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INSPECTION BY ULTRASONIC TOMOGRAPHY (UT) LEADING TREND IN WELDING JOINT MONITORING

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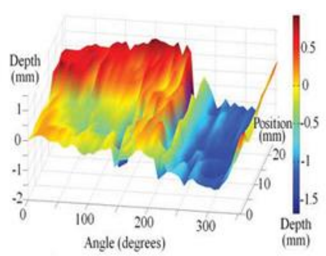
Graphical abstract



Abstract

Welding work is a connection process between the structure and the materials. This process is used in the construction, maintenance and repair especially mechanical engineering. This study discusses the type of welding used in the industry, mainly involving the pipeline welds. On-demand need to every work process when finishing weld requires quality tests to ensure compliance to the standards required. Monitoring through the display image has long been used in Non-Destructive Testing (NDT). Various methods of monitoring used in NDT focused on Ultrasonic Tomography (UT) as a method used in NDT and as an option for the future. Previous imaging result was in two-dimensional (2D) and then upgraded to a three-dimensional image (3D). Besides, there is potential of 3D imaging beyond the existing limits in terms of size, material thickness, especially for welding steel pipes. Achievement through research of existing pipe size so far outside diameter of 200 mm and a thickness of 5.8 mm should be limited in view of the obstacles to enhanced image resolution is less effective when compared to other tomography methods.

Keywords: Welding joint, non destructive testing by ultrasonic tomography and 3D imaging

1.0 INTRODUCTION

Welding activities play an important role today, especially in the construction phase of a public building, petrochemical, marine and construction involving the oil and gas industry, whether it is a new construction, renovation, conversion or even repair during operation. To improve the quality of welding includes improving the structure and process of welding defects such as monitoring, inspection for verification on a construction site.

In addition, the use of tools and techniques to ensure productivity and quality more effectively. The lack of attention to the inspection of welding quality problems that could potentially arise in the issues of quality to required specifications. Welding is a method of joining [1] which is used in metal welding and work piece [2].

This method is also used for plastic industry [3] called ultrasonic welding. In addition, the welding process involves the insertion of the groove using a metal or thermoplastic [4]. It is regarded as binding between the structures and the metal is melted to bind with other substances. The difference between soldering [5] compared to welding process is soldering material melts to form a connection and non-connection to the structure.

2.0 WELDING AND ITS CLASSIFICATION

Welding involves various methods, for example welding joints refer to two or more structures that are linked with joint structures or materials, preparation of position welding including welding point, a combination of zone and thermal stress zone. Welding zone experiences a more rapid cooling after welding before the solidification process [2]

Preparation of a welding used a welding pool of small size so that it can be quickly cooled, control the chemical composition of the welding material composed of carbon, sulphur, phosphorus is relatively low in reaction to adjust the chemical composition of alloying, while welding materials contain some alloying elements, so the performance of the weld metal needs to meet performance, especially power connections, up to the required standard [3].

The welding process consists of the use of different levels of heat. Therefore, the heat affected zone of the welded joints depends on the size and thickness of the material. In addition, different methods of welding lead to different mechanical protective effect. Thus, the degree of purity of weld metal depends on the impurities which affect the welding performance is different. Factors affecting the welding quality to ensure that all physical quantities selected as the welding current, arc voltage, welding speed, wireless energy in general, called the parameter of the welding process, should be controlled properly

There are various types of welded joints such as welding joints [6], T-joints welding, angle joints welding and joints round four welds [7]. Sometimes, there is a welded structure of some other types of connector, such as cross-connectors, termination fittings, crimping fittings, tube fittings, oblique joints, joint lock down. All are contained in the national standard GB 985-88 [8], which describe the relevant detailed rules.

Butt joints [9], [10] have several variations for preparing different needs. Two types of welding used consist of welding groove types (butt weld) where welders fill the grooves that are cut on the inside of two pieces of metal that are positioned next to each other. Fillet weld types [11] fill the space outside the metal pieces that are mounted at an angle to each other in the weld material [12]. Butt welding as shown in Figure 1, as the girth welded together, is the most common type used together in making a welded pipe system. It is the most universal method that can be used for the connection of pipes, fittings and equipment installation, flange connection, connection valves, and other purposes [13].

When the material to be welded exceeds 3/16 inch thickness, the end of the pipe, fittings and flanges must be chamfered at about 37.5°, burned in the small upright (root advance); in connection with welding Bevel practice [14], [15].

