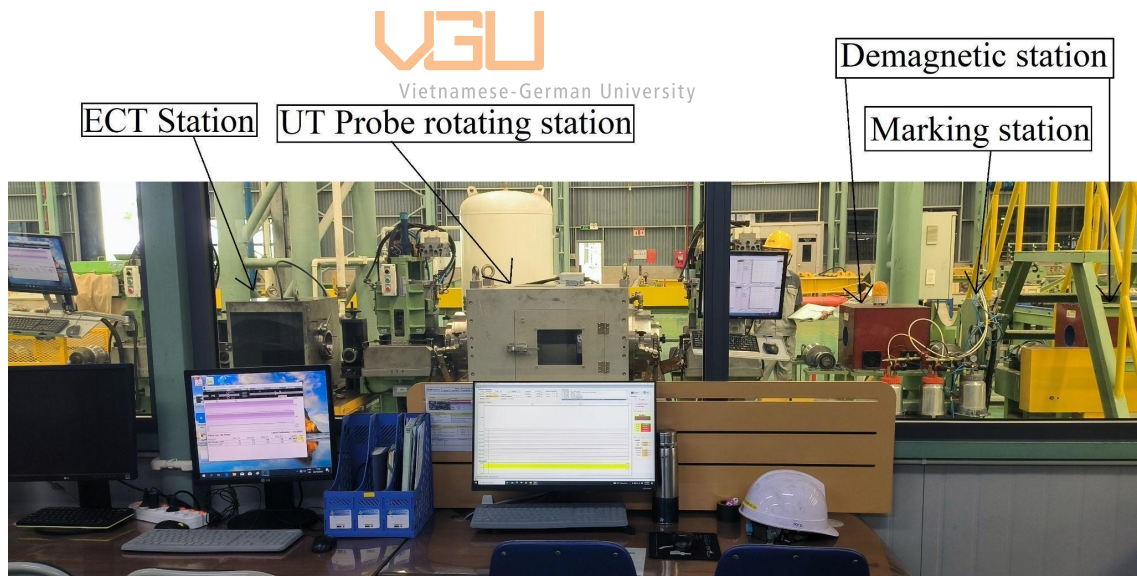
In my bachelor thesis, I intend to contribute to the field of non-destructive testing, specifically focusing on ultrasonic testing for curved steel pipes. I will explore the challenges faced during detection in these pipes and propose the utilization of the IF START function as a potential solution. My goal is to provide insights that can benefit NDT specialists and professionals in the industry.



The main objective of my research is to address the issue of identifying interfaces and deflecting echoes with the aim of improving the reliability and accuracy of ultrasonic testing for steel pipelines. By developing a formula for gate setting using the IF START function, I aim to provide guidelines for implementing this solution in industrial settings. Overall, my bachelor's thesis seeks to advance our understanding of testing methods, within the context of curved steel pipes. It also aims to present a solution to enhance defect detection processes in various industrial applications.

### ***1.3 NDT Station***

Non-destructive Testing (NDT) plays an important role in ensuring the quality and integrity of steel pipes used across industries[25]. Our factory's NDT station is specifically designed to identify any defects on both the outer and inner surfaces of these pipes without causing any harm to the product. This station consists of three sub-stations: Eddy Current Testing (ECT)[26] station, Ultrasonic Testing (UT)[27] station and Marking station, which collectively contribute to the inspection process.



*Figure 6: NDT station at SeAH Global Vina*

The workflow at our NDT station commences with the source conveyor, where testing samples are initially placed. With the help of swing arms, these samples are carefully transferred onto the roller conveyor, beginning their journey through the NDT process. Throughout this process, safety is paramount; operators must refrain from accessing the working zone while the machine is in operation.

The roller conveyor acts as a component in facilitating the movement of testing samples throughout the entire NDT station. As these samples progress through each sub-station, four pinch rollers located strategically at both ends ensure they remain stable during inspection. These pinch rollers play an important role in protecting machine components, especially when dealing with curved steel pipes that may arrive at the testing machine with varying orientations.



*Figure 7: ECT sub-station*

The ECT sub-station is equipped with a machine that detects and measures defects on or near the outer surface of steel pipes. To ensure flexibility, it allows for the interchange of guide tubes and probes to accommodate the sizes of steel pipes, making it easier for them to pass through the ECT station smoothly. The following UT sub-station complements the ECT station by providing an inspection of both the inner and outer surfaces of the steel pipelines. By combining ECT and UT, we significantly improve our quality assurance process as we can detect not only surface flaws but also internal defects within our products. After undergoing ECT and UT inspections, an automated marking station was applied to spray paint to areas where defects might occur. This efficient marking system helps us identify and categorize flaws, making subsequent quality assessment and decision-making processes more streamlined.





*Figure 8: NDT Control Room*

The NDT station is managed by an inspector who oversees the entire inspection process from a dedicated inspection room. Using logic controllers (PLC Siemens), the inspector sets up the sensors and other components to gather the necessary information to identify and classify defects accurately. After completing the NDT inspection process, the swing arms come into action again to smoothly transfer the tested samples to the sink conveyor. This conveyor collects the inspected samples, making them available for processing and ensuring efficient workflow in our seamless steel pipe production.



*Figure 9: Marking and Demagnetizing station*

To summarize, our factory's NDT station plays a role in our quality assurance procedure[28]. By integrating ECT, UT, and an automated marking system, we

achieve reliable detection of defects on steel pipes. This ensures that only high-quality products move forward in our production line. The flawless workflow of the NDT station guarantees on-time delivery of reliable steel pipes to meet various industry needs and applications.



## Chapter 2: Literature review

### 2.1 Principle of Ultrasonic Testing

Ultrasonic testing relies heavily on the use of waves to detect, characterize, and measure defects in materials. These waves have a high-frequency range, exhibiting behaviors when they pass through substances like reflection, refraction, and attenuation[29]. The ability of vibrations to deeply penetrate materials, interacting with internal structures, provides valuable insights into material properties and the presence of defects[30].

In ultrasonic testing, reflection plays an important role. When an ultrasonic wave encounters a boundary between two substances with impedances, part of the wave reflects back toward the transducer. These reflections occur due to differences in propagation velocities and material densities. By analyzing these reflected wave properties during the testing process, we can gather information about flaw aspects such as the position of defects, distance from the outer surface to the defects and size of defects[31]. For example, it helps differentiate whether it is material that has been overstressed or if there are voids that were not properly bonded or filled during manufacturing, leading to bonding between layers or surface finish.

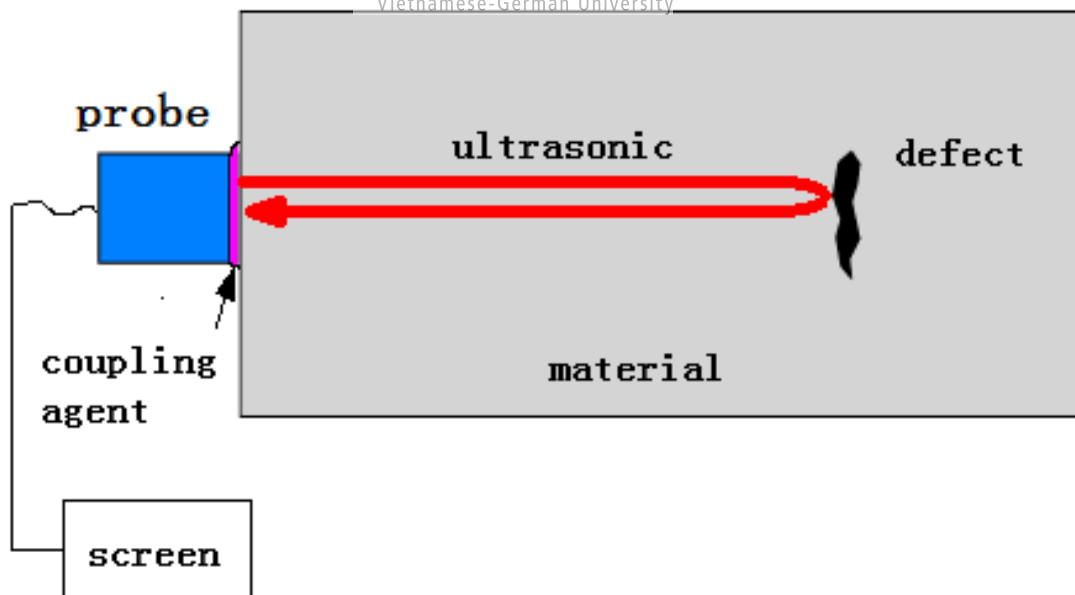


Figure 10: Sound wave reflection contributing to defect detection[32]

Refraction is also another crucial phenomenon in ultrasonic testing. This happens when an ultrasonic wave passes through a boundary between two materials with distinct acoustic impedances and then changes direction due to variations in its velocity as it moves into a substance that has different properties than the one before. The knowledge gained from the refraction analysis allows us to determine

incidence angles and refraction angles, which all together provide valuable details about material properties and defect occurrences[33]. With this information, when a sample is examined, it gives insight into internal structures and flaws within the materials. To successfully identify the size, shape, and location of defects, specialists rely heavily on both reflection and refraction in ultrasonic testing, by scrutinizing patterns along with the characteristics, associated with reflected and refracted waves material integrity as well as quality are maintained during the examination process[34].

The concept of "time of flight" is essential in ultrasonic testing[35]. It refers to the time taken for an ultrasonic wave to travel from the transducer to a target and back. This parameter is used to measure distances and identify any faults or defects in materials. When a transducer generates a wave, it travels through the material until it encounters a boundary or defect. At this point, some of the wave reflects back towards the sensor while the rest continues deeper into the material. Technicians can precisely determine the location of defects or boundaries by measuring how long it takes for the reflected wave to return to the transducer, relying on analyzing how sound travels within the material being tested[36]. The transducer produces a wave with a frequency, which travels at a constant speed within that particular material. The distance, which measurement plays a role in determining both the severity and location of defects in any given material, can be calculated by dividing travel time by two, providing detailed information about where their measurements originate from (whether it is a defect or boundary)[37].

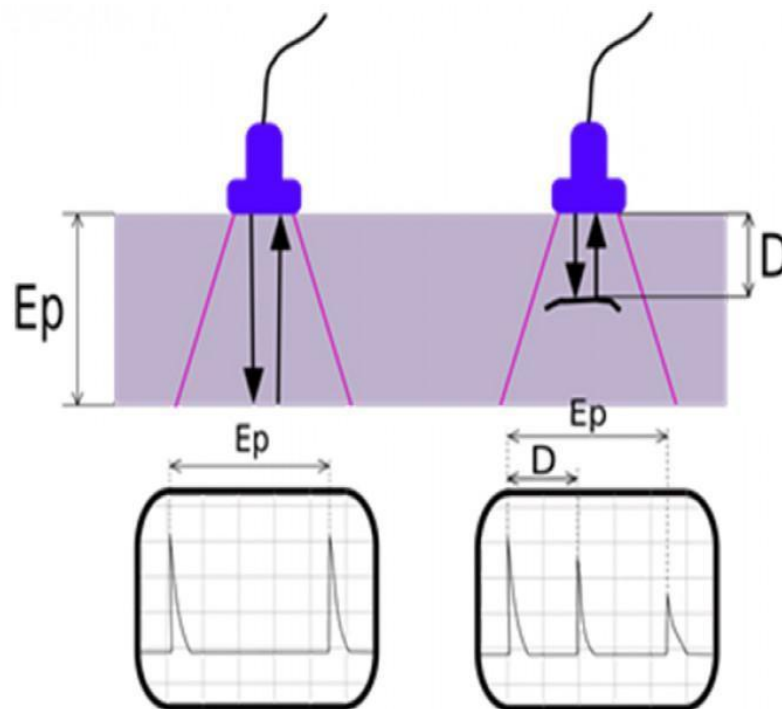


Figure 11: Ultrasonic testing detecting defect method[38]

Furthermore, useful information regarding the type of flaws can be gained by examining the strength and properties of the reflected wave. Typically, bigger defects correspond with stronger reflections, whereas smaller or shorter defects tend to exhibit weaker reflections[39]. Non-destructive testing (NDT) experts can examine the amplitude, configuration, and temporal properties of the reflected wave to ascertain different parameters like defect size, shape, and other particular characteristics. This complete investigation includes applying an extensive range of approaches, including the computation of wave propagation time and waveform analysis[40].

