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Diagnosis Of Surface And Subsurface Defects By Using Ultrasonic Techniques

Abdellatif Jamal Hayajneh

Department of mechanical engineering for graduate studies Istanbul Aydin University
ajamalhayajneh@stu.aydin.edu.tr, *https://orcid.org/0000-0003-2951-3363*

Abstract— Recently, industries have achieved many technological advancements. The risk of material failure increases with these advancements. Ultrasonic techniques are one of the important methods used for the detection and improvement of material efficiency. There are many techniques of ultrasonic used for different applications. In this paper, previous studies of the ultrasonic testing techniques for non-destructive material testing have been conducted.

Keywords: none-destructive testing, ultrasonic, ultrasonic testing, ultrasonic techniques, ultrasonic application

1. INTRODUCTION

Non-destructive testing (NDT) is a method for evaluating the integrity of materials for surface or internal defects or metallic conditions without interfering in any way with the destruction of materials or their suitability for service. [1] In another sense, nondestructive testing (NDT) is the process of analyzing and scrutinizing materials or components in order to characterize or find faults and deficiencies against some standard without altering the original features or causing harm to the object being tested. Non-destructive testing techniques are used to evaluate a single sample or the entire material for verification in a product quality control system. [1]

For more than 30 years, NDT (non-destructive testing) techniques have been used in science and business to analyze the properties of a substance, component, or system [2]. There are numerous non-destructive procedures available. These techniques can be used on metals, plastics, ceramics, composites, and coatings to detect cracks, internal voids, surface cavities, and defective or incomplete welds, as well as any other flaw that could cause premature failure. [3] Here are some of the popular NDT techniques that are widely used:

1.1 Radiography testing

Compared with some other operations, radiography has a distinct advantage. The inner integrity of the object being x-rayed is permanently referenced through radiography. The capacity of X-rays produced from the source to pierce metals is dependent on the accelerating voltage in the X-ray emission tube. If the part being x-rayed contains a void, more x-rays will flow through that area, exposing the film beneath the component more than the non-blank sections. This technique is suitable for the detection of internal defects in ferrous and non-ferrous metals and other materials. [4]

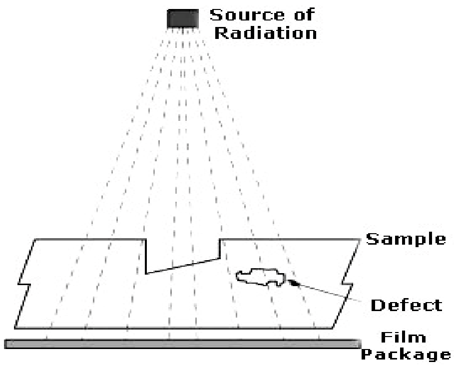

Figure1: illustration of typical exposure arrangement of radiography [4]

1.2 eddy current

The main applications of this technology are to detect surface or subsurface flaws, conductivity testing, and measure coating thicknesses. In this technique, physical conductivity, permeability, and product size are all essential aspects. Eddy currents can be produced in any electrically conducting material subjected to an alternating magnetic field (typically 10 Hz to 10 MHz). [4]

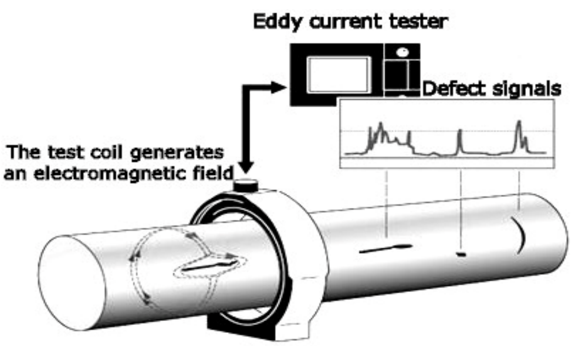

Figure 2: illustration of Eddy currents [5]

1.3 Dye penetration testing

This technique is based on the ability of the fluid to drift to a "clean" surface that breaks up the defect with the action of capillaries. Materials commonly inspected with DPT or LPI (liquid penetration inspection) include metals (aluminum, steel, titanium, copper, etc.), glass, many ceramic materials, rubber, and plastics. DPT is used to identify defects such as capillary cracks, surface porosity, leaks in new products, and fatigue cracks in in-service or operating components in casting, forging, and welding. [4]

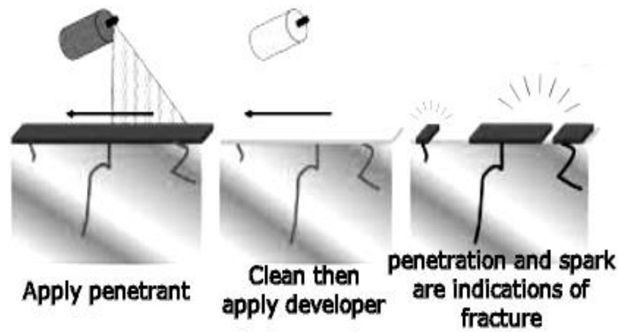

Figure 3: Illustration of Dye Penetrant Testing [6]

1.4 Visual testing

Visual examination is particularly effective for detecting eye defects, such as weak welds. Many of the defects in the welding are visual, such as cracking the hole, cutting, inserting slag, incomplete penetration welds, and the like. Similarly, VI (Visual inspection) is also appropriately used to detect defects in composite structures and pipes of all kinds. Welds or bad joints, clamps or missing components, bad fit, wrong dimensions, improper finishing of surface, large cracks, cavities, scratches, inappropriate size, wrong parts, lack of code approval stamps, and similar test guides.[4]

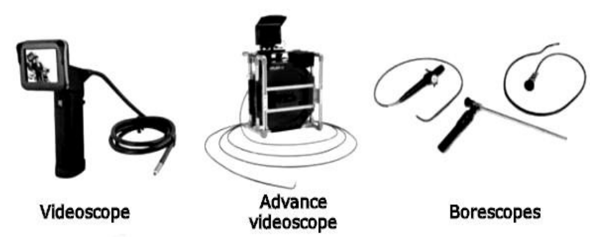

Figure 4: Visual testing equipment [7]