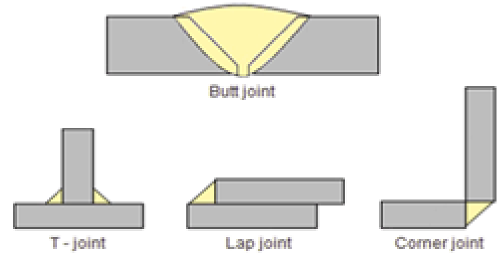


Figure 1 Example of types of welding [13]

The most widely used bevel is the "oblique Plain" [16], [17] of the wall thickness (t) 4-22, 5 mm, and "Compound oblique" for wall thickness above 22mm. This connection method from the viewpoint of mechanical joints is a type of ideal, the ability of endurance in good shape, stress concentration is small, can withstand greater load static or dynamic loads, the inclusion of this type of structure is most widely used as connectors [9], [18], [19].

T-connector welded [20] with other surfaces at a right angle or angle connectors [21] is called T-joint. T-joints as structural steel are used more frequently as a contact welding as it can withstand the power and momentum in all directions [22]. Applications requiring a higher yield can weld groove 'K' shaped [23]

Through Figure 2a, 2b and 2c, a guide to quality required for classification of welding joints for connection can be summarized [6], [24], [25].

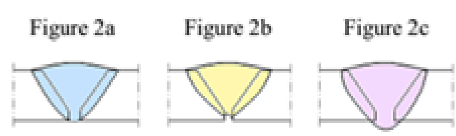


Figure 2a, 2b and 2c Summarized quality required for classification of welding joints for connection [6], [24], [25]

The use of friction welding niobium and tungsten alloys pseudo D18 has also been found [26]. Friction welding process is different from that in the case of joint niobium-tungsten [27], [28]. The stability of metal-Fe-Nbnew happens in the same zone. The use of copper [29] as a middle layer prevents intermetallic phases from forming and joints with strength of 317 MPa is produced [26]

Welding joints 6013-T4 T have successfully been designed with different welding parameters by friction welding in two modes with combination skin layer [30]. The results showed that the T-joint with no tunnel defects can only be obtained with a traverse speed of 100 mm/min in the experiment, and the welding parameters affect the characteristics and size of the defect bonds. Effect of welding parameters and configuration tools on the surface appearance, mechanical properties and microstructure are similar [31] and unlike Friction Stir Welding (FSW) joints in thin sheet, Aluminium-Aloy-5754 (AA5754) and Magnisium-Aloy-31 (AZ31) have also been introduced [32].

Two different device configurations, with and without a pin, are used. As far as friction stir welded joints in alloy AZ31 and the AA5754 is concerned, it has been shown that "pin-less" tool leads to obtaining higher values of tensile strength and elongation compared to a "pin" tool [33]. On the other hand, taking into account the dissimilar friction stir welding between AZ31 and AA5754, thin sheet welding process becomes critical as "pin-less" tool is used

Besides improving the use of development consisting of aluminium welding, FSW method has represented a better microstructure and mechanical properties of conventional methods of welding aluminium alloys [34]. In this study, FSW was used to join pieces of AA5083 aluminium alloy and commercially pure copper and the effects of process parameters, including rotation and speed welding on microstructure and mechanical properties of joints were investigated and analysed for the different joint defects [35].

The study was conducted with the rotational speed of 600, 825, 1115 and 1550 rpm, each of them with a welding speed of 15 and 32 mm / min. In the same window, friction stir welding was developed to effectively participate AA2219 [36] of aluminium alloy [37]. Based on the analysis of microstructures, window friction stir welding has been built. The strength of joints in different areas of friction stir welding window was analysed by using the features of stress, microstructure studies, and joint fracture site, which was associated with the lowest profile of the distribution force. This window will serve as a reference map to choose friction stir welding process parameters suitable for obtaining a good quality welding of aluminium alloy AA2219

Ultrasonic welding [38] is a solid-state joining process that produces joints using high-frequency vibration energy [39] in the work piece held together under pressure without melting [40]. In electronic and automotive applications, copper wire is connected to the equipment (alternator / rectifier) through the process of joining the solid state. The dominant issues facing the industry deal with the ultrasonic metal welding process [41] is of poor quality welding and weld strength due to improper selection of welding parameters [31]. The implementation of these welding parameters consisting of welding pressure, welding time and the amplitude of the vibrations were considered while generating ultrasonically welded joints using copper [42], which is 0.2 mm thick.