Multiple techniques are utilized for the analysis and visualization of signals, with the purpose of improving the detection and assessment of defects. Various advanced imaging technologies, like pulse echo, phased array, and time of flight diffraction (TOFD), to obtain images of structures and imperfections in materials[41]. Controlled transducers are used to guide and concentrate waves through phased array technologies that enable defect detection via material scanning and imaging. Small bursts of waves are released in the pulse echo technique, and by examining the resulting reflections, any flaws can be discovered along with their precise location[42]. Lastly, specialists can estimate the magnitude and position of the defect by observing diffracted waves that result when an ultrasonic wave hits a defect while utilizing TOFD techniques[43].

Ultrasonic testing (UT) is based on a range of principles, including reflection, refraction, time of flight measurements, wave analysis, defect identification, description, and quantification of materials. To ensure safety in industries like manufacturing, construction, aerospace, etc., experts must exercise caution when using transducers along with signal processing techniques and visualization methods to prevent any harm or damage to both materials involved as individuals working with them.



## 2.2 Type of sound wave

### 2.2.1 Transverse sound wave

Transverse ultrasound waves exhibit a pattern of movement where particles move perpendicular to the direction of wave propagation. Think of it as a rope being pulled up and down or from side to side; this motion demonstrates how transverse waves behave (figure 12)[44]. In ultrasonic testing, these waves are extremely valuable for detecting flaws on surfaces and measuring the thickness of materials[45].

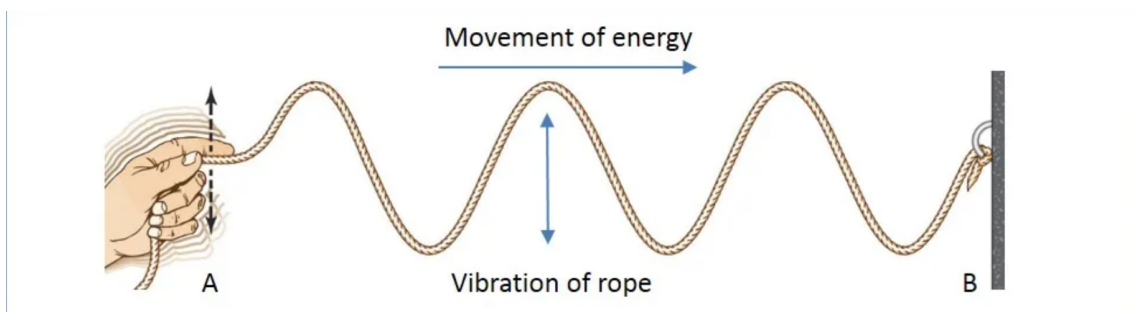


Figure 12: Transverse wave[46]

Because of their wavelength, transverse waves provide resolution and sensitivity, making them highly effective in detecting small defects. However, their strength diminishes rapidly as they travel through a material, which limits their ability to penetrate deeply[47]. As a result, their usefulness may be limited when inspecting materials or identifying flaws hidden within the core.

Transverse waves also have some limitations; they cannot propagate through fluids or gasses because these substances lack the shear strength required to sustain transverse wave motion[48]. Additionally, they are more sensitive to factors like surface conditions and grain structure within materials, which can affect their effectiveness on surfaces with pits or materials with grain structures. In ultrasonic testing scenarios, transverse waves complement longitudinal waves by providing unique capabilities. The understanding of the material condition could be obtained by utilizing both types of waves, ensuring thorough inspections that meet specific testing requirements[49].

### 2.2.2 Longitudinal sound wave

Compared to transverse waves, longitudinal ultrasound waves behave differently. They create wave movement in the direction as they travel, similar to compressing and stretching a spring (figure 13)[50]. Their ability to penetrate into



materials allows them to locate defects hidden within the core are the reason why longitudinal waves are excellent at finding defects and measuring the thickness of materials in ultrasonic testing. As they move through the material, they create tension, revealing imperfections like voids, cracks, and delaminations[51].

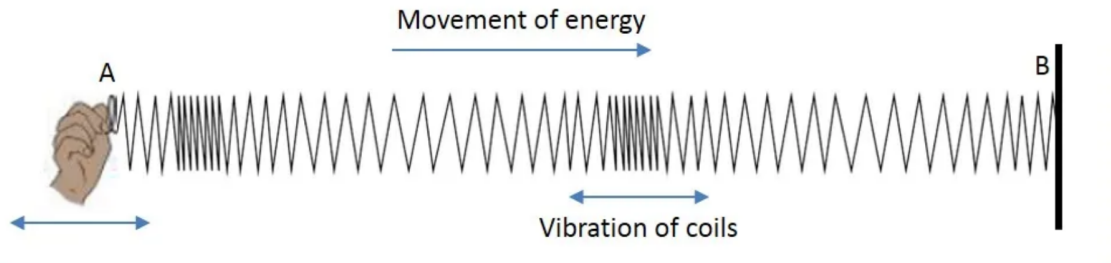


Figure 13: Longitudinal wave[52]

When comparing longitudinal waves to transverse waves, it becomes obvious that characteristics like material orientation and surface conditions receive particular benefits from longitudinal waves, making them particularly well-suited for materials that have grain structures or rough surfaces. Additionally, when they travel through a material, they require less energy losses compared to transverse waves, allowing them to penetrate deeper and increase their efficiency in identifying faults[53]. By employing longitudinal waves alongside transverse waves in ultrasonic testing, both types of waves contribute significantly to the inspection process, offering an in-depth examination[54]. Longitudinal waves have a huge impact on detecting faults while also providing information about the overall qualities of the material being evaluated. Their versatility across materials and adaptability to shifting conditions make them valuable tools for non-destructive testing applications[55].

### 2.3 A-scan and its application in detecting defect

Ultrasonic testing relies on the A-scan as a tool for evaluating the condition of materials, specifically in steel pipes. The A-scan provides a representation of how the amplitude of an ultrasonic wave changes as it passes through the material[56]. To conduct this test, a transducer emits a high-frequency ultrasonic wave into the steel pipe. As the wave travels through the material, it encounters variations in properties like flaws or material boundaries. These variations cause some of the wave's energy to bounce back, to the transducer, where it is recorded and shown as the A-scan on a display[57].

The graph of an A-scan plots the amplitude of the reflected wave signal against distance with distance indicating how far the ultrasonic wave has traveled within the material. This graphical representation enables inspectors to analyze and understand the structure of materials and identify any flaws or defects present[58]. The amplitude of reflected wave signals holds significance as it provides insights

into flaw size and shape, aiding crack detection, corrosion assessment, and other related issues. The figure below show the A-scan screen of USIP40:

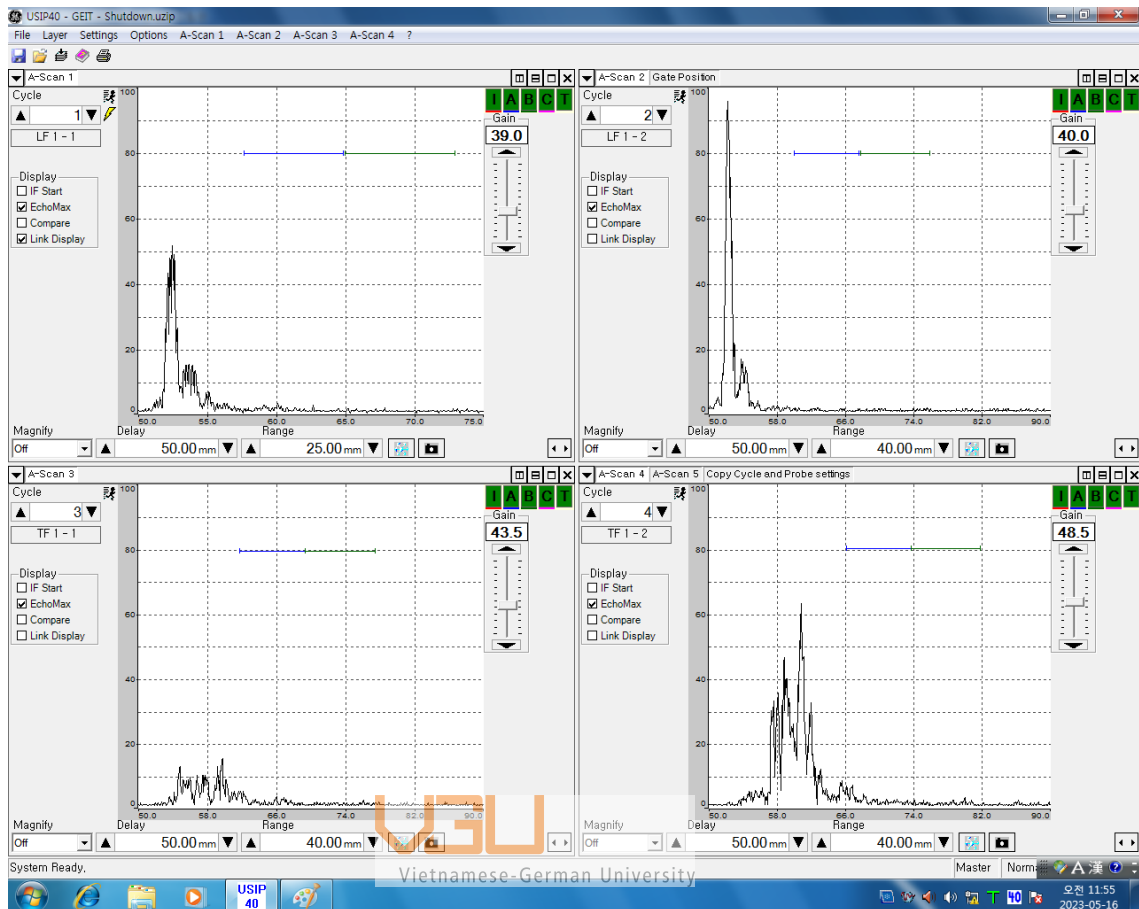


Figure 14: A-scan

Inspectors can combine A-scan analysis with other techniques, such as B-scan and C-scan imaging, to obtain a comprehensive evaluation of steel pipe integrity[59]. By studying A-scans, inspectors not only detect flaws but also determine their location accurately, assess the remaining lifespan effectively, and plan for necessary maintenance or repairs accordingly[60].


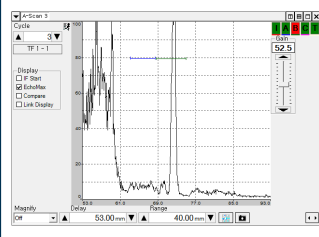

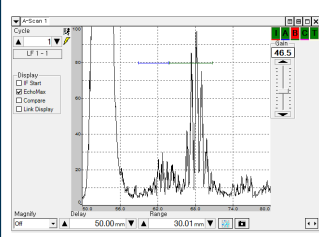
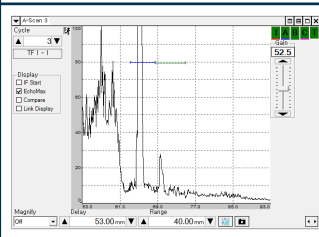
The A-scan is designed to inspect materials, like metals, plastics, and composites, without causing any damage. It's a sensitive tool because it can detect even small changes in material properties and provide highly accurate depth measurements in real-time. Engineers can optimize the A-scan settings, such as frequency, gain, and time base, to improve its accuracy and reliability[61]. In non-destructive testing, the A-scan plays a critical role by providing inspectors with essential information to ensure the safety and dependability of steel pipes and other materials used across different industries.

## 2.4 Typical defects on product

The production of steel pipes involves complex processes that affect the quality and characteristics of the final product. However, it's important to note that these processes also carry the risk of creating flaws in both the inner and outer surfaces of the pipes. Our method creates seamless pipes by piercing solid steel billets to form hollow tubes. While this method has its advantages there are instances where inadequate control over factors like temperature, pressure and material alignment can lead to thickness, dimensional inconsistencies and misalignment. As a result, flaws can develop on both inner and outer surfaces.

During the production of seamless pipes, the most common types of defects encountered are horizontal and vertical defects found on both the outer and inner surfaces. The presence of defects on the outer surface can often be attributed to mechanical interactions between the pipe and the machinery used in the production process. Vibrations or oscillations during manufacturing can cause collisions between the pipe and machinery surfaces, resulting in defects[62]. On the inner surface, defects typically occur due to interactions between the solid piecing bar and billet during the piercing process. The table below show each defect along with its corresponding A-scan result in a calibration sample:

Table 1: Calibration sample's defects

Name	Location	Probe	Image	A-scan result
Horizontal defect	Outer surface	TF		
Vertical defect	Outer surface	LF		
Horizontal defect	Inner surface	TF		

Vertical defect	Inner surface	LF		
Hole	Outer surface	TF & LF		
Welding spot		TF & LF		

The use of ultrasonic testing (UT) has significantly enhanced the detection and identification of these defects. UT, a non-destructive testing method, utilizes sound waves to penetrate through materials to identify flaws on both the inner and outer surfaces of seamless pipes[63]. One of UTs' advantages is its ability to examine components without causing any damage or affecting their attributes. Furthermore, it excels at detecting defects or variances in material properties that might not be obvious to the human eye. This level of accuracy makes sure the components' structural integrity and general reliability remain uncompromised[64].