1.5 Thermography testing

Infrared thermal imaging is the science of measuring surface temperature and mapping it. Infrared and thermal testing methods are characterized by the use of thermal measurements of the test body where it is stimulated. Thermal imaging cameras are the most common sensing method. Passive imaging of electronic machines or devices can be used to detect hotspots that indicate problems. Imaging of test objects can be used after energy is applied to monitor the flow of heat in the body, which is a function of material characteristics as well as boundaries. [4]

1.6 Ultrasonic testing

The term ultrasonic refers to the study and application of ultrasound, which is an extremely high-pitched sound that the human ear cannot hear, as shown in table 1. [8] This technique is used to detect internal and surface (particularly the far surface) defects in sound-conducting materials. The principle is similar in some ways to echo sounding. A short ultrasound pulse is generated by an electric charge applied to a piezoelectric crystal, which vibrates for a very short time at a frequency related to the crystal thickness. [4] Ultrasonic has a variety of applications over a wide range of intensities, including cutting, cleaning, and destroying tissue. [3] Since the 1940s, most of the ultrasonic tests have been used in industrial applications for flaw detection. The transmission of sound waves within solid materials is used to detect hidden voids, porosity, cracks, and internal discontinuities in different parts of the material. [17]

Table 1: different types of frequencies for each categorie

Type	Frequencies	Human range	Reference
Ultrasonic	Above 20 kHz	Inaudible	[9]
Subsonic	Below 10 Hz	Inaudible	[9]
Humans	20 Hz - 20kHz	Audible	[10]
Animals	0.01 Hz – 300kHz	--------	[11][10]

Ultrasonic allows the accurate measurement of the pipe wall thickness based on sound velocity and attenuation measurements [18]. Ultrasonic testing is a recognized technology that offers a high accuracy level. This accuracy level can be achieved when competently performed [19]. During wave propagation, three properties are utilized: wavelength, frequency, and velocity. The ultrasonic wave length plays a significant effect towards the probability of discontinuity detection. There are four principal modes for ultrasonic propagation, which are surface, longitudinal, plate waves, and shear. [20]

Ultrasonic testing uses high frequency waves (HFWs) above the range of human hearing. The reason for using it is that it passed under an inspection through the material as shown in figure 6. These waves travel in different materials at different speeds, and at constant speeds in the same material. Whenever waves pass through the material, an interpretation of its defects, and geometric properties are inspected to know the flows in it. A probe sends a high frequency sound wave into the material being tested. The output signals are one from the initial probe of sound wave. The second result from the back-wall echo. [21]

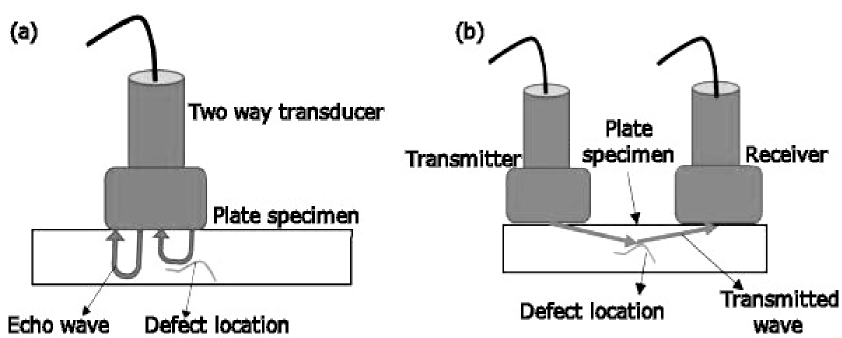

Figure 6: Pulse–-echo method with a transducer; (b) Pitch–catch method with two transduce(R) [22]

2. Ultrasonic applications

Ultrasonic has many applications. The following section explores these applications.

A. Application in the medical field for detection of atherosclerosis

Atherosclerosis is a circumstance affecting the partitions of the arteries inside the heart. Atherosclerosis is characterized with the aid of using calcified plaques, lipids, and cell particles inside the internal layers of the partitions of large and medium-sized arteries as shown in figure 7. Of the diverse check analysis for the identity of the condition, Doppler ultrasound is fine preferred [12] as it's a noninvasive technique that's broadly utilized in medication for the evaluation of blood flow with the drift in intact vessels. The obtained Doppler indicators may be analyzed both with the use of discrete wavelet evaluation of carotid artery Doppler indicators, the Welch technique for spectral evaluation or important issue evaluation. For this reason, a Levenberg–Marquand back-propagation algorithm, an synthetic neural network (ANN), can then be used for the sample category, allowing fast execution of the sign processing. The important benefit of the sort of machine is that it's extremely fast, smooth to operate, noninvasive and inexpensive. [13]

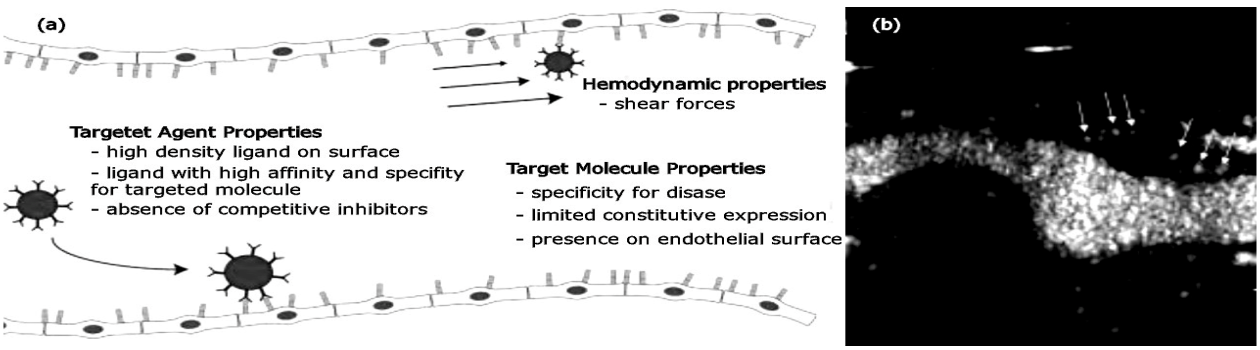

Figure 8: Contrast-enhanced ultrasound (CEUS) imaging of plaque neovascularization in a carotid plaque (a) Determinants of targeted micobubble retention [23], (b) Carotid artery with intraplaque neovascularization on CEUS [24]

B. Application in the oil industry for pipeline testing

Ultrasonic In-Line Inspection Tools [14] may be used for detecting, sizing, and finding metal loss and cracks in transmission pipelines. These gadgets are pumped through the segment of pipe to be inspected collectively with the medium being transported therein. Various new hardware has been added for execution strategies for the calculation of the illness parameters. There are essentially two forms of sensor designs: the wall thickness degree kind and crack detection version. The latter has sensors oriented at a predetermined attitude to the pipe wall, which guarantees that ultrasonic shear waves will travel beneath Neath a 45-degree angle in the metal. The drawback of this technique is that the small-scale performance of that gear and its cost-effectiveness has now no longer been tested. Thus, there may be inadequate evidence for his or her argument of better accuracy and simplicity. On the other hand, a multi- channel ultrasonic inspection system [15].