Another mode of application used in other studies as well is if this is a very small size, it can damage the welding. A research centre of the Institute of Materials Science and Engineering at the University of Kaiserslautern (FKK), Germany realized the innovative hybrid joints by ultrasonic welding metal [43]. In addition to ultrasonic welding of different materials such as metal to Cuprum or Aluminium for steel, new materials developed as aluminium foam sandwich or flat flexible cable can also be realized [44]. This method is used in the automotive industry. In addition, the systematic investigation of the weld ability of copper wire and a flexible flat cable has been carried out [42]. In the case of aluminium wire, joint cross-sectional area of 80 mm2 and the tensile shear load of about 3500 N were finally realized

Monitoring the implementation of the welding quality, various institutions were established to support the delivery of information, competent certification for inspectors and workers involved in welding activities. In the latest development, various methods used were either conventional techniques such as gamma radiation or the use of science classification is radiography [1]. But more emphasis on development aspects of security, which are more prone to use the previous method of x-ray radiation hazard, presents an impression to the user. Then, there is the diversity of techniques such as the list shown in Table 1 [45], which is now classified as None Destructive Testing (NDT) [46]

Table 1 List of Non Destructive Testing (NDT) [45][46]

Inspection Technique	Symbols
Visual	VT
Magnetic Particle	MT
Wet Flourescent Particle	WFMT
Liquid Penetrant	PT
Leak	LT
Eddy Current	ET
Radiography	RT
Ultrasonic	UT

The involvement of NDT inspections includes many critical areas that are ongoing to guarantee the quality meets the standards set [47]. Examples of appropriate checks carried out are shown in Table 2, which shows the use of the method by which the materials are monitored.

Table 2 Capability of the Applicable Inspection Method for Weld Type Joints [47]

	Inspection Methods						
Joint	**RT**	**UT**	**PT**	**MT**	**VT**	**ET**	**LT**
Butt	A	A	A	A	A	A	A
Corne r	O	A	A	A	A	O	A
Tee	O	O	A	A	A	O	A
Lap	O	O	A	A	A	O	A
Edge	O	O	A	A	A	O	A

Legend:

A – Applicable method

O – Marginal applicability depending on other factor such material thickness, discontinuity size, orientation and location.

3.0 ULTRASONIC INSPECTION FOR STEEL WELD MONITORING

Monitoring ultrasonic tomography is able to detect defects on the surface and subsurface of the discontinuities that have been carried out during welding work [48]. A beam of sound in the ultrasonic frequency range (> 20,000 cycles per second) moves straight through the metal, and is a reflection signal [49]. When reflecting back from disruptions in the continuity, generating a wave in the waveform was improved and processed to produce an image signal to translate its size and position information of this discontinuity on the surface of the impact [50]. In addition, the use of force transducer converts electrical signals into ultrasound waves during delivery and during the acceptance or otherwise, and to change the ultrasound waves into electrical signals that can be controlled with a computer [51].

Two different types of ultrasonic transducers were used, 1) immersion transducers, and 2) the transducer contacts. In the case of 'monostatic' known as ultrasound imaging, a single transducer is used to scan the area of interest.

In the image display UT, as examples of A-scan, as shown in Figure 3, is the most common type of exposure. It shows rave reviews along the path of sound beams for investigation. It shows the amplitude of the signal coming from the discontinuity in the function of time [52]. Axis 'X' (right) represents the time of flight and shows the depth of the discontinuity or the back wall (thickness). Meanwhile, the axis 'Y' shows the amplitude of the reflected signal as an echo and can be used to estimate the size of the discontinuity compared to the known reference reflector.

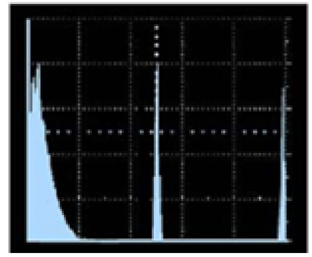


Figure 3 A-Scan [52]

The B-scan display in Figure 4 shows the cross-sectional image that is monitored by scanning probe along an axis [53]. Horizontal axis (left) in relation to the position of the investigation as it moves along the surface of the object and provides information about the location of this discontinuity side. The amplitude of the echo is usually shown in the display color or gray-scale intensity shows echoes.