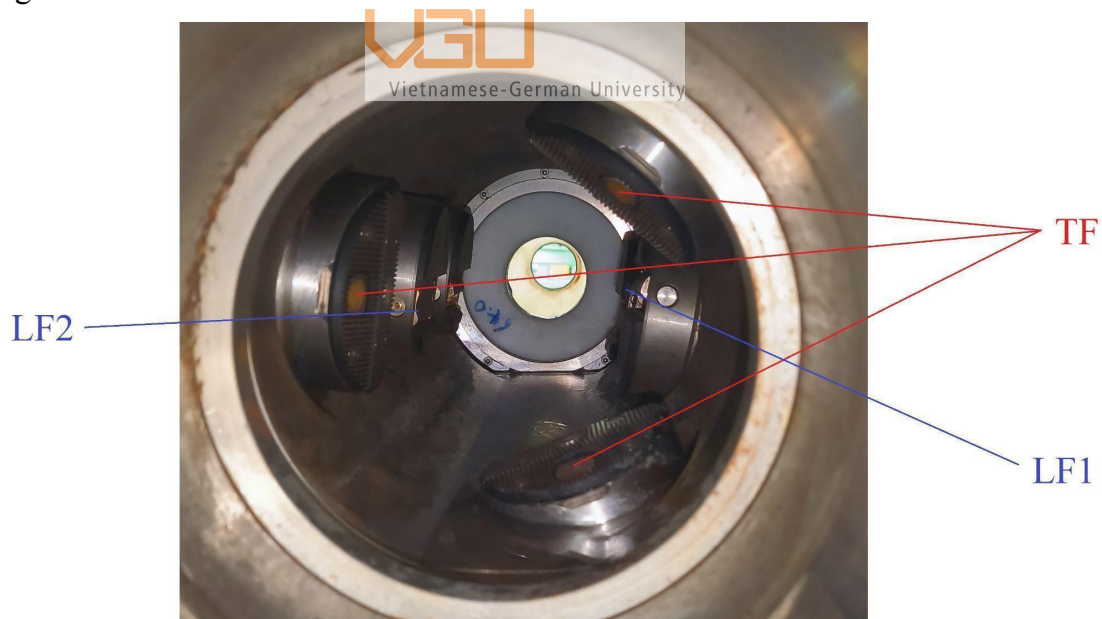
However, while there are numerous advantages to using UT, it's important to also recognize its drawbacks. One notable challenge is that UT may struggle to detect faults that run parallel to the direction of the energy beam. Additionally, it may not be as effective in identifying small defects that resemble or are smaller than the materials' grain structure. The surface conditions also play a major role; rough or contaminated surfaces can hinder the transmission and reception of ultrasonic waves thus impacting the accuracy of flaw detection[65].

To sum up, when manufacturing steel pipes, there is a possibility for various defects to occur on both inner and outer surfaces. These imperfections often arise from interactions that occur during the manufacturing processes. Ultrasonic testing has proven to be a method for identifying and describing these flaws, providing a non-destructive and precise means of inspection[66]. By acknowledging the

limitations of UT and recognizing its benefits, manufacturers can effectively utilize this technique to improve the quality control of steel pipes throughout the production process.

### ***2.5 Rotating probe station and probe installation***

The setup for ultrasonic testing includes a probe rotating station and an ultrasonic instrument that are crucial for conducting thorough inspections on steel pipes[67]. The rotating station plays a vital role by synchronously rotating all five probes at a constant speed along with the moving steel pipe, allowing for a comprehensive scan of the entire surface of the pipe. This station is divided into three circles, each containing specific probes. In the first circle, there is longitudinal probe 1 and its corresponding balancer positioned strategically to form a 180-degree angle between them. In the second circle, longitudinal probe 2 is placed next to the balancer of longitudinal probe 1 in an opposing arrangement with a 180-degree angle between them. This arrangement ensures that the two longitudinal probes are oriented in opposite directions, resulting in thorough coverage. The third circle accommodates all three transverse probes, evenly spaced at intervals of 120 degrees, ensuring balanced distribution during rotation. Probes distribution are shown in the figure below:



*Figure 15: Probe distribution in Probe rotating station*

Achieving adjustment of probe depth is made possible by utilizing a digital depth indicator. To ensure no contact between the probes and the sample during testing, both longitudinal and transverse probes are set to half the diameter of the steel pipe. This careful calculation minimizes the distance between the probes and



the sample, effectively reducing any interface echo distance in the A-scan output[68].

To maintain balance at high speeds of approximately 1000 rounds per minute (RPM), strategically positioned balancers are employed. These balancers are placed on the opposite side of each longitudinal probe to counterbalance their weight, preventing any potential operational issues caused by imbalances[69]. Although they don't directly contribute to the scanning process, their presence ensures stability and longevity for the components of the station. Similar to using balancers for balance, arranging three transverse probes in a circular formation at 120-degree intervals also helps maintain equilibrium during scanning operations. This arrangement primarily focuses on balancing and does not compromise the station's effectiveness in detecting defects throughout the scanning process[70]. A picture of our probe rotating station is shown below:



*Figure 16: Probe rotating station*

The seamless coordination between the testing instrument and the station is facilitated through a shared LAN network. The data acquired by the station is effortlessly transmitted to the instrument for analysis. The advanced algorithms used in the ultrasonic testing instrument allow for a thorough analysis of the transmitted data, providing detailed A-scans that reveal important information about the internal characteristics of the steel pipe[71]. However, a more detailed explanation of the data analysis process on A-scans assist in defect detection will be discussed in later sections of this thesis. The ultrasonic testing instrument efficiently identifies defects within machinery by leveraging its capabilities. It automatically determines defect locations based on the data collected during the testing procedure[72].

## ***2.6 Gate setting for inner and outer defect***

The gate setting plays an essential role in ultrasonic testing by helping to detect defects on both inner and outer surfaces, allowing the instrument to analyze reflected waves and identify vertical defects[73]. The gate plugin is very important in the A-scan output, which shows the amplitude and location of reflected waves. It lets us adjust parameters like the length and amplitude threshold of the gate to identify defects systematically. When a reflected wave exceeds the predetermined amplitude threshold within the gate, an alarm is triggered, indicating the presence of defects at that location. This gate-based approach makes defect detection efficient by automatically flagging potential issues in real time during the non-destructive testing process[74].

### **2.6.1 Longitudinal Flaws Probes**

In ultrasonic testing, particularly in longitudinal sound waves, the gate setting plays a crucial role in detecting flaws in test samples. As explained earlier, the longitudinal flaws probe is positioned at a 45-degree angle to the sample, allowing sound waves to pass through it. The path these sound waves take inside the sample is dynamic. Any defects they encounter cause reflected waves to be generated, which are then captured by the transducer and displayed on the A scan[75].

While the A-scan provides information about the wavelength of the sound wave, further analysis is needed to determine whether defects are located on the inner or outer surface of the sample. To differentiate between these two possibilities an important step involves calculating how far the sound wave has traveled within the sample. This calculation serves as a factor in configuring the gate setting. By determining this travel distance, we can judiciously set parameters for the both length and positioning of the gate. This strategic setup ensures that all reflected sound waves related to both inner and outer defects are effectively captured, enhancing our ability to detect flaws with precision and reliability. The figure below shows ultrasonic wave, which is generated by longitudinal flaws (LF) probes, interact with defects inside the testing sample:

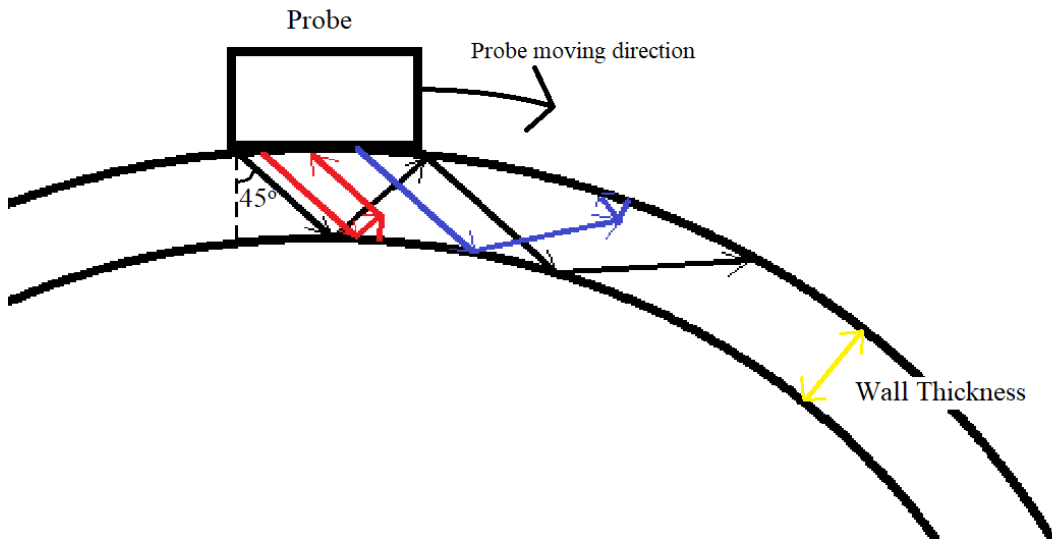


Figure 17: Ultrasonic wave traveling path of LF probes

The distance sound waves, which generated by LF probes, have to travel to hit the inner surface is calculated as follow:

$$x = \pm \sqrt{r^2 - (R \sin 45^\circ)^2} + R \cos 45^\circ$$

Where:

$x$ : The distance sound wave traveled in the tested sample (mm)

$r$ : Inner diameter of the sample (mm)

$R$ : Outer diameter of the sample (mm)

In order to calculate the distance sound wave generated by LF probes traveling in the tested sample, we can utilize the Law of Cosine. We have:

$$r^2 = x^2 + R^2 - 2xR \cos(45^\circ)$$

$$r^2 = x^2 - 2xR \cos(45^\circ) + R^2 [\sin^2(45^\circ) + \cos^2(45^\circ)]$$

$$r^2 = x^2 - 2xR \cos(45^\circ) + R^2 \cos^2(45^\circ) + R^2 \sin^2(45^\circ)$$

$$r^2 = [x - R \cos(45^\circ)]^2 + R^2 \sin^2(45^\circ)$$

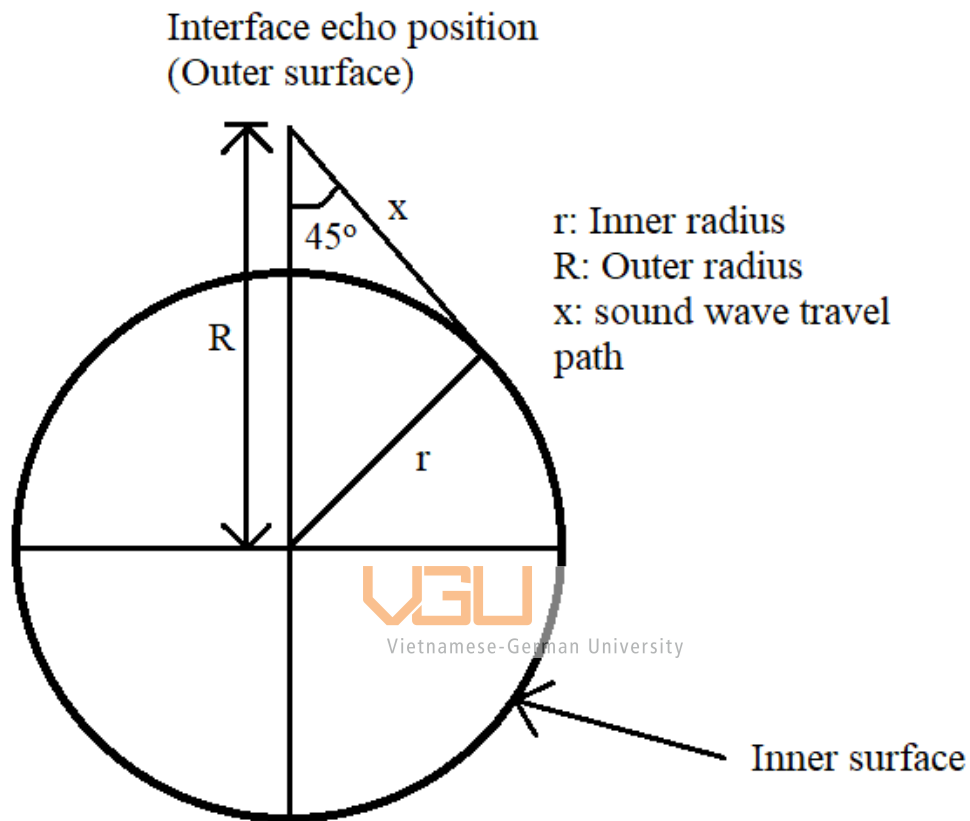
$$[x - R \cos(45^\circ)]^2 = r^2 - R^2 \sin^2(45^\circ)$$

$$[x - R \cos(45^\circ)] = \pm \sqrt{r^2 - R^2 \sin^2(45^\circ)}$$

$$x = \pm \sqrt{r^2 - R^2 \sin^2(45^\circ)} + R \cos(45^\circ)$$



The following photos illustrate the propagation path of ultrasonic waves within the tube in normal circumstances (refer to Figure 18) and after hitting a defect on the inner surface (see Figure 19). The variable 'x' indicates the length of the sound wave's travel path within the test specimen, originating from its outer surface (depicted as the interface echo in the A-scan). By discovering this distance, we may establish the size of the defect gate, ensuring the exact identification of flaws on either the inner or outer surface.