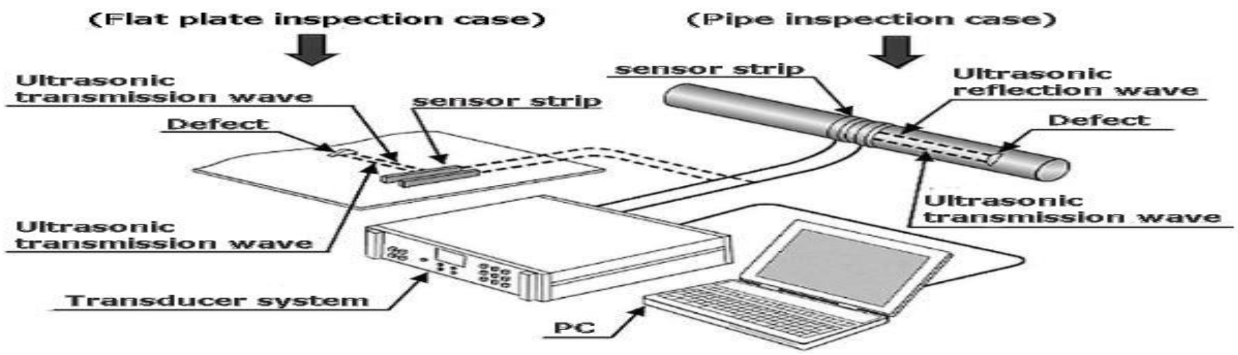

Figure 9: typical guided wave inspection system [16]

C. Application in Civil Engineering in the Evaluation of Concrete and Steel

Nonlinear ultrasonic [34] is used in the assessment of broken concrete in business programs like nuclear strength plants, bridges, etc. In the experimental procedure, nine cylindrical concrete specimens with three wonderful water–cement ratios are deliberately broken beneath compression and then examined ultrasonically to enable the size of the amplitudes of the fundamental, second, and 0.33 harmonics. This is stored apart for future use and ultrasonic trying out of the equal specimens is accomplished with the use of narrow-band and broadband transducers with one of the frequencies. The outcomes are plotted and compared so that they will decide the overall performance of narrow and broadband transducers as transmitters in ultrasonic testing.

Ultrasonic techniques are also used in steel for the in-situ sizing of fasteners with hollow cracks. [35] A twin perspective beam through transmission method may

Another new technique combines the software of non-linear DE convolution and the Hilbert–Huang Transform (HHT) for higher detection of defects in closely attenuating materials. [36]

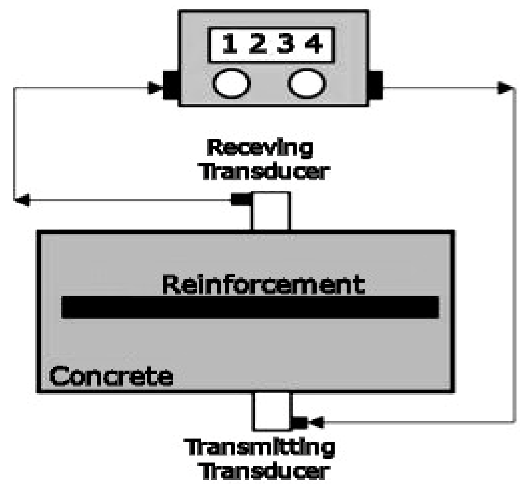

Figure 10: The principle of ultrasonic pulse velocity in civil engineering. [26]

D. Application in Nuclear Power Generation

Nuclear energy has emerged as one of the maximum critical power reserves in the world. Nuclear electricity plants contain heavy concrete and metal joints to defend the environment from nuclear radiation. The smallest of cracks within the protection ought to cause heavy harm to the entire region of the plant. Thus, it is crucial that utmost care is taken to discover even the slightest damage to the systems as quickly as possible.

Ultrasonic strategies offer smooth entry and portability in those instances and therefore are typically used. The only trouble is that most of the additives of the nuclear electricity plant are inaccessible for checking out equipment. [37]

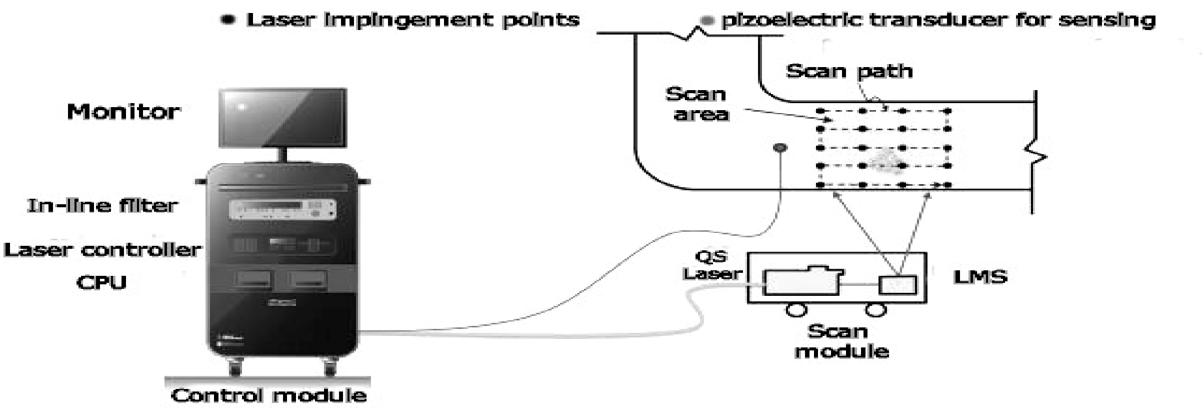

Figure 11: Ultrasonic propagation imager (UPI) for inspection of the nuclear power plant (NPP) pipeline (LMS: laser mirror scanner; CPU: central processing unit). [25]

E. Application in welding underwater

Welding and wet underwater repair have been widely used in marine construction, such as nuclear power plants, offshore platforms and gas pipelines [27, 28] It can also be used for the urgent repair of submarines and warships in wartime because of its distinct operational capability. However, direct contact with surrounding water will cause some problems, leading to a deterioration in welding stability and quality [29]. According to Chen et al., ultrasonic spread in the welding basin through the core material is caused by pressing the ultrasonic horn on the surface of the core material [30]. The result showed that a (TIG) grain of pure aluminum tungsten gas welds are broken periodically, due to periodic ultrasound. Wang et al. discovered that the application of ultrasound can reduce the fluctuations of the larger arc voltage signal and the smaller arc voltage signal [31].