Category C-scan display [54] shows a plan view of the test object reference in Figure 5. The images are produced by mechanical or electronic scanning in the 'xy' plane [49]. The 'x' and 'y' axis form a coordinate system that indicates the probe/discontinuity. Color or grayscale intensity can be used to represent the depth discontinuity or echo amplitude.

Figure 4 B-scan [53]

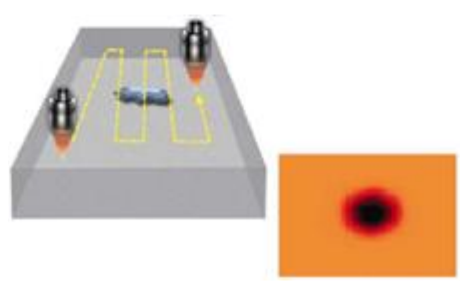


Figure 5 C-Scan [49]

The D-scan display shows the view through-thickness, which shows a cross-section perpendicular to the surface of the test object scanning and perpendicular to the beam axis projection on the scanning surface. D-scan display is the same as B-scan display unless there is oriented view perpendicular to the view of the B-scan in the plane of the plate. D-scan enables fast indication of discrimination during welding by presenting their position in depth from the surface scanning. Examples of the relationship between the four regular ultrasound displays are shown in Figure 6.

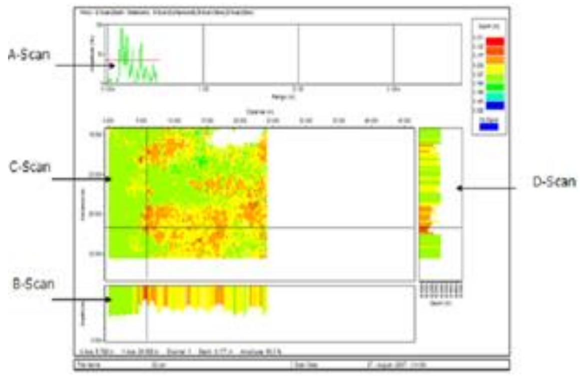


Figure 6 D-Scan [49]

Phased array ultrasonic uses the power transducer [55], which contains a variety of elements, including 8-128 elements [56], which excited the term to establish a constructive interference in the presence of ultrasonic energy waves. Interference signal is controlled by a built-in time delay element excitation and noise that can navigate through various angles. Beam angle is then plotted to create a scan of this sector [57]. The resulting ultrasonic energy in the form of pulse-echo beam and angle beam is as straight as conventional techniques.

Time of Flight Diffraction (TOFD) [58] [59] where B-scan and C-scan display is in a different format than the B & D displays scan obtained using ultrasonic is provided in the fashion pulse echo. B & D TOFD scan images provide information concerning defective walls and level the results of the diffracted signal comprises of pulse echo signal. The TOFD B & D scan displays are created by compiling A-scan display at preset intervals or go and see the collection of data in the gray scale image in which 100% of the amplitude of the sine wave in either a positive or negative direction is plotted as all black or all white with images gray signal amplitude less than 100% [60].

TOFD consist of sound energy through the welding area using a transducer sending and receiving transducers [61]. Any changes in materials, such as crack or defect is detected, it will be vibrated by the ultrasonic energy induced [62]. This sound vibration signal varies according to the scanning surface made. Set TOFD probes can be manipulated with welding or welding across to make the scan. TOFD inspection with TOFD probes by moving along the welding surface scanned.

The criteria for quality of welding joints to build a gas pipeline penetration are that there must be no space in the joints and no defects that could cause leaks. Ultrasonic inspection system using the world's first synthetic aperture method for ultrasonic welding of steel pipe for the gas line is used, and this invention involves the use of pipe size of 200mm outside diameter, and pipe wall thickness of 5.8mm [63].

Various methods such as ultrasonic TOFD is widely used, but ultrasound is the method of synthetic aperture imaging technology that can synthesize some internal thousand waveform data at high speed, image clarity is the best in the world [64] [56]. Four features of this system are, 1) the ability of imaging to see the inside of the pipe at the weld joint, 2) the ability to see the full image with the quantity of root penetration beads, 3) high-speed automated data processing and 4) a good database management. Mobile control and compared with X-ray testing methods, these methods can detect defects in welds that cannot be discovered by external visual inspection can be used in work areas with the three-dimensional and image quality with high resolution.