*Figure 18: Sound path at normal condition*

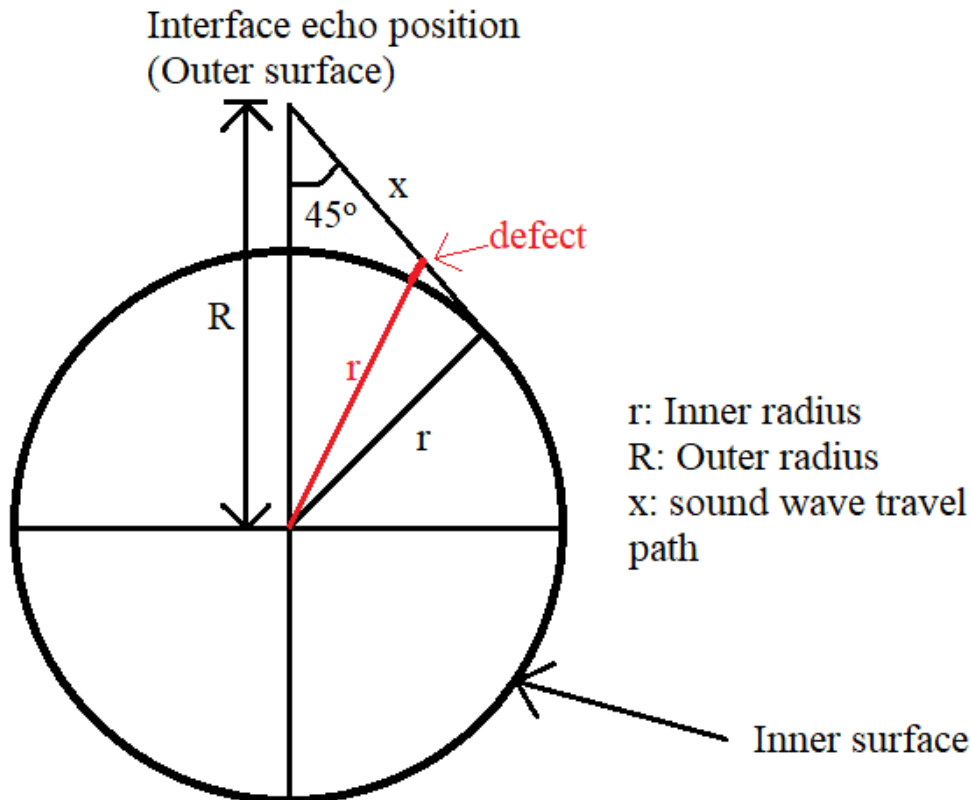


Figure 19: Sound path when hit the inner defect

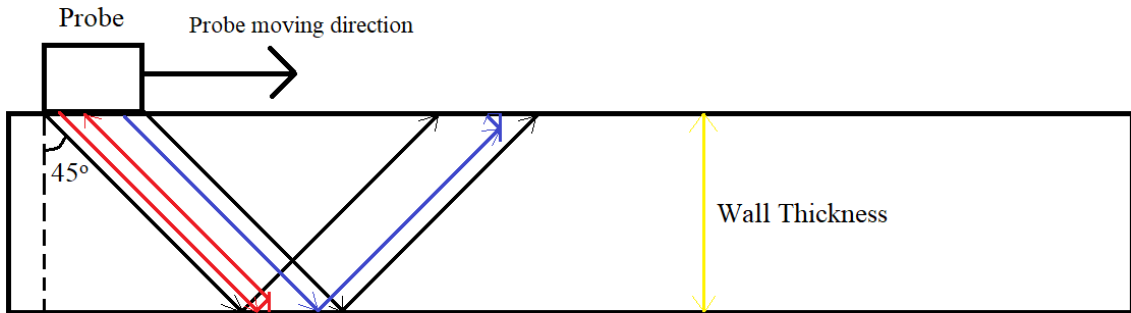


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Essentially, the gate setting takes on a deliberate path when it comes to sound waves. It aligns the characteristics of how the sound waves travel with careful calculations and parameter adjustments. This comprehensive approach results in an optimized method for revealing and classifying flaws based on their location within the test sample and enhances the efficiency of non-destructive testing methods.

### 2.6.2 Transverse Flaws Probes

In the field of ultrasonic testing when it comes to examining transverse sound waves, the way the transverse probe is positioned and installed is extremely important. The probe needs to be placed at a 45-degree angle in relation to the sample being tested. This specific angle helps transmit waves through the material being examined. As these waves pass through the sample any defects can be detected by analyzing how the reflected waves behave, which are then shown on an A-scan display[76]. However it's worth noting that the A-scan only tells us about the wavelength of the sound wave. To determine whether a defect is, on the outside surface of the material we need to calculate how far the sound wave has traveled within it. Once this calculation is done, adjusting a setting called "Gate" becomes crucial. The figure below describe how Transverse Flaws (TF) probes move and generate ultrasonic waves to examine the tube:



*Figure 20: Ultrasonic wave traveling path of TF probes*

The distance sound waves, which generated by TF probes, have to travel to hit the inner surface is calculated as follow:

$$x = \frac{a}{\sin(45)} = \sqrt{2}a$$

Where:

- x: The distance sound wave traveled in the tested sample (mm)
- a: Wall thickness of the tested sample (mm)



Determining the presence of defects in sound wave testing is heavily influenced by the gate setting. By calculating how far the sound wave has traveled into the material, intelligent adjustments can be made to the gate parameters. These parameters include both the length of the Gate and its amplitude threshold. The length of the Gate is strategically modified to cover the entirety of any reflected sound wave associated with external defects[77]. When a reflected wave's amplitude exceeds a set threshold within this gate an alarm is triggered by the ultrasonic instrument, precisely indicating where the defect is located. This approach improves non-destructive testing by utilizing the intricate characteristics of interactions between transverse sound waves enhancing accuracy and efficiency.

## Chapter 3: Methodology

### *3.1 Previous gate setting method lead to fault defect detection*

In the field of non-destructive testing, especially in ultrasonic testing, the calibration process is extremely important as it helps establish an effective method for setting gates. Similar to the testing process, calibration requires using a sample that contains intentionally created defects marked for reference. During calibration, the ultrasonic testing (UT) machine scans this sample, detecting these defects and generating an A-scan that captures all the characteristics of the entire sample. By utilizing the known attributes of these defects, the calibration process can effectively fine-tune the UT instrument[78].

The old gate setting method relies on analyzing reflected echoes from the calibration sample. Reflected echoes directly indicate any defects found during the testing process. The process involves manually moving the calibration sample to align its defects with the path of the transducer. By identifying positions on the A-scan, where reflected echoes have highest amplitudes, this systematic approach configures inner gate settings during the calibration (Figure 21). This methodology eliminates calculations and provides an intuitive approach based on practical observations.



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This methodology stands out because it can distinguish between defects, inside and outside based on the known properties of the calibration sample. By utilizing the known defect characteristics, the UT instrument adjusts the gate parameters accordingly ensuring that the gates effectively capture the reflected echoes related to types of defects. This targeted approach is important for achieving defect discrimination and enhancing the accuracy of detection by the instrument.

However, it is important to consider this approach of using fixed gate settings. While convenient, this method still has its limitations. The fixed gates, determined through calibration, may unintentionally overlook defects that fall between gate intervals. The curvature of real-world specimens also introduces complexities that are not encountered in calibration samples, resulting in variations in the distance between the transducer and the outer surface. This can confuse the UT instrument by identifying interface echoes as defects when fixed gate settings fail to adapt to changes in distance caused by curvature.

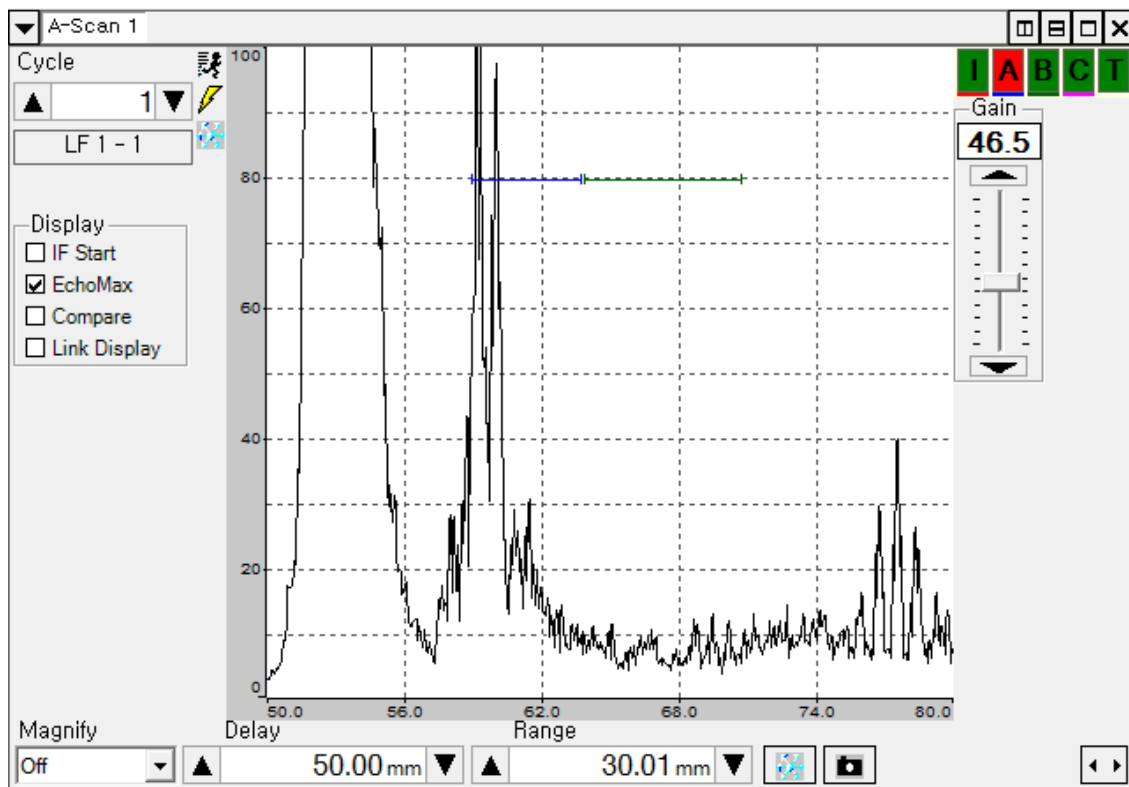


Figure 21: A-scan of inner vertical defect detected by LF

One notable drawback arises when applying this method to products of different sizes. Each size requires recalibration and adjustment of gate settings, which involves time-consuming and procedures. Despite these limitations, information about gate settings serves as a foundation for localizing defects and determining their magnitude. When the echo bouncing back exceeds the specified gate values, the UT instrument intelligently activates alarms revealing where defects are located and how severe they are. This highlights the role of setting gates for effective non-destructive testing procedures.