Chen et al. observed the influence of ultrasonic power on melt flow in the weld pool and the effect of ultrasonic force on the exact structure and characteristics of wet underwater welding connections. In his experiment, ultrasonic vibration was at 27 kHz. During the welding process, the ultrasonic horn was installed at a fixed distance (30 mm) as shown in (figure 12) from the welding flame to make sure it did not melt due to the intense arc heat. [32]

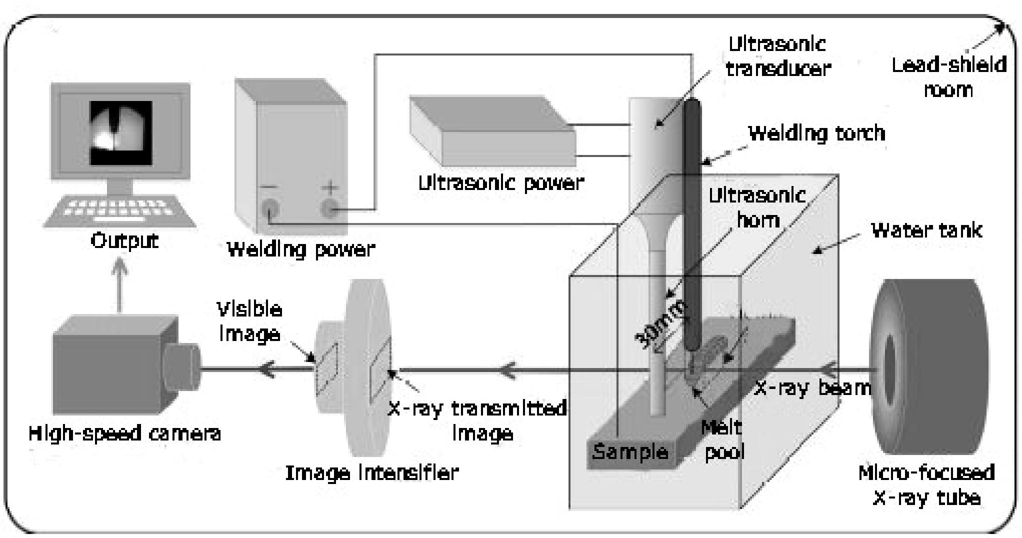

Figure 12: Schematic diagram of the experimental setup. [32]

At the end of the experiment, ultrasonic vibration enhanced melt flow and fairly good welding appearance. However, high-level ultrasonic energy would break the welding-covered slag and generate more welding sprinklers. The ultrasonic cavity bubble will be left in the welding metal and become welding pores. The number of these pores increased with increased ultrasonic strength, which may be one of the reasons for the decrease in the mechanical property of the weld when the energy came out relatively high by ultrasound. [32]

Ultrasonic testing techniques

The ultrasonic technique is used in sound-conducting materials for the identification of internal defects. In certain ways, the theory of the process of ultrasonic research is similar to that of echo sound. [45] In order to detect cracks, internal voids, surface cavities, delamination, imperfect faulty welds, and any kind of deficiency that would lead to premature failure, these methods can be carried out on metals, plastics, ceramics, composites, cermet's, and coatings.[46] The following sections contain the different ultrasonic techniques & usages.

- **Ultrasonic testing setup**

Ultrasonic testing enables the assessment of crack activity as a function of ultrasonic wave propagation under various loading situations. The mechanical vibrations of medium particles are called ultrasonic, which have a particular frequency, velocity, and amplitude as in equation (1), is the particle displacement from an average position; frequency is the number of cycles per second; and wavelength is the length of the cycle. The relationship between velocity, frequency, and wavelength is given by:

$v = f\lambda$ (1) [33]

The UT inspection system includes a portable probe transmitter/receiver, a transducer, and a display screen (oscilloscope) as shown in (Figure 13). A pulse is created by imposing an alternating effort that activates the crystal of an electromagnetic probe to produce signals by coupling the probe with it. Sound waves emitted from the boundaries of the work piece reveal any crack/cracks received as feedback from the probe. Through the effect of the photovoltaic crystal, the received waves are converted into an electrical voltage and displayed on the screen. [33]

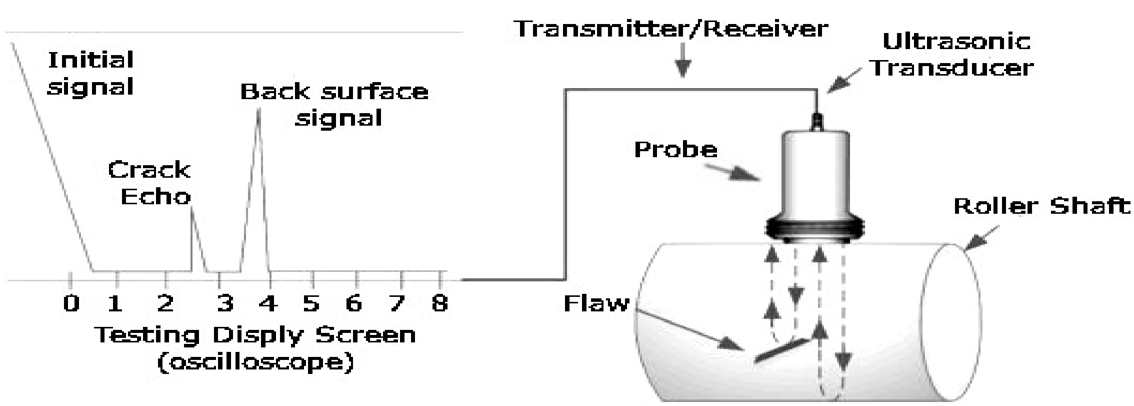

Figure 13: Illustration of ultrasonic testing (UT) set-up. [33]

Calibration blocks (CBs) are used in most cases of non-destructive testing (NDT). During ultrasonic testing, CBs are needed to adjust the flaw detectors and evaluate the quality of the test results. During the penetrating and magnetic examination, reference samples with artificial slits are used. They are necessary to test the quality of the material being subjected to flaw detection and to ensure a specific sensitivity level [58] as shown in (Figure 14).