Comparative method adopted by the ultrasonic synthetic aperture conversional ultrasound system was found to have a weakness in the resolution at the focal point [65]; the resolution was reluctant in front of and behind the focal point. By the method of synthetic aperture, ultrasonic probe covers a wider angle [66]. In this study, the possibility of using a 16-element flexible dimensional ultrasonic transducer (FUT) [68], [69] an array of nondestructive testing at 150°C was investigated. FUT arrays were made by the sol-gel sprayed piezoelectric film technology; Lead-Zirconate-Titanate (PZT) composite film was sprayed on titanium foil 75m thick. Due to various FUT is flexible; it has served the steel pipe with an outer diameter of 89 mm and a wall thickness of 6.5mm at 150°C. Using pulse-echo mode ultrasound, measuring the thickness of the pipe can be done. In addition, by using ultrasonic pulse-echo and pitch-catch mode, each element of FUT can detect defects that have been carried out on alloy block with a thickness of 30 mm Side Drilled Hole (SDH) [70] of mm F3 at 150°C. In addition, post-processing algorithm based on the amount of attention has processed the full matrix of A-scan signals for every single transmitter and multiple receivers, and later-phase images were acquired to show various defects [69]. Both results indicate the ability of FUT various operating at 150°C to detect corrosion and defects.

4.0 THE ACHIEVEMENT OF THREE-DIMENSIONAL IMAGES ON MONITORING THE USE OF ULTRASONIC TOMOGRAPHY

Three dimension (3D) image as an enhanced level of existing two dimension (2D) which was previously described as the number of dimensions involving exposure to the axis 'X' and 'Y' and while involving 3D as an additional element to the display on the axis of 'Z' For example, Figure 7 briefly illustrates basic 3D application.

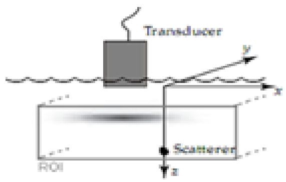


Figure 7 '3D' visualization via cross-dimension [40]

Through a review of previous studies, a wide range of applications that are used to monitor the use of ultrasonic tomography was found. The study of ultrasonic in-line inspection system on crude oil pipelines [71] as an observation of the effects of corrosion in oil pipelines in the industry BCS involves criteria welding line adjustments, modifications outside orientation and the orientation angle of rotation. In this study, 3D images are generated by the use of ultrasonic 20 channels.

The principle of using ultrasonic echo monitoring to check the erosion of pipeline wall is shown in Figure 8. Echo F1, F2 are the first and second views of the inner wall of the pipe and echoes B11 is seen from outside the walls of the pipeline. The rest of the pipeline wall thickness will be calculated according to hose F1and B11. If rust appears on the walls of pipes, hoses are converted.

However, there are difficulties in arriving at an interval of two previously because the intensity of the ultrasonic echo. This is why there is a clear mistake and the results are not obtained. This period is proportional to the thickness of the pipe wall [72]. Information frequency f wall thickness is given by the power spectrum is estimated echo and the calculated thickness d = v / f, where v stands for the speed of ultrasound transmission distances that can be calculated.

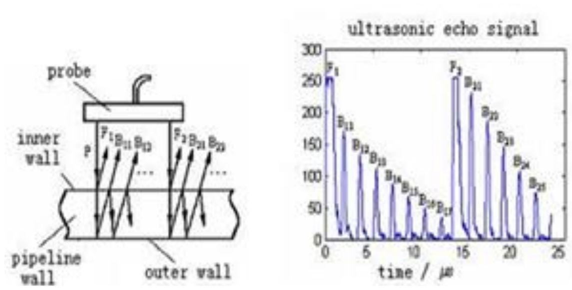


Figure 8 Principle of ultrasonic inspection in pipeline [25]

Meanwhile, a study was conducted on 3D imaging with the issue of leakage magnetic flux leakage technique (MFL) [73] used in the inspection of oil pipelines. This technique presents some limitations in detecting cracks, where internal crack on the surface of the steel pipeline was identified and measured [74]. The design of this study refers to what is commonly known today as smart PIG (Pipeline Inspection Tool). In this system, the magnetic flux loss is measured using the MFL. This is quite a sensitive technique [75] to the many defects such as dents and corrosions in the internal or external surface of the steel pipeline [76].