### 3.2 Introduction to IF START function

Ultrasonic testing is a method used in various industries to assess the strength of materials and identify any internal flaws. When it comes to non-destructive testing, it is crucial to achieve precise defect identification and accurate localization[79]. However, one of the challenges in ultrasonic testing is dealing with the variability in the position of the interface echo especially when inspecting curved products within acceptable ranges. This variability can sometimes lead to confusion between the interface echo and the defect echo, potentially leading to fault results. To solve this challenge effectively, we have introduced a tool called the IF START function.

The main purpose of the IF START function is to anchor the interface echo at the beginning of the A-scan which acts as a reference point in testing. By adapting the defect gates based on any changes in the position of the interface echoes, this flexible approach enables accurate division between interface echoes and defect echoes, decreasing confusion and boosting the reliability of defect detection[80]. When evaluating products with various degrees of curvature during ultrasonic testing, which create changes in the position of interface echoes, implementing the IF START function becomes essential. To solve this problem, we apply the IF START function to align defect gates and adapt to any movement in interface echo location. This technique facilitates identification of interface echoes by carefully altering both outer and inner defective gates, reducing potential confusion or ambiguity[81]. The figure below shows the use of Gate I in anchoring the interface echo at the beginning of the A-scan:

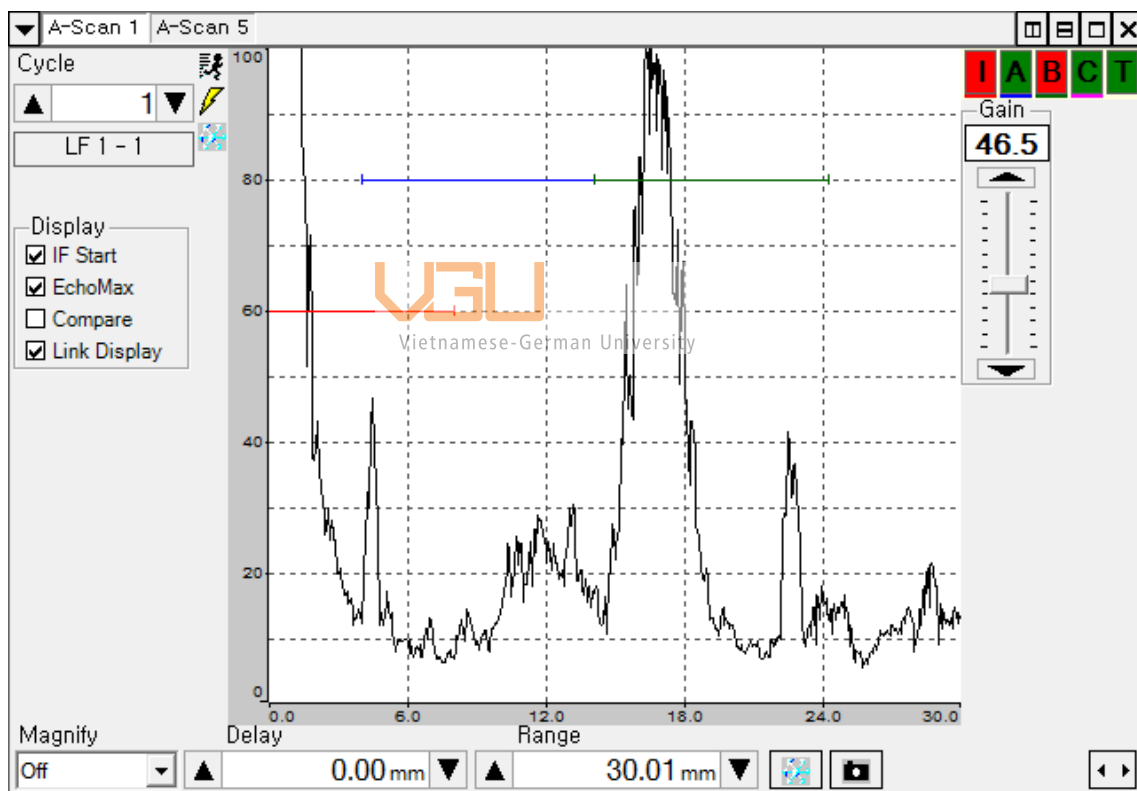


Figure 22: A-scan of outer vertical defect detected by LF

However, it's important to note that there are limitations associated with using the IF START function. One key consideration is carefully configuring the length of the "interface gate". If it's set too generously, there's a risk of including defects within this gate, leading to misclassification as interface echoes. This could potentially result in shifting of echoes, even missing defects altogether ultimately affecting inspection accuracy.

In our effort to enhance testing capabilities, exploring advanced features like IF START plays a crucial role. With this introduction in mind, we can delve deeper into understanding its principles and applications. Moreover, it explores the potential of this feature to completely transform the process of identifying defects in ultrasonic testing[82]. It also discusses how well it works with the testing devices, specifically highlighting the USIP 40 instrument as an example.

### 3.3 New gate setting method to detect defect

The core of ultrasonic testing (UT) lies in configuring the parameters for setting the gate position, which is a crucial aspect that ensures the accurate detection of defects in materials. Within UT instrumentation, the gate plugin plays a role by providing engineers with the tools to fine-tune and optimize these parameters for reliable and precise testing results[83]. The primary objective of gate setting revolves around measuring the distance sound waves travel and determining the amplitude of the reflected echo. An automatic alarm is triggered whenever a reflected echo exceeds a predefined threshold, indicating a defect at that exact position. Important parameters used for gate setting include "gate delay" "gate width" and "threshold", each playing a role in the process. The following flow-chart illustrates the gate setting process:

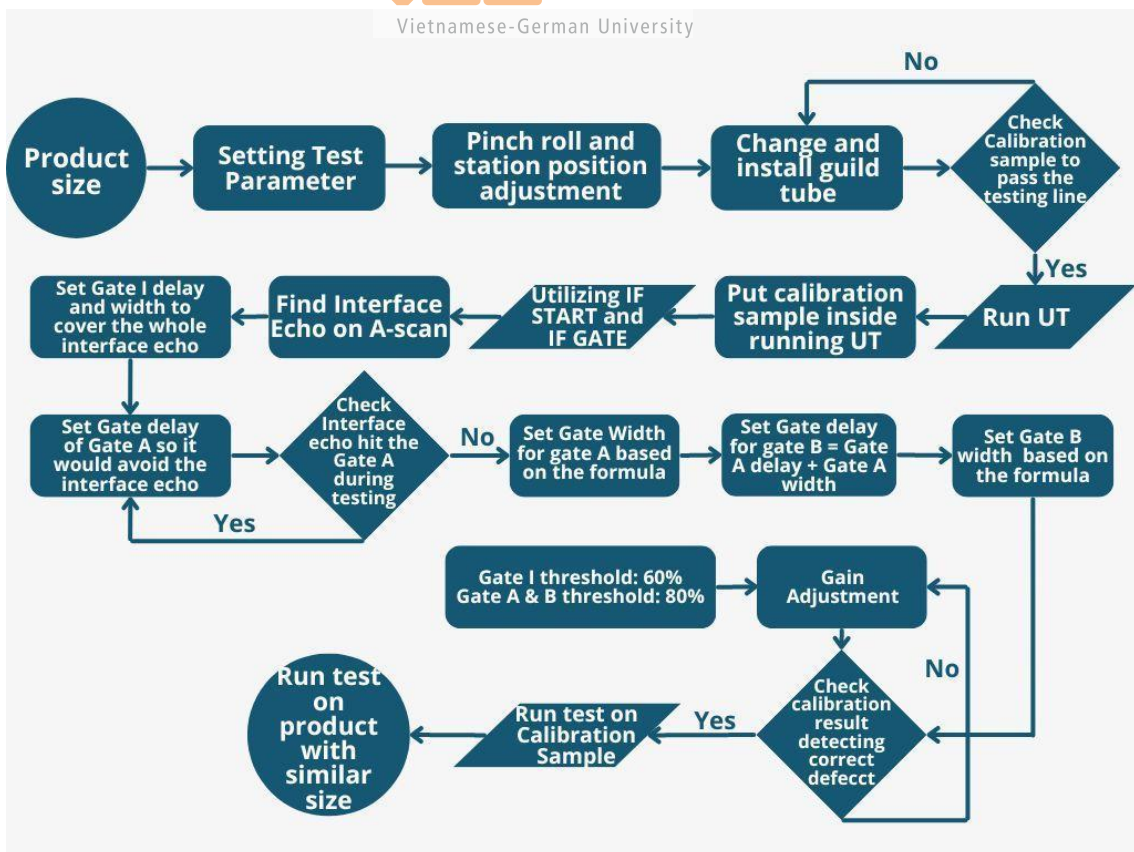


Figure 23: UT Gate setting flow-chart

Gate Delay assumes the responsibility of establishing the initial point of the gate on the A-scan, dictating when the gate begins its assessment of the sound wave's return journey. Gate Width determines how much distance on the A-scan is covered by the gate. Threshold defines at what magnitude a reflected echo is considered significant to warrant an alarm by the gate. Engineers have the ability to fine-tune these parameters in a manner that allows them to match defects with individual gates[84]. By judiciously adjusting these parameters, engineers can configure individual gates to correspond with different types of defects, customizing the sensitivity and specificity of the testing process.

When it comes to detecting defects on both outer and inner surfaces, technicians use two gates called “gate A” and “gate B”. These gates are positioned based on the understanding of how sound waves interact with defects on each surface. Gate A is set for inner surface defects while gate B is set for outer surface defects. If an echo with an amplitude above the threshold occurs within these gates, it automatically triggers an alarm on the UT instrument, allowing engineers to identify and locate defects based on their position and severity[85]. The following figure shows the default setting in the Gate Position plugin:

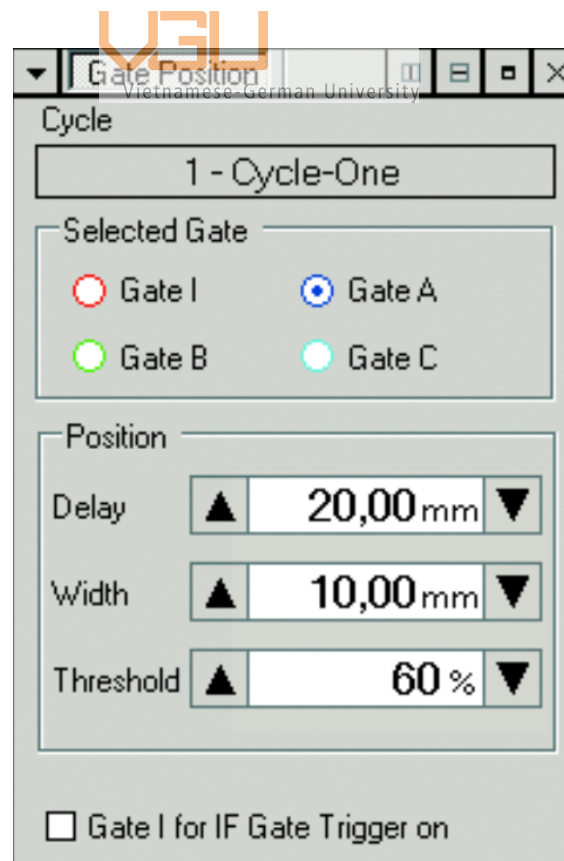


Figure 24: Gate setting parameters



The Interface Echo mode adds another element to the gate configuration. In this mode, engineers can adjust the parameters of "gate I" using the "IF gate" function. Unlike gates A and B, gate I doesn't correspond to any defects; instead, it plays an important role in detecting the interface echo and aligning it with the starting point of the A-scan waveform. By aligning the interface echo, the distance of the sound waves that have traveled within the material remains consistent in spite of any variations in the position of the interface echo[86]. This function guarantees identification and measurement of flaws while reducing the chances of misinterpretation between echoes from interfaces and echoes from defects.

Moreover, the gate settings are designed to withstand external influences, such as variations in the test samples position caused by movement or other factors. The alarm only triggers when a reflected echo surpasses the threshold at its highest amplitude, thereby insulating the testing process from the influence of sample movements. This robustness ensures that the parameters for setting the gate position remain dependable and effective in testing situations.