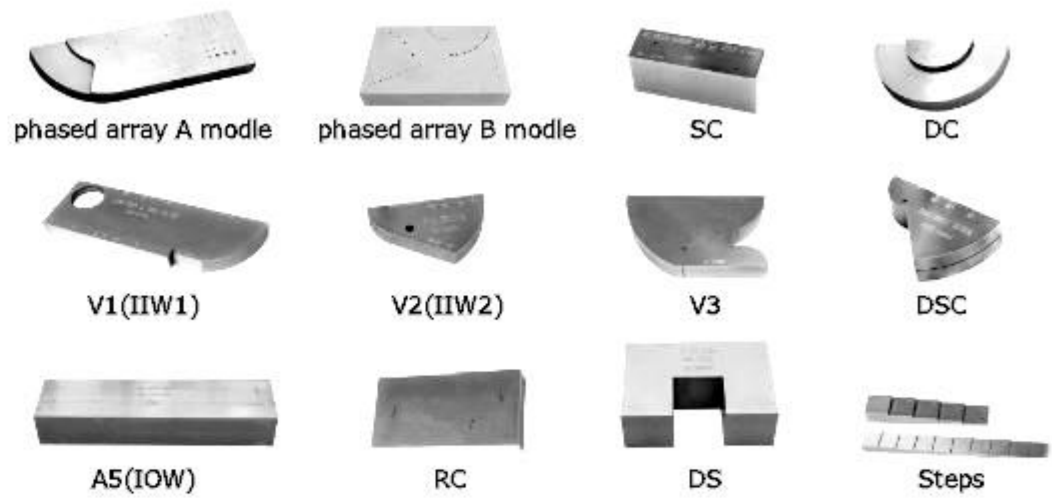

Figure 14: various types of ultrasonic calibrations testing blocks. [59]

1. Ultrasonic Pulse echo

The ultrasonic pulse-echo method can easily identify defects in homogeneous materials. In this method, the operator worries more about the wave transit time and energy loss due to attenuation and wave scattering on defects. It helps locate the inconsistency in a material, whether it is homogeneous or heterogeneous. The increased velocity of ultrasonic waves inside a rigid body depends on the density and the constant of the elasticity. In addition, both density and the constant of the elasticity vary within materials from one point to another due to various parameters, such as structural inhomogeneity, changes in quality and production ways (for instance, the blowing agent for manufacturing polyurethane foam). [38] A straight beam transducer, which is vertically set on the tested material as shown in (Figure 4), transmits high-frequency sound waves. A liquid (or semi-liquid) material is also necessary during the inspection process between the searching units and the surface of the material. The reflection of material surface signals is visualized by a digital inspection analysis oscilloscope. At locations with restricted access, the inspection efficiency of this system is reduced. (Inspection underground) [42][43]

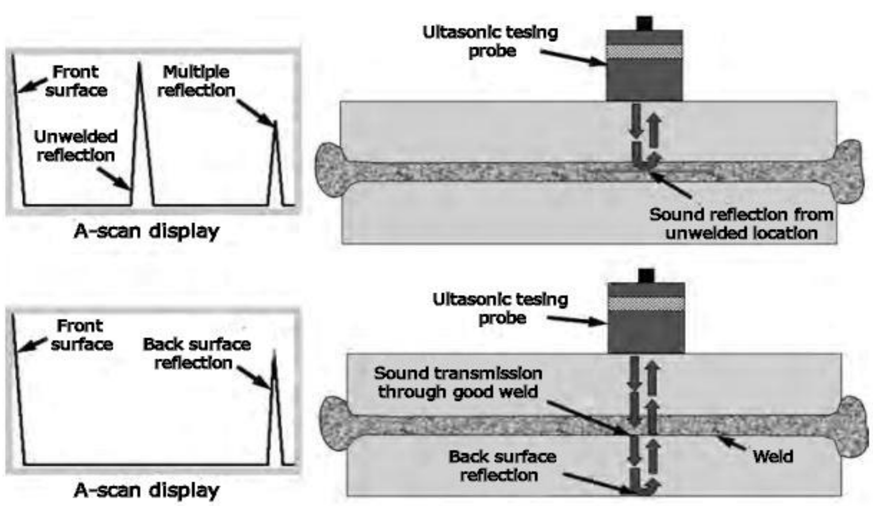

Figure 15: Ultrasonic pulse-echo technique for a solid-state weld examination. [44]

Yang Zhan-feng et al [41] describe the nonlinear ultrasonic testing technique for micro-damage of TATB based Polymer Bonded Explosive (PBX). An ultrasonic non-destructive testing technique is used to evaluate the defects inside explosive parts. For PBX parts examination, the linear wave theory based ultrasonic testing method such as the ultrasonic pulsed echo method or transmission method is mainly used.

The non-linear ultrasonic techniques used in the research of micro-damage and the performance of PBX parts can be meaningful, which will present a new method for the evaluation of micro-damage and its expansion regularity as well as the reliability of explosives storage. During this examination, we found out that the ultrasonic linear parameters such as gain or velocity were not changed, obviously, during the whole fatigue cycle loading process. Concluding to this work The author suggested that the ultrasonic linear parameters are not sensitive to accumulation and development of micro-damage, unlike the ultrasonic nonlinear coefficient, which is very sensitive to that.

1. **Ultrasonic pulse velocity**

For large defect detection, location, imaging purposes, and quality control, ultrasonic pulse velocity measurements are well suited. [40] The strength and reliability of materials are tested in this process by sending ultrasonic pulses from a pulse generation circuit. The transducer then transforms the electronic sounds into mechanical pulses. Inhomogeneity and air intrusions into 4 materials are demonstrated by deviations from the average speed and perceived wave amplitude variations. Ultrasonic pulse velocity is a non-destructive tool and is mainly used in the field to analyze the strength and efficiency of concrete.