However, MFL technique quite often fails to detect cracks, especially if they are oriented in a particular direction [77]. Signs crack is not easily identified for MFL tool [78]. There are cases where large non-axial-oriented cracks were found in the pipelines that were examined by means of magnetic flux leakage and were not detected [79]. The study by Gomez *et al*. in using sonar to vertical pipe limited short-term immersion in water tank [80], [81].

The prototype used in the experiment from a study carried out by Abdellatif Bouchalkha is shown in Figure 9. It has 8 adjustable wheels to stick to the pipe surface for additional stability and two wheels driven by a stepping motor for moving the pig [74].

Another stepper motor is used to scan the ultrasound sensor in a circular motion around the inner surface of the pipe. The rotating sensor output voltage is recorded as a function of position to generate a graph of the output signal as a function of the position sensor. Instead, we have written a LabVIEW program to control the movement of PIG, scanning process, and data collection. Fully automated experimental setup used a personal computer equipped with Educational Laboratory National Instruments Virtual Instrumentation Suite (NI-ELVIS) Hardware and Software LabVIEW [82], [83]. PIG is connected to a computer using an analog to digital (AD) converting circuit module NI-Elvis [84].

Figure 9 A picture of the prototype used in the experiment [27]

The results in this study as shown in Figure 10, show the inner surface of the pipe in the form of a 3D display, where the screen view of x-axis and y-axis and z axis represent the red and blue respectively, indicating the depth of the surface being monitored. The results were recorded after scanning 30 cm section of pipe. Conclusions can be drawn from these figures in the event of a sharp decline (between 250° to 300° angles) as the internal space and may suffer corrosion cracking.

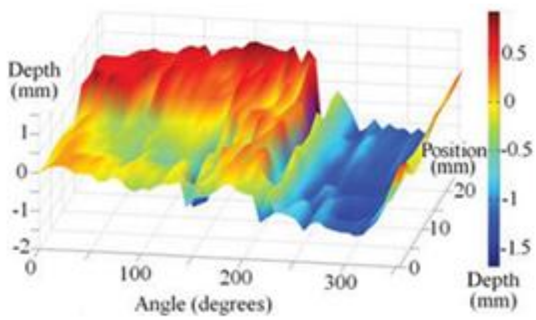


Figure 10 A 3D plot of a 30cm length from the inner surface of a heavily corroded pipe [74]

Monitoring the application of ultrasonic welding of austenitic steels exhibits a multi-pass heterogeneous and anisotropic structure that is difficult to use. The new model presented ideas to improve 2D model MINA towards the lighting of the 3D [85]. Modeling was performed with the ultimate goal of using inverse methodology in testing UT.

One application of synthetic aperture imaging is known in the NDT as Synthetic Aperture Focus Technique (SAFT) [67], which uses delay and sum technique to mimic the physical lens. One of the advantages is that it can achieve the SAFT focus in all places at the same time [86], [87].

In NDT, SAFT algorithm is usually carried out in the time domain [88]. However, the investigation of an object immersed in water that has a layered structure, causing refraction ultrasound signal propagation delays having problems is required in the processing. SAFT is used in the frequency domain instead. If implemented in the frequency domain, it uses a technique known as phase shift migration [89].

4.0 CONCLUSION

Regular inspection and monitoring are essential to maintain the security of the pipeline for a long time. Delivery process through pipelines is the most economical way for gas, oil, bio fuels, water, sewer distributions. However, pipelines constantly suffer from aging and damage, which can cause great waste of resources and environmental pollution, for example, petroleum pipeline leak caused the pollution of the seas and ecocatastrophe. The occurrence of cracks and corrosion of the pipe does not just happen, but most of weld joints are often the causes of corrosion or leaks. Therefore, simple and effective method during the construction process must be implemented to ensure welding quality and choice of priorities is presented as a choice of using ultrasonic methods. Research on improving the production of images in the browser in the form of 3D as a contribution to the interpretation of the scan job is done. The development described earlier, including upgrading the design and use of which is adapted to the environment as a counterweight to keep the weld quality, is better. The level of resolution and depth of the pipe thickness play a role ultrasonic monitoring system performance. In addition, the processing speed level examination to obtain faster results without compromising the quality of the resulting image is set as a benchmark for future design. The suitability of various material parameters can often be improved for future progress.

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