In special scenarios, like when measuring the thickness of rotating tubes, the use of the IF START function and gate settings is crucial. By placing gates A and B in relation to gate I, we ensure that accurate measurements are maintained despite the object's movement[87]. To put this into terms, let's consider a scenario where specific dimensions are important, such as an outer diameter of 62.22 millimeters. By creating a parameter table, engineers can carefully adjust gate delay, gate width and threshold settings to match the characteristics of the sample being inspected. This meticulous calibration process ensures that our gate settings perfectly align, with the attributes of each test sample resulting in defect detection. The result and gate parameter for LF probes are described in the following figure:

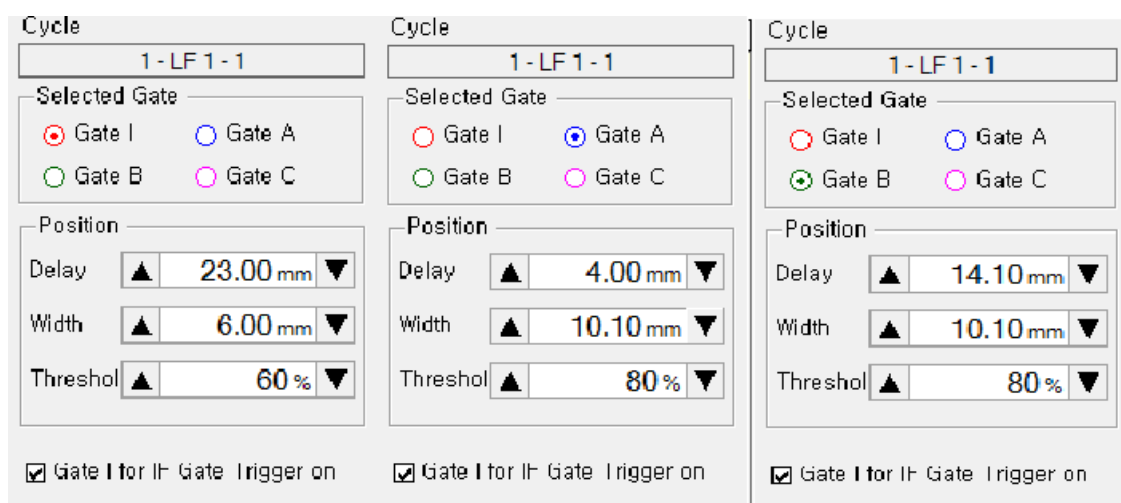


Figure 25: New gate setting parameters for LF

In summary, carefully utilizing gate position setting parameters in ultrasonic testing is a major aspect of non-destructive evaluation. Through adjustments of gate delay, gate width and threshold values, engineers can customize their testing process for detecting defects with accuracy. Moreover, the utilization of the IF START feature, in situations where tubes are being rotated and curvature may occur, demonstrates the flexibility and versatility of gate configurations. This dynamic approach along with the robustness of gate settings in varying testing conditions highlights their contribution to achieving reliable and consistent results in ultrasonic testing. In the next section, we will look into the differences between these setting methods and their result.

## Chapter 4: Results and Discussion

### 4.1 New method vs Old method comparison

As stated in the section above, in this part, we will look into the differences between two setting techniques. Both methods would be applied to one calibration sample with known parameters and purposely flaws. The precise differences in a few criteria between those methodologies would be mentioned in the table below:

Table 2: Old method and new method comparison

Criteria		Old method	New method
<b>Ultrasonic testing probe station setting</b>		Manually setting the position of the probe in the Rotating probe station.	Manually setting the position of the probe in the Rotating probe station.
<b>Calibration</b>		Needed calibration to set each gate and gain.	Needed calibration only to set gate I and gain.
<b>IF START mode</b>		Do not operate.	Active IF START mode and IF GATE trigger function.
<b>Gate setting for Gate I</b>	Delay	Do not operate.	In calibration, we have to find the range of the Interface echo, based on what is shown on the A-scan. Move set the delay value to the shortest position on the A-scan.
	Width		Due to the instability of the interface echo, the width of Gate I depends on the curvature of the product. Gate I should cover the whole Interface echo along the testing.
	Threshold		Interface echo amplitude would always be higher than the reflected echo so we only need to set the threshold of gate I at 60%.
<b>Gate setting for LF gate A (detecting inner</b>	Delay	On the calibration sample, there are already intentional defects on specific locations. Based on	Based on the Interface echo location, we will set the delay of Gate A after the interface echo location, normally, we will set about 4-5 mm depending on the

<b>surface defect)</b>		this information, we have to move the calibration sample to the position where the reflected echo reaches its maximum amplitude and set the gate that can cover the whole reflected echo. When we get the reflected echo at its maximum magnitude, combined with the information we have about which that defect is, we have to drag the corresponding gate to cover those echoes. We will keep this gate parameter constant while testing the product with the same size as the calibration sample.	interface echo.
	Width		The width of Gate A for LF is calculated in previous section with this formula: $x = -\sqrt{r^2 - (R \sin 45)^2} + R \cos 45$
	Threshold		80%
<b>Gate setting for LF gate B (detecting outer surface defect)</b>	Delay	this information, we have to move the calibration sample to the position where the reflected echo reaches its maximum amplitude and set the gate that can cover the whole reflected echo. When we get the reflected echo at its maximum magnitude, combined with the information we have about which that defect is, we have to drag the corresponding gate to cover those echoes. We will keep this gate parameter constant while testing the product with the same size as the calibration sample.	The start of gate B should be right after Gate A.
	Width		The width of Gate B for LF is the same as Gate A, calculated by this formula: $x = -\sqrt{r^2 - (R \sin 45)^2} + R \cos 45$
	Threshold		80%
<b>Gate setting for TF gate A (detecting inner surface defect)</b>	Delay	this information, we have to move the calibration sample to the position where the reflected echo reaches its maximum amplitude and set the gate that can cover the whole reflected echo. When we get the reflected echo at its maximum magnitude, combined with the information we have about which that defect is, we have to drag the corresponding gate to cover those echoes. We will keep this gate parameter constant while testing the product with the same size as the calibration sample.	Based on the Interface echo location, we will set the delay of Gate A after the interface echo location, normally, we will set about 6-8 mm depending on the interface echo.
	Width		The width of Gate A for TF is calculated in previous section with this formula: $x = \sqrt{2}a$
	Threshold		80%
<b>Gate setting for LF gate B (detecting outer surface defect)</b>	Delay	this information, we have to move the calibration sample to the position where the reflected echo reaches its maximum amplitude and set the gate that can cover the whole reflected echo. When we get the reflected echo at its maximum magnitude, combined with the information we have about which that defect is, we have to drag the corresponding gate to cover those echoes. We will keep this gate parameter constant while testing the product with the same size as the calibration sample.	The start of gate B should be right after Gate A.
	Width		The width of Gate B for TF is calculated in previous section with this formula: $x = \sqrt{2}a$
	Threshold		80%

Overall, in the table above, we have compared the differences between various strategies. The new technique gives more comprehensive settings for each gate instead of the old method dependent on the calibration sample, saving time for technicians to adjust the gate and easier to detect the interface echo.

## 4.2 Experiment setup

### 4.2.1 Calibration sample preparation



In order to receive the correct comparison between the two setting methods, we have to use the same sample with known defects. I have prepared a calibration sample with an outer diameter of 62.22mm, wall thickness of 6mm and length of 3000mm.



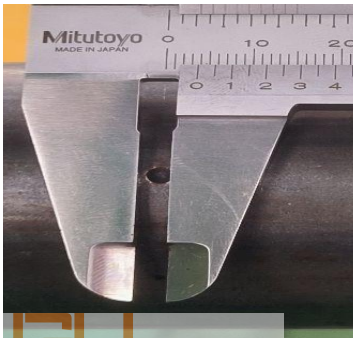

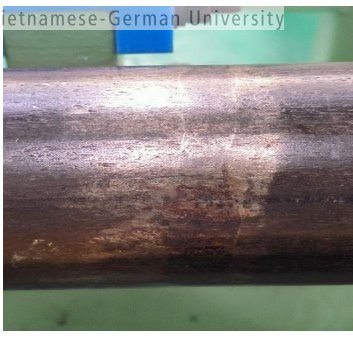

### 4.2.2 Defect on calibration sample

We already have the data about the position and type of defects on the calibration sample. By using Visual Testing (VT) and measuring by a tape ruler, I have created a table showing the image of the defect and its position (table 4). Based on the defect position, we can easily see that there is a welding spot at the middle of the calibration, two holes at the ends of the tube, one horizontal defect and one vertical defect on the outer surface. Due to the limitation of the VT technique, we can not observe the inner surface of the calibration sample; however, based on the given document about the calibration sample, we know that there are one horizontal and one vertical defects on the inner surface. If we take the welding spot as a midpoint, all horizontal defects are on one side and all vertical defects are on the other side.

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Table 4: Sample's defects and its location

Name	Location	Probe	Image	Position
Horizontal defect	Outer surface	TF		

Vertical defect	Outer surface	LF		
Horizontal defect	Inner surface	TF		After the welding spot
Vertical defect	Inner surface	LF		Before the welding spot
Hole	Outer surface	TF & LF		
Welding spot		TF & LF		

Based on the result obtained by the Visual Testing method, we can predict the final A-scan result would have highlighted the welding spot at the middle and all horizontal defects on one side of the A-scan and all vertical defects are on the other side. Overall, the Visual Inspection shows many limitations so we can only apply this NDT method in predicting the outcome of the UT result.

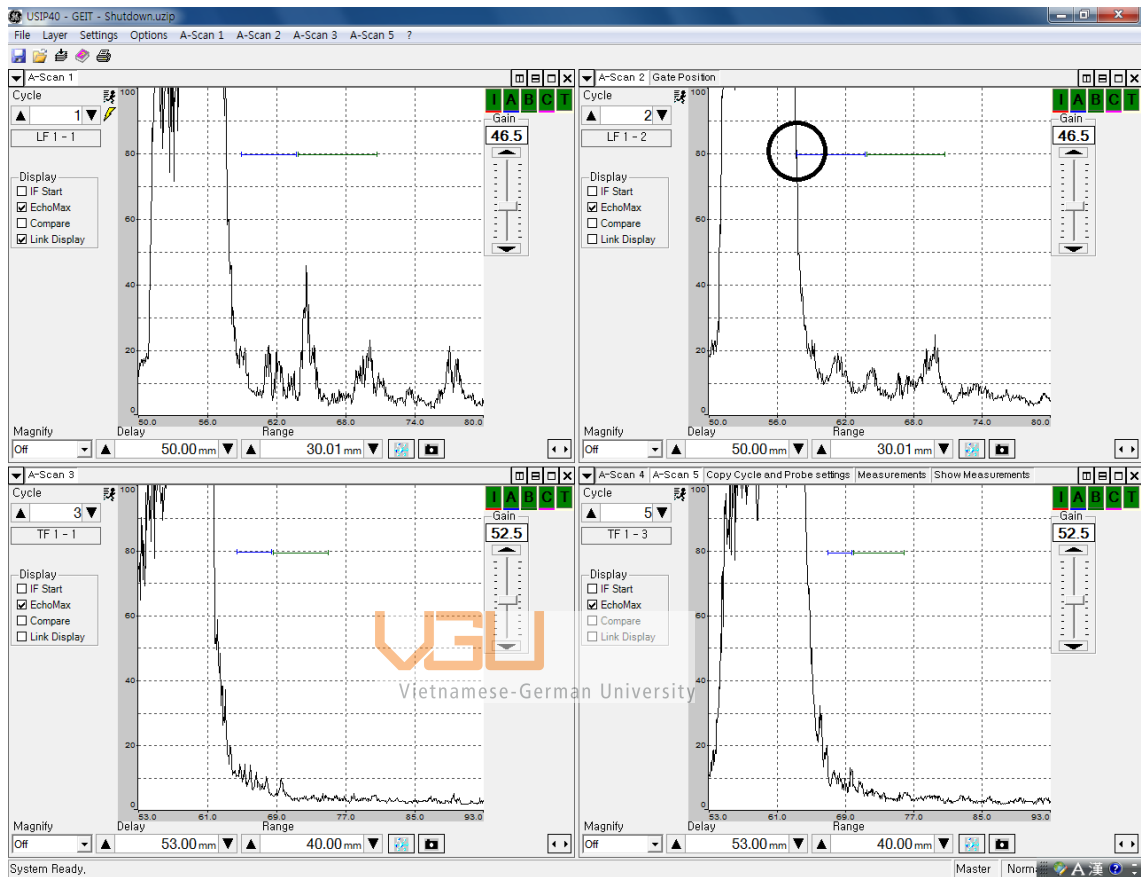
### ***4.3 Results comparison***

#### **4.3.1 A-scan setting and result of old method**

In the original method employed for establishing gate parameters, a notable level of uncertainty was noticed which in turn, brought potential inaccuracies into



our testing result. This was mainly due to the fixed positioning of the gate in the A-scan, an aspect that proved problematic for some unique testing scenarios. Specifically, situations arose where the gate's placement collided with an interface echo, creating a false alarm at that precise position, which would be shown in the figure below:



*Figure 26: Old setting method causing collaboration between interface echo and gate*

Moreover, the absence of verified data about the gates dimensions and location has raised concerns about flaws. This uncertainty also extends to distinguishing defects as either external surface irregularities, which adds another level of complexity to the testing procedure. As Figure 27 shown below, we can clearly see that the gate setting was totally based on the engineer's experience to set defect gates, which would become uncertain when defect echo happened between two defect gates. These challenges highlight the requirement for a more dependable and precise method in setting gate parameters. Such considerations are bound to improve the accuracy and effectiveness of our testing efforts.