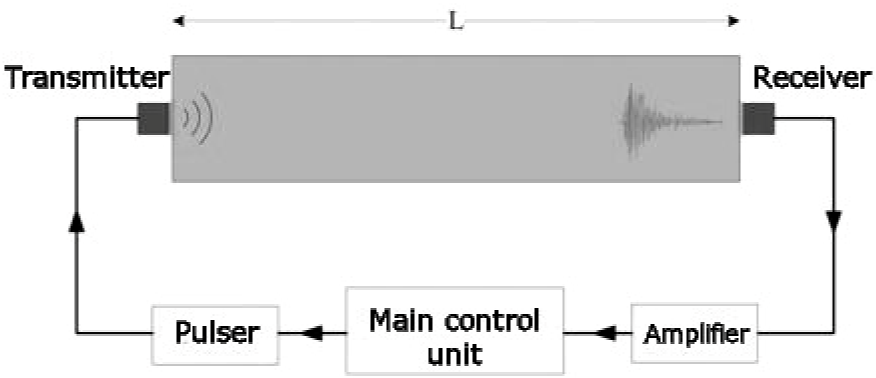

Figure 16: Schematic of apparatus of the UPV test system. [39]

Today, the UPV method is gaining more ground in the scientific community in the field of structural health monitoring (SHM). The in-site measurements are compared with the reference measurements in order to assess the condition of the material. The ratio of these measurements indicates the level of degradation of the material. While the majority of current technologies are based on the use of piezoelectric transducers installed on the concrete surface, special attention is paid to the very promising technology of using piezoelectric transducers embedded in concrete structures. The results so far show good agreement with classic ultrasound tests using external transducers. [47, 48] There is a great need for in-site testing of concrete as a result of the steady increase in the number of concrete structures showing signs of structural deterioration and the infrastructure agencies' shifting efforts from building new concrete structures to assessing and rehabilitating existing structures. It has become apparent that reliable tools are required to obtain error-free concrete strength and integrity performance evaluations of existing structures so that the most cost-effective rehabilitation strategy can be adopted. Reducing the cost of inspection and the risk of unexpected failure by using real-time online monitoring systems is of paramount importance. [49]

2. Phased Array Ultrasonic

In various industries, from power generating units to the building industry, phased array ultrasonic technology can be used. PAU is engaged in the area of non-destructive testing of ultrasound technology. The method can be used effectively as a corrosion test to measure the wall thickness of components. The array is referred to in this technique as a single large probe that is paired with multiple piezoelectric crystals. These piezoelectric crystals are split into very tight segments and the ultrasonic waves are pulsed and received separately. Usually, the width of these segments will range from 0.5mm to 2.5mm. Since it is possible to combine various beam angles and focal depths with only one probe, several different tests can be performed independently without switching the transducer. The inspection results are clearly stored and accessible for examination. [50, 51]

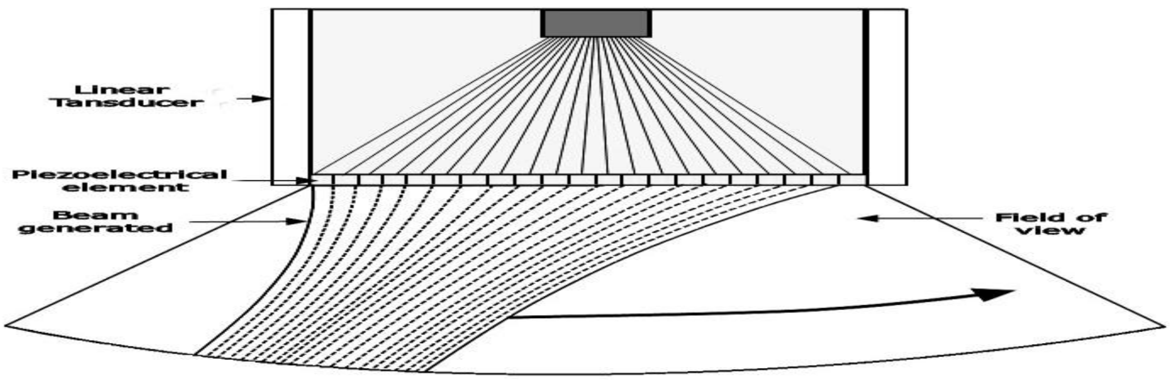

Figure 17: Diagram of linear ultrasound transducer - phased array. [52]

1. Guided Wave Ultrasonic Testing (GWUT)

This ND inspection approach is typically used from a single remote location, for example, above ground metallic pipelines and rail tracks, to determine corrosion and structural integrity in the long-distance in-service network. Three distinct driven wave modes, torsional, longitudinal, and flexural, can be used in the material body during the testing process. Each of these directed waves is selected on the basis of element geometry and frequency application. The method uses low-frequency ultrasonic waves (10–100 kHz) which are transmitted in both forward and backward directions along the pipelines as shown in (figure 17b. An array of transducers equipped with ultrasonic piezoelectric sensors is used in this technique to generate directed waves (torsional or longitudinal) along the segment of the pipe. The waves are mirrored back to the original position to evaluate the shape and location of damage when any discontinuities are recognized in the pipelines. The key advantage of this strategy lies in its ability to inspect a system for its limited access areas. [53] [54] [55] to determine wave velocity, see equation (2).

$$V_L = \sqrt{\frac{E(1-v)}{\rho(1+v)(1-2v)}} \qquad (2) \quad [57]$$

Where V_L is Longitudinal Wave Velocity, E is Modulus of Elasticity, ρ is Density, and ν is Poisson's Ratio.

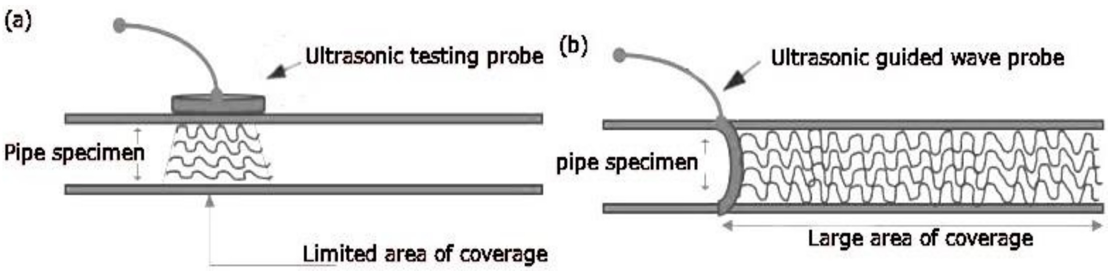

Figure 18: Difference between (a) ultrasonic testing, UT; and (b) guided wave ultrasonic testing, GWUT [56]

Conclusion

In this review, a general idea about NDT testing and its techniques was discussed, explaining the setup of ultrasonic, the different usages, and the applications in the construction, medical field, oil industry, nuclear power, and underwater were covered. While at the end, ultrasonic testing techniques were discussed.

