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REVIEW PAPER

A REVIEW ON WELD FLAWS DETECTION USING VARIOUS ULTRASONIC TECHNIQUE

[1]Devendra Kumar Singh* and [2]S.C. Jayswal
[1]Research Scholar, [2]Associate Professor, [1,2]Department of Mechanical Engineering,
Madan Mohan Malaviya University of Technology, Gorakhpur, Uttar Pradesh, INDIA.
*Corresponding Author's Email ID: devmjpru010@gmail.com

ABSTRACT

For quality assurance of structural member during manufacturing stage and operational life, NDE is a vital tool to confirm that. Among number of NDE methods Ultrasonic has been tool of choice to inspect, since the likely defects and important material properties are very easily and inexpensively, uncovered in ultrasonic NDE. Manual ultrasonic is better in comparison to radiography for planar defects .For better quality and safety the defected item must be identified. This can be achieved using Non Destructive Testing (NDT). That is, Flaw Detection is a challenging as well as significant task in NDT. One of the main aim of the digital signal processing is to enhance the detect ability of the flaws. This study presents various ultrasonic techniques for detecting the welding defects.

Keywords: UT, WT, SSP, Pulse-Echo, SAFT, TOFD, PHASED ARRAY.

1. INTRODUCTION

Non-destructive testing (NDT) may be defined as the science of examining objects, materials or systems, in order to determine their fitness for certain purposes, without impairing of their further usefulness and their desirable properties. The term is generally applied to non-medical investigations of material integrity.

Non-destructive evaluation (NDE) of material plays a vital role in quality assurance of structural members during manufacturing process and working life. Ultrasonic Non-Destructive Evaluation (NDE) is a critical diagnostic tool in many industries. Imaging of defects in materials plays an important role in non-destructive evaluation (NDE) for aerospace, automotive, and energy applications. Among many other NDE techniques, ultrasonic methods play a prominent role in the both quantitative and qualitative assessment of discontinuities in materials.

Nowadays the Ultrasonic Testing techniques are used for inspecting the materials during production than that of radiography. One of the main objectives of the digital signal processing is to improve the detect ability of the defects. Due to hazardous nature of x-rays, ultrasonic CT gain gained importance in medical and NDE. Due to physical constrained of accessing other side of structure and immeasurability of transmitted signal (such as cardiovascular imaging) ultrasonic reflection testing has great importance in NDE and medical.

Non Destructive Testing is a branch of material science involves concept of finding flaws without damaging the product or material i.e. without destroying the functional properties or characteristics of material or component, the defect can be identified using Non Destructive Testing. Different types of commonly used traditional methods used in our daily life involves Visual testing, Liquid Penetration testing, Electromagnetic testing, Eddy-current, Low coherence interferometry testing, Thermo graphic testing ,MPT ,RT ,Ultrasonic testing. These are implemented for finding defect and flaws evaluation or internal defects of leaks in system. Flaw Detection is one of the scopes where Non Destructive evaluation is frequently utilized. It widely finds its scope in as Automobile Industry, Boilers, Aircraft industry, Building and Bridge, Furniture and wood processing, Pressure Vessels, Railway wagons, ship industry etc. (Singh and Udpa, 1986).

Metal joining is a process of joining two or more metals by the application of heat and pressure. Where Welding, Brazing, and Soldering are three sub division of joining (metal) process. Welding is a process of joining two similar metals by the application of heat. On the basis Filler metal & Pressure, welding process is sub divided into two sub groups i.e. Non-Pressure Welding (Fusion welding) & Pressure Welding (Resistance welding) where Arc welding, TIG welding and MIG welding comes in the class of Fusion welding and Butt, Projection, Seam & Spot welding are Plastic Weldin or Resistance type of welds (Singh and Udpa, 1986).

Welding defects involve defects like cracks, Porosity, Planar defects, slag, incomplete Penetration etc i.e. planar defect(Surface), subsurface planar defect, Laminar flaw etc., are known as weld defects. The welded joints must be inspected for reducing risk and increase safety and quality using NDT techniques on the basis of this test the weldments are identified as acceptable or rejected .lack of any flaws during various NDT methods result in good weld structure. Digital signal processing aims at regeneration of flaw in image form with good accuracy and resolution about processes such as welding, quality of material property and life of weld structure (Singh and Udpa, 1986). Now Let us review various ultrasonic testing methods to see how the flaws in the weldment can be detected.

Ultrasonic Testing and Setup: Ultrasonic Testing (UT) uses high frequency sound energy whose frequency is greater than 20 kHz to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection/evaluation, dimensional measurements, material characterization, and more. To illustrate the general inspection principle, a typical pulse/echo inspection configuration as illustrated below will be used.

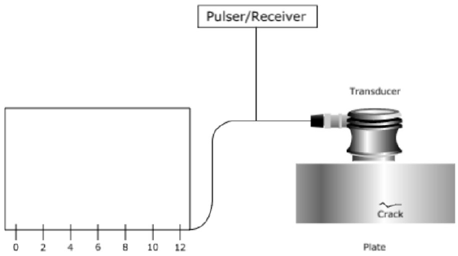

Fig. 1: Ultrasonic Testing Unit

On the basis of sound wave frequencies, the sound waves are of three types.

- Infrasound wave whose frequency < 20 Hz.
- Audible wave whose frequency lies between 20 Hz to 20 kHz.
- Ultrasonic wave or ultrasound whose frequency >20 kHz.