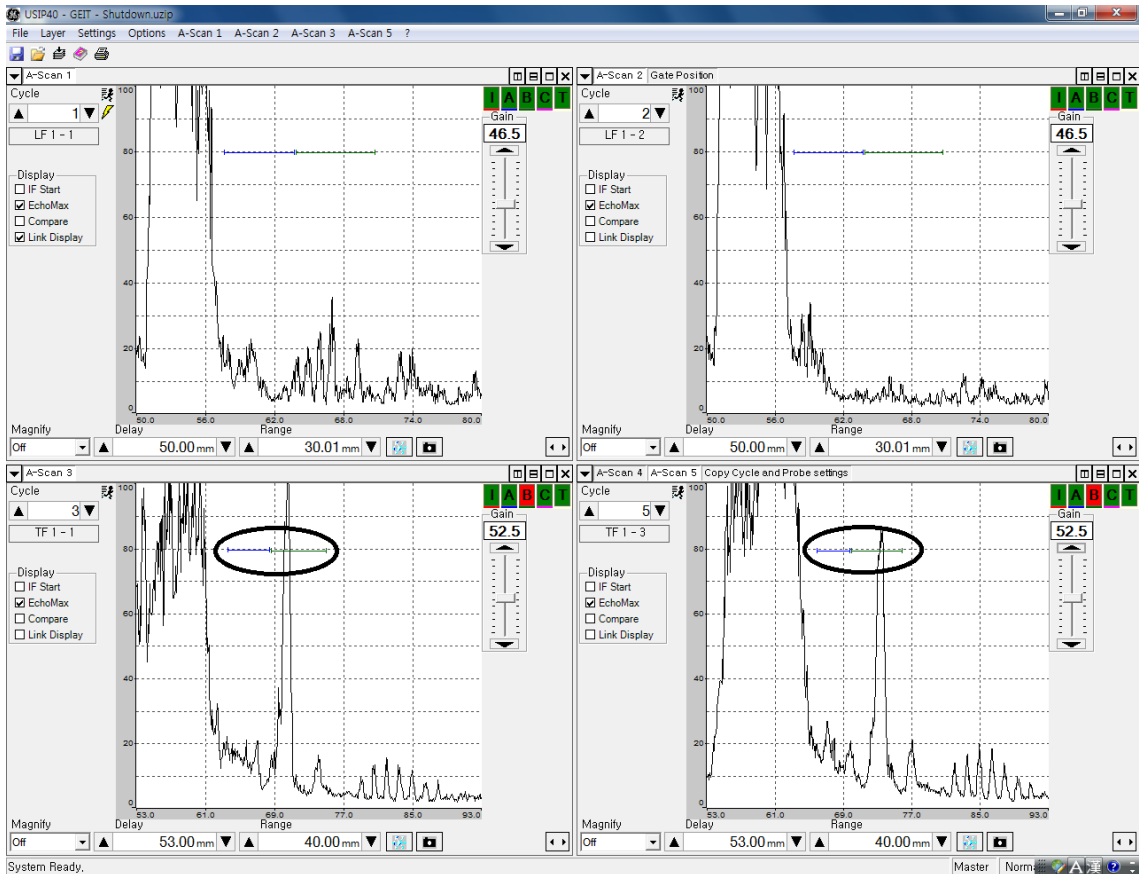


Figure 27: Old setting method causing uncertain position of the defect

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### 4.3.2 A-scan setting and result of new method

The development of an approach for setting gate parameters has led to significant improvements in our ultrasonic testing process. By making adjustments, we have successfully solved many of the challenges we faced with the previous approach. "Gate I" has played a vital part in improving our testing accuracy, allowing us to easily locate Interface echoes, guaranteeing that we pin their places and prevent fault alarms caused by interference from these echoes with the defect gates. Additionally, by calculating gate parameters for each gate, we have achieved a high level of precision in identifying flaws on both inner and exterior surfaces. This boosted precision, providing us confidence that the results represent the state of the product. The method now excels at recognizing flaws and associating them to their corresponding locations on the reflected echo profile. This development represents a step toward, achieving exceptional dependability and efficacy in our ultrasonic testing efforts.

Based on the formula we created from the previous section, we can calculate the sound wave traveling path and set the "Gate A width" to cover this area, making

sure that any defect happening on the inner surface would result as a defect echo inside the “Gate A width”. Similarly with inner defects, we would use “gate B” as the defect gate for outer surface defect, we need to set “gate B width” to cover the area that the sound wave traveled. As a result of this setting method, we can clearly see that the UT instrument has successfully detected flaws at inner and outer surfaces. The Gate setting parameter for LF probes and their A-scan result at that position where defect happened are shown in figure below:

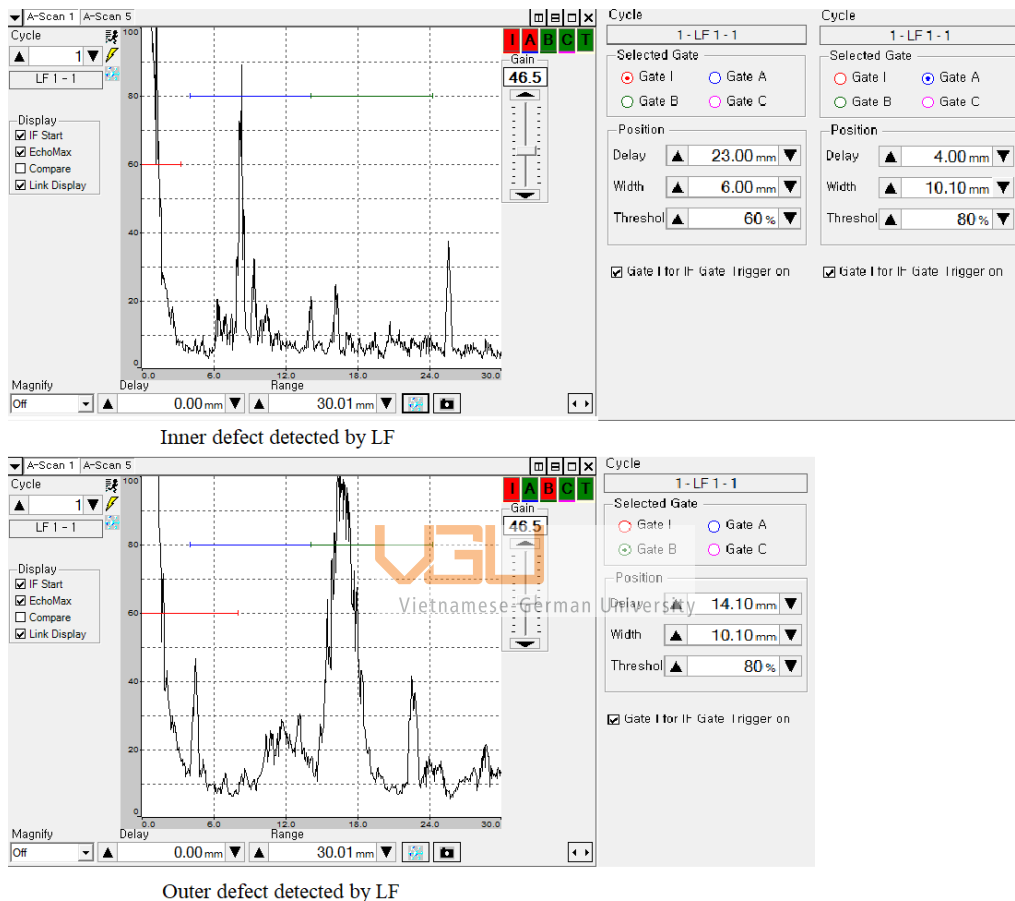


Figure 28: New gate setting parameter and its result in the A-scan for LF probes

Similar to the LF probes, in order to set TF probes, we have to continue our earlier procedure. First, we need to determine the Interface echo position on the A-scan, applying IF START and IF GATE function to set the gate I to cover them. After anchoring the interface echo to the start of the A-scan, we will use our formula, which was developed in the previous section, to calculate the ultrasonic wave moving route and set “gate A width” to cover this area. Any defects that result in a defect echo within this gate A would be considered as inner defect. Similar strategies apply to outer flaws also; by setting “gate B width”, we can cover the area where an outer flaw can result in a defect echo within this gate. The detailed gate

configuration parameter and the outcome of inner and outer flaws on A-scan is presented in the image below:

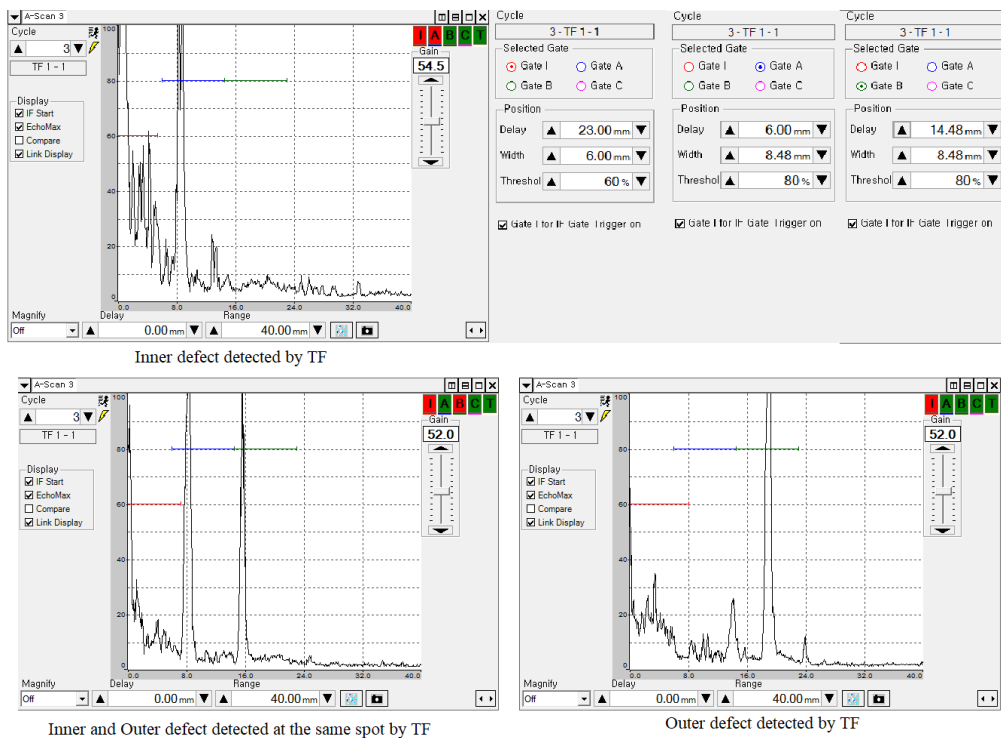


Figure 29: New gate setting parameter and its result in the A-scan for TF probes

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### 4.3.3 Final A-scan result comparison

The comparative analysis between the new and old gate parameter setting methods reveals some remarkable improvements in the accuracy and reliability of our ultrasonic testing process. Employing the exact same calibration sample with purposefully created defects, the previous arrangement approach revealed considerable shortcomings. It repeatedly exhibited false alarms in the final results, mostly due to the interference of interface echoes with the defect gate. This interference led to incorrect defect detection at many sites, weakening the dependability of the testing outcomes. The final A-scan result of the old setting method is shown below:

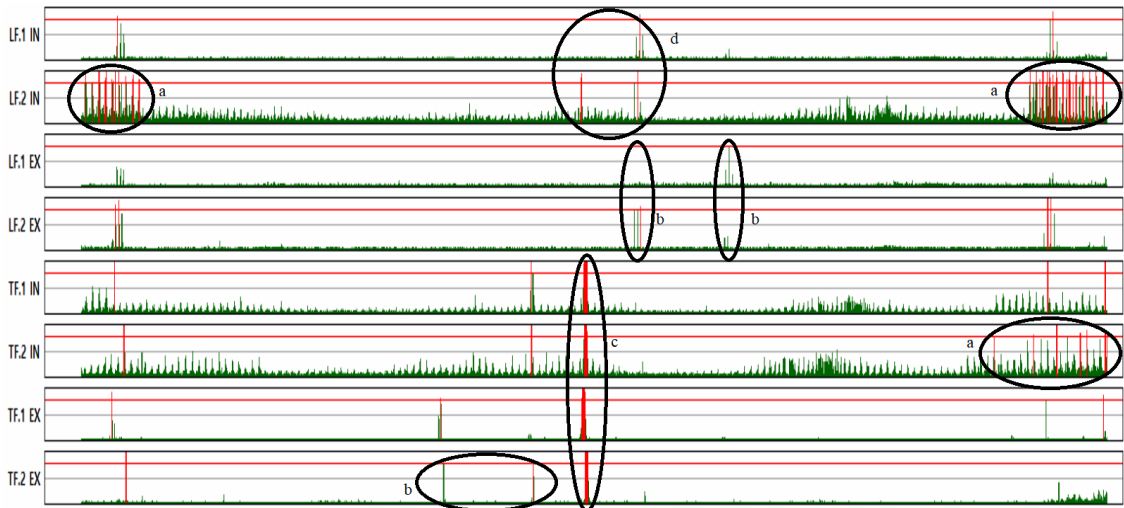


Figure 30: Old method final result, (a): Interface echo hit the gate, (b): Unconfirmed defect, (c): Welding spot, (d): Uncertain defect

In contrast, the newly developed setup procedure has shown extremely promising outcomes. It reliably recognizes the flaw type and precisely locates their location, giving a dramatic contrast to the previous method's shortcomings. Most significantly, the new approach effectively removes the interference of interface echoes, ensuring that there is basically no confusion between interface echoes and defect echoes in the final A-scan results. A significant advancement improves and enhances the accuracy and dependability provided by the new gate parameter setup of our ultrasonic testing system. The final A-scan result of the new setting method is shown below:

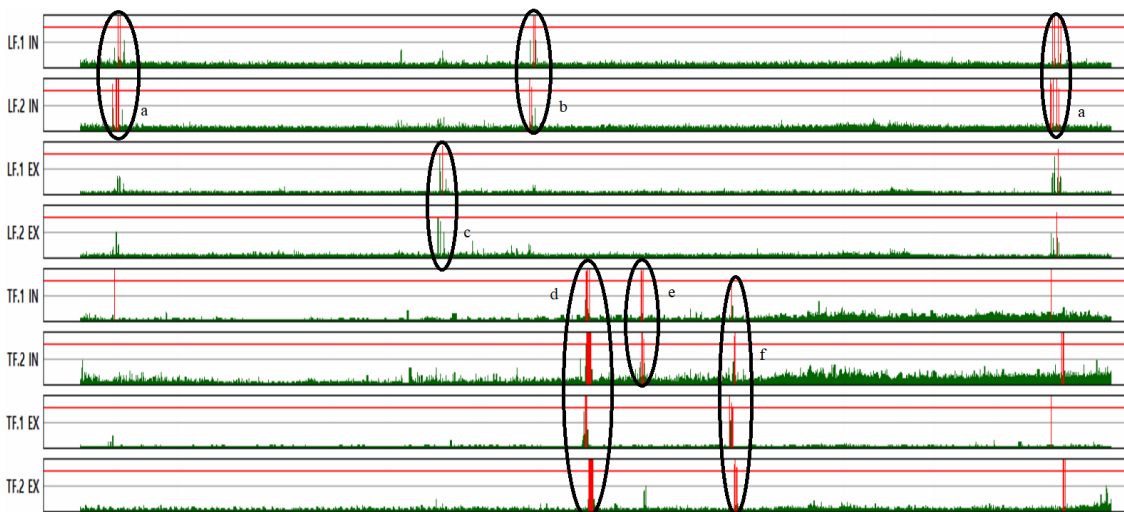


Figure 31: New method final result, (a): Holes, (b): Outer vertical defect, (c): Inner vertical defect, (d): Welding spot, (e): Inner horizontal defect, (f): Inner and outer horizontal defects at the same position

#### ***4.4 Effectiveness of new method***

In this section, we will look into the effectiveness of the new gate setting technique, comparing it to the original methodology and showing the advantages it provides to ultrasonic testing. A major step forward in defect detection and testing efficiency and accuracy are provided by the new technology.

The new method for configuring gates has significant advantages compared to the previous way. Its ability to precisely locate the interface echo at the beginning of the A-scan and automatically adjusts other defective gates based on its location is one of the key advantages. This crucial innovation avoids any chances of interface echo conflicts with flawed gates, which used to be an important issue in the previous technique[88]. Additionally, a formula has been created to determine the length of each defective gate, improving the whole process simpler and lowering gate setup time for each A-scan.

To assess the effectiveness of the new method, comparative studies were conducted involving the examination of calibration samples with intentional defects. These calibration defects provided a means of validating the results obtained using the new method. Knowing the type and location of these defects allowed us to verify the accuracy of our testing outcomes.

One of the typical advantages of the new gate-setting technology is its remarkable adaptability. Given that varied product sizes unavoidably create curvature, resulting in varying interface echo positions, this technique excels at handling this difficulty. By pinning the interface echo to the A-scan's outset and automatically changing other defect gates correspondingly, it enables consistent defect identification across product variances. Moreover, the technique developed for computing gate lengths based on product size characteristics strengthens this adaptability. The figure below (Figure 32) shows the improvement in the A-scan result, we can clearly see that interface echo has successfully pinned to the beginning of the A-scan and based on our formular, we can conclude that our gate setting would consider the defect is on the outer surface.



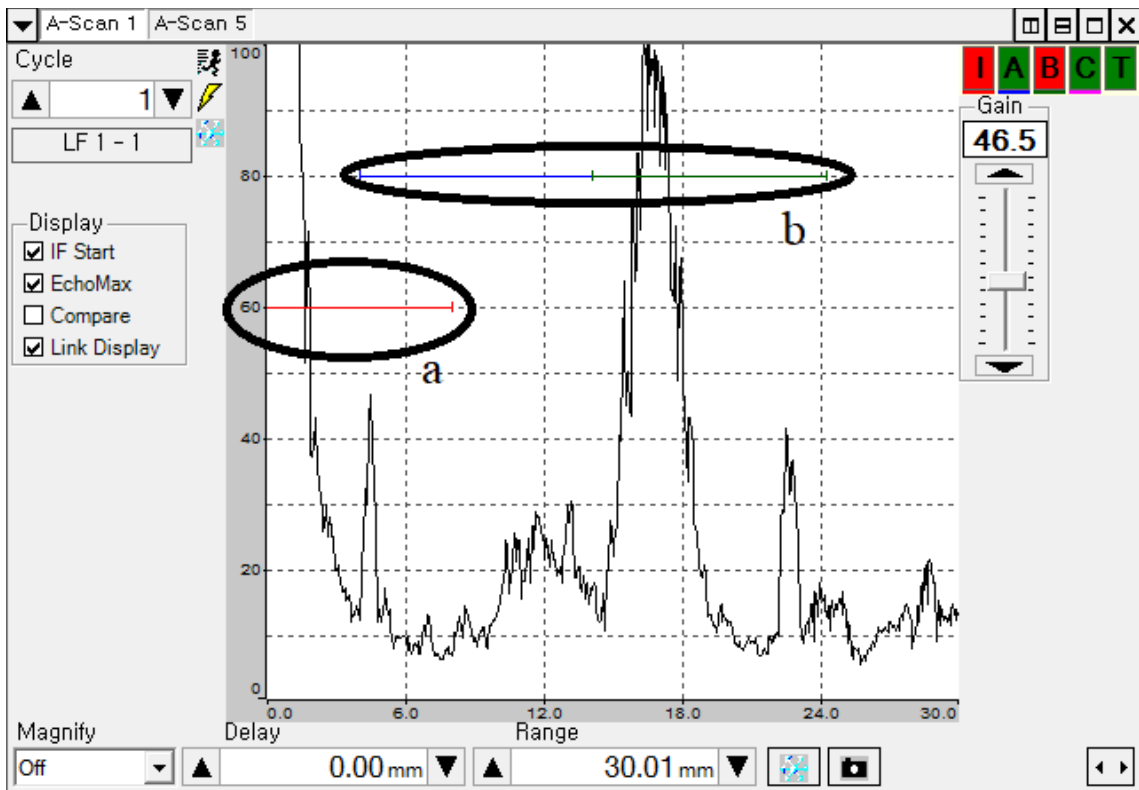


Figure 32: New method setting on an A-scan (a) New method anchor the interface echo to the beginning of A-scan, (b) Defect gate setting based on formula



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In conclusion, the novel gate setting method makes a major leap in the efficiency and accuracy of ultrasonic testing. It avoids interface echo collisions, streamlines gate configuration processes, and promotes flexibility across various product sizes. Comparative studies verify its efficacy, and while some obstacles persist, it represents a potential route for further study and practical implementation, ultimately offering dependable and exact results in non-destructive testing.

## Chapter 5: Future development

In the field of future developments, several critical areas have been identified to enhance the efficacy of ultrasonic testing. Firstly, there exists a substantial opportunity for refinement in the logic guiding each gate within the UT instrument. Presently, the Gate I option exclusively offers the "flank" mode, which identifies the first rising echo and anchors it to the beginning of the A-scan[89]. However, this approach leaves a portion of the interface echo still visible on the A-scan. Future endeavors will be centered on fine-tuning the logic of each gate, trying to obtain a more comprehensive and accurate representation of echoes, thereby significantly increasing defect detection capabilities[90].

Moreover, the fixed nature of threshold parameters provides an interesting route for investigation. It has been demonstrated that the defect gate threshold remains at a constant value of 80%. Consequently, calibration using a known standard is important prior to product testing. This calibration procedure involves purposefully creating defects at specified depths in the sample. By carefully setting the probe's gain during calibration, we can assure that any faults on the product exceeding the specified depth will be consistently recognized during testing, hence enhancing the dependability of our defect identification procedure[91].

While the threshold remains a fixed parameter, its crucial role in defining the target amplitude for defect echoes needs a more complex understanding. Presently, there is no defined procedure for computing this threshold value. However, leveraging the data acquired from the calibration sample, which includes the type, position, and depth of flaws, we may strategically adjust the gate thresholds. This strategic approach ensures that defects on the product exhibiting similar depths to those on the calibration sample will be accurately identified by the ultrasonic testing apparatus.

In summation, the path forward in ultrasonic testing lies in developments in gate logic and a nuanced approach to threshold calibration. By optimizing the logic of each gate, we intend to achieve greater accuracy in echo representation and boost defect detection capabilities[92]. The constant nature of threshold parameters needs a comprehensive calibration process where known standard defects contribute to the setting of gate thresholds. This strategic calibration ensures the reliable detection of defects on the product that match those on the calibration sample, thus increasing the precision and reliability of our ultrasonic testing process.

## Chapter 6: Conclusion

In conclusion, this bachelor thesis has studied the challenges of applying ultrasonic testing to discover surface defects on curved seamless steel pipes. The existing fixed gate placement method poses limitations, typically leading to incorrect outcomes due to changes in transducer-to-surface distance caused by pipe curvature. To address this issue, I proposed integrating the IF START function to automatically modify the defect detecting gate based on the interface gate position.

Through a thorough literature analysis, I analyzed the basics of ultrasonic testing and investigated techniques such as A-scans that are beneficial for defect detection and characterization. My experiments with calibration samples with intentional flaws proved the efficiency of the new IF START function - based gate setting method compared to the traditional fixed gate approach. Formulas have been developed to deterministically calculate the gate lengths and positions for pipes of varying sizes and curvatures.

The results reveal that the new method correctly identifies defect types and precisely locates them without interference from interface echoes. This marks a major improvement over inconsistencies in defect identification seen with the former technique. The IF START function excels at adjusting to variable interface echo positions created by pipe curvature changes. It reduces the gate setup process and provides testing versatility across diverse product sizes.

In future, the gate setting formulas could be further refined through additional tests. The technique's performance should also be assessed on full-scale industrial pipe tests under varied situations. Opportunities also exist to automate the gate parameter computation and selection process. Overall, this research adds useful insights for enhancing ultrasonic testing accuracy, especially essential applications like automobile bearing, where errors might have devastating implications. The proposed IF START-based method has promise for boosting defect detection reliability and pipeline integrity evaluation.

In conclusion, through rigorous experimentation and quantitative analysis, this bachelor thesis has expanded understanding of effective gate setup methods for curved seamless steel pipes. The new technique seeks to aid non-destructive testing professionals and quality control personnel in seamless steel pipe manufacturing companies.

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