References

[1] Newswire, P. (2013, 2013 Feb 07). Global Non-Destructive Testing (NDT) Equipment Market - By Technology (Ultrasonic, Eddy Current, Electromagnetic, Radiography, Thermography), Verticals (Manufacturing, Petrochemical, Aerospace, Automotive, Power Generation)& Geography (2013 - 2018), PR Newswire

[2] Xiao, N.H. New Technologies and Technical Standards for Modern Non-Destructive Testing Technology and Application; Beijing Silver Sound Audiovisual Press: Beijing, China, 2004 (in Chinese)

[3] Web.Itu.Edu.Tr/~Arana/Ndt.Pdf.

[4] Kumar, S., & Mahto, D. G. (2013). Recent trends in industrial and other engineering applications of non-destructive testing: a review. International Journal of Scientific & Engineering Research, 4(9).

[5] Eddy Current Testing. (2017). http://www.ndttechnologies.com/products/eddy_current_testing.html

[6] Dye penetrant inspection. (n.d.). http://artimis.eu/En/ProductDetails/15/Dye-penetrant-inspection

[7] Introduction to visual inspection. (2020). The American society for nondestructive testing https://worldofndt.com/introduction-to-visual-testing/

[8] S. J Blitzg, B. J, Blitz J and G. Simpson, Ultrasonic Methods of Non- destructive, Testing, 1996 ,1st ed. (London: Chapman & Hall)

[9] Krautkrämer, J., & Krautkrämer, H. (2013). Ultrasonic testing of materials. Springer Science & Business Media

[10] Roi Polanitzer. (2022). Ultrasonic Wave and Electromechanical Impedance Spectroscopy https://medium.com/@polanitzer/ultrasonic-wave-not-what-you-thought-888bcc6cd44d

[11] Pye, J. D., & Langbauer, W. R. (1998). Ultrasound and Infrasound. Animal Acoustic Communication, 221–250. doi:10.1007/978-3-642-76220-8_7

[12] S. Kara ; F. Dirgenali, A system to diagnose atherosclerosis via wavelet transforms, principal component analysis and artificial neural networks. Expert Systems with Applications, 2007, 32, pp. 632–640

[13]Muthumari, S. and A. Singh, Review of various ultrasonic techniques employed in modern industries. 2011, IJEST, 3(4).

[14]Reber, K. et al. (2002). A New Generation Of Ultrasonic In-Line Inspection Tools For Detecting, Sizing And Locating Metal Loss And Cracks In Transmission Pipelines. NDT Systems & Services Ag, Am Hasenbiel 6, 76297 Stutensee, Germany. IEEE Symposium.

[15] Bo, Dai et al. An Ultrasonic In-line Inspection System on Crude Oil Pipelines.

Beijing Institute Of Petro-Chemical Technology, Beijing 102617, P. R. China.

[16] Kuroishi T, Sakata F. New application of non-destructive inspection technology guided wave pipe inspection and monitoring system. Journal of the Japan Welding Society. 2006;75:220-224. DOI: 10.2207/jjws.75.220

[17] H. K. . Lee, K. M. Lee, Y. H. Kim, and D. B. Bae, “Ultrasonic in-situ monitoring of setting process of high performance concrete,” Cement and Concrete Research, vol. 34, no. 4, pp. 631–640, 2004.

[18] K.V. Surbmanniam, J. Lee, materials and structure, 2006, 40 n0 3:301- 309

[19] A.A., Carvalho, J.M.A., Rebello, M.P.V., Souza, L.V.S., Sagrilo, and S.D Soares,. Reliability of Non-Destructive Test Techniques in the Inspection of Pipelines used in the Oil Industry. International Journal of Pressure Vessels and Piping. 2008, 85, 745-751.

[20] A. Mostavi; N. Kamali; N. Tehrani; S. Chi; Ozevin, Didem; Indacochea,

J. Ernesto. "Wavelet Based Harmonics Decomposition of Ultrasonic Signal in Assessment of Plastic Strain in Aluminum". Measurement. 106: 66–78. doi:10.1016/j.measurement.2017.04.013

[21] A Sharma, & A. Sinha, Ultrasonic Testing for Mechanical Engineering Domain: Present and Future Perspective, 2018, 10.22105/riej.2018.100730.1018.

[22] Driveklepp, A. Ultrasound Examination of Steel Pipes. Master’s Thesis, Norwegian University of Science and Technology, Trondheim, Norway, 2007

[23] Lindner, J.R. Molecular imaging of vascular phenotype in cardiovascular disease: New diagnostic opportunities on the horizon. J. Am. Soc. Echocardiogr. 2010, 23, 343–350.

[24] Staub, D.; Schinkel, A.F.L.; Coll, B.; Coli, S.; van der Steen, A.F.W.; Reed, J.D.; Krueger, C.; Thomenius, K.E.; Adam, D.; Sijbrands, E.J.; et al. Contrast-enhanced ultrasound imaging of the vasa vasorum from early atherosclerosis to the identification of unstable plaques. JACC Cardiovasc. Imaging 2010, 3, 761–771.

[25] Truong, T. C., & Lee, J. R. (2018). Thickness reconstruction of nuclear power plant pipes with flow-accelerated corrosion damage using laser ultrasonic wavenumber imaging. Structural Health Monitoring, 17(2), 255-265.

[26] Komlos, K.; Popovics, S.; NÃrnbergerovÃ, T.; BabÃl, B.; Popovics, J.S. Ultrasonic pulse velocity test of concrete properties as specified in various standards. Cem. Concr. Compos. 1996, 18, 357–364.

[27] Chen, H.; Guo, N.; Zhang, X.; Cheng, Q.; Zhou, L.; Wang, G. Effect of water flow on the microstructure, mechanical performance, and cracking susceptibility of underwater wet welded Q235 and E40 Steel. J. Mater. Process. Technol. 2020, 277, 116435

[28] Guo, N.; Zhang, X.; Xu, C.; Chen, H.; Fu, Y.; Cheng, Q. Effect of parameters change on the weld appearance in stainless steel underwater wet welding with flux-cored wire. Metals 2019, 9, 951.

[29] Li, H.; Liu, D.; Ma, Q.; Guo, N.; Song, X.; Feng, J. Microstructure and mechanical properties of dissimilar welds between 16Mn and 304L in underwater wet welding. Sci. Technol. Weld. Join. 2018, 24, 1–7.

[30] Chen, Q.; Lin, S.; Yang, C.; Fan, C.; Ge, H. Grain fragmentation in ultrasonic-assisted TIG weld of pure aluminum. Ultrason. Sonochem. 2017, 39, 403–413.

[31] Wang, J.; Sun, Q.; Zhang, T.; Tao, X.; Jin, P.; Feng, J. Arc stability indexes evaluation of ultrasonic wave assisted underwater FCAW using electrical signal analysis. Int. J. Adv. Manuf. Technol. 2019, 103, 2593–2608.

[32] Chen, H., Guo, N., Xu, K., Liu, C., & Wang, G. (2020). Investigating the advantages of ultrasonic-assisted welding technique applied in underwater wet welding by in-situ X-ray imaging method. Materials, 13(6), 1442.

[33] Jamil, M., Khan, A. M., Hegab, H., Sarfraz, S., Sharma, N., Mia, M., ... & Pruncu, C. I.

(2019). Internal cracks and non-metallic inclusions as root causes of casting failure in sugar mill roller shafts. Materials, 12(15), 2474.

[34] Shah, A. A. Et al., Nondestructive evaluation of damaged concrete using nonlinear ultrasonics. Materials and Design, 2009, 30, pp. 775–782.

[35] Michaels et al., an Ultrasonic Angle Beam Method for in situ Sizing of Fastener Hole Cracks. Journal Of Nondestructive Evaluation, 2006, 25(1).

[36] R. Kažys, et al., Ultrasonic detection of defects in strongly attenuating structures using the Hilbert– Huang transform. NDT & E International, 2008, 41, pp. 457–466.

[37] Muthumari, S. and A. Singh, Review of various ultrasonic techniques employed in modern industries. 2011, IJEST, 3(4).

[38] Warnemuende, K. (2006). Amplitude modulated acousto-ultrasonic non-destructive testing: Damage evaluation in concrete. (3243085 Ph.D.), Wayne State University, Ann Arbor. Retrieved from http://search.proquest.com/docview/304968621?accountid=28930 ProQuest Dissertations & Theses Global database.

[39] Karaiskos, G., Deraemaeker, A., Aggelis, D. G., & Van Hemelrijck, D. (2015). Monitoring of concrete structures using the ultrasonic pulse velocity method. Smart Materials and Structures, 24(11), 113001.

[40] Oguma, I., Goto, R., & Sugiura, T. (2012). Ultrasonic inspection of an internal flaw in a ferromagnetic specimen using angle beam EMATs. Przeglad Elektrotechniczny, 88(7B), 78-81

[41] Yang Zhan-Feng, Zhang Wei-Bin, Tian Yong, LI jing-ming, LI li. Nonlinear ultrasonic testing technique for micro-damage of TATB based Polymer Bonded Explosive, 2012 , 18th World Conference on Nondestructive Testing, 16-20 April 2012, Durban, South Africa.

[42] ASTM E114 – 10 (2010) Ultrasonic Pulse-Echo Straight-Beam Contact Testing.

[43] Guoli Wang, Y.H., Jia, Z. and Xie, H. (2005) Application of Ultrasonic Pulse-echo Method to Insulation Condition Diagnosis for Large Generators.

[44] Na, J., Spencer, R., Todorov, E., Gleeson, S., & White, P. (2011). Nondestructive Evaluation of Solid-State Welds.

[45] S. Kumar, D. G.Mahto. Recent trends in industrial and other engineering applications of non-destructive testing: a review. International Journal of Scientific & Engineering Research. 2013 Sep; 4(9)

[46] S.K. Dwivedi, M. Vishwakarma, P.A. Son, Advances and researches on non-destructive testing: a review Mater Today: Proc, 5 (2018), pp. 3690- 3698

[47] Dumoulin C, Karaiskos G, Carette J, Staquet S and Deraemaeker A 2012 Monitoring of the ultrasonic P-wave velocity in early-age concrete with embedded piezoelectric transducers Smart Mater. Struct. 21 047001

[48] Li Z, Qin L and Huang S 2009 Embedded piezo-transducer in concrete for property diagnosis J. Mater. Civ. Eng. 21643–7

[49] American Concrete Institute 2003 ACI 228.1R-03 In-place methods to estimate concrete strength (Farmington Hills, MI: American Concrete Institute)

[50] ASTM E2491 – 13 (2013) Evaluating Performance Characteristics of Phased-Array Ultrasonic Testing Instruments and Systems

[51] Ciorau, P. and Pullia, L. (2007) How Reliable is Your Call? OPG Phased Array Ultrasonic Inspection Experience on Siemens-Parson Turbine Blade Roots 2001-2007

[52] Rachael Nightingale. (n.d.). Phased array Case courtesy of, Radiopaedia.org https://radiopaedia.org/cases/phased-array-1?lang=gb

[53] ASTM E2775 – 11 (2011) Guided Wave Testing of Above Ground Steel Pipework Using Piezoelectric Effect Transduction

[54] Zhang, L. (2014) A Multi-channel Transmitter System for NDT Pipeline Testing using Guided Waves Ultrasound

[55] Sonia, D. (2010) Propagation of guided waves in a hollow circular cylinder application to nondestructive testing

[56] Olisa, S. C., Khan, M. A., & Starr, A. (2021). Review of current guided wave ultrasonic testing (GWUT) limitations and future directions. Sensors, 21(3), 811.

[57]Nondestructive Evaluation Techniques. (n.d.) https://www.nde ed.org/NDETechniques/Ultrasonics/index.xhtml

[58] GOST (State Standard) 14782–86: Nondestructive Testing. Welds. Ultrasonic Methods, 1996.

[59] Aliexpress.(n.d.). Ultrasonic Test Block (NDT, ultrasound, ultrasonic, calibration). https://tr.aliexpress.com/item/990787859.html?gatewayAdapt=glo2tur