In Ultrasonic testing very short ultrasonic waves with centre frequencies are allowed to scan the test specimen i.e. the waves are passed through the specimen and collected by corresponding receiver to detect the flaws if any, to specify characteristics and thickness of test sample. UT methods are used to identify and indicate the presence of detect sub surface (inner) as well as surface flaws in structural materials (Doyle and Scala, 1978). (UT) i.e. ultrasonic testing is one of tool of non destructive evaluation adopted in different areas of materials such as concrete, different alloys, composites, Austenitic stainless steels and other metals, etc.

Table 1: Comparison between through Transmission and Pulse Echo Methods

S. No.	Attenuation Mode (Transmission Method)	Refection Mode (Pulse Echo Method)
1	Utilizes the transmitted part of the ultrasonic wave	Utilizes the reflected part of the ultrasonic wave
2	Probe are on the different sides of the material	Probes are on the same side of material
3	Does not give the depth i.e. location of the defect	Give the location of the defect
4	Two probe used-each on opposite side of material	Either one or two probes used if two probes-both on the same side of the material

Ultrasonic testing techniques extends its scope in detecting the presence of flaws in a test sample either planar or internal (Krautkramer and Krautkramer, 1977). Because of development of design complexities and demand of high quality and low cost product with enhanced safety Quantitative techniques are developed in place of Qualitative techniques (Doyle and Scala, 1978).

The working principle of ultrasonic NDT is whenever there is change of material occurs in the testing sample, the reflection will occur at that interface .As the defect can be detected without breaking or destroying the test sample, it is called Non Destructive Testing. An ultrasonic probe is used to produce ultrasonic waves in Ultrasonic Testing and apart of this the different type of couplants which are used are oil, water, Grease etc., which is used to remove air between probe face and testing sample. Basically there are two methods to receive ultrasonic waveform first is Pulse-Echo method and second is through transmission.

With Pulse-Echo mode the same probe works as transmitter and receiver. Short ultrasonic pulse wave is emitted by probe and also receives the reflected wave pulse after it is reflected back (Manjula *et al*., 2012)

Here the reflected pulse wave is due to back wall echo of reflection from defect interface. Oscilloscope type of instrument is used to present signal on screen which can be recorded and used for further digital signal processing. The reflection and intensity of the reflection is represented by distance and amplitude (Manjula *et al*., 2012). On the other hand in through-transmission method a transmitter transmits waves pulse on one side of the surface received by receiver (probe) on the other surface of the test sample. If there is any a flaw or defect in material between the front wall and back wall of test sample another wave pulse showing the discontinuities will be produce between the front and back wall echo. Because of this receiver probe have decreased received signal's intensity gives the idea about the defect (Manjula *et al*., 2012). Also efficiency of testing processes is improved by implementation of suitable couplant. An outline of comparison between the through transmission mode and pulse echo mode is shown in Table no 1.

Ultrasonic's was used as a method of weld inspection since 1990 (Ditchburn *et al*., 1996).Different ultrasonic techniques such as phased Array, EMAT, ART, Projection array, TOFD, SSP, Acoustic Microscopy, SAFT etc are used now a day. The following Digital signal processing techniques are implemented to improve SNR which results in improved flaw detection ability (Chiou and Schmerr., 1991) as well as utilised to analyse ultrasonic waves (Abbate *et al*., 1997). Frequency Agility, Signal Averaging, Matched Filtering, Beam Forming, Moving Window Detector, Autoregressive analysis , Random Sig. Correlation technique., Cross & Auto correlation, artificial intelligence , Neural networks , Spectral correlation etc.,

For industrial applications ToFD and SAFT are the two imaging techniques used in ultrasonic testing to determine the flaws and FLDA and ALN are utilised for pattern recognition i.e. To identify the defect type(Singh and Udpa, 1986) & Signal features are recognized by the measurements of ToF, Time Domain waveform characteristics, frequency Domain Amplitude ratio, Time Domain Amplitude ratio, FAS (Chiou and Schmerr, 1991).On the basis of amplitude of reflected ultrasonic signals, the stages in ultrasonic testing (ndt) are (i) Detection and Localization, (ii) Characterization and Defect sizing, etc (Corneloup et al., 1994).

2. TECHNIQUES USED IN ULTRASONIC TESTING

Apart of flaw Detection which seems to be promising area, signal de noising (Praveen *et al*., 2012) i.e. removing unwanted noise signals from pure signals, Noise Reduction (Manjula *et al*., 2013) are of concern to locate the presence of flaws if any before ultrasonic testing techniques, By changing the properties of ultrasound wave pulse the presence of flaw is detected (silk, 1977). A review of different ultrasonic testing techniques is presented in this section. Ultrasonic testing techniques are of (i) Contect type (ii) Immersion type. The difference between two is that in contact type the probe face is in direct contact with test sample using suitable couplant and in immersion type the probe (water proof) is placed at a certain distance apart of test sample.

Digital Correlation Flaw Detection Method: The researcher (Lee and Furgason, 1983) adopted the paired pseudo_random algorithm, also named complementary golay codes. This method in comparison of earlier single Probe flaw detection system produce optimal correlation of detection for wide range of Sound to noise ratio condition and operating speeds. Self noise problem was beaten by golay code which occurs due to incomplete compression of pulse wave in correlation process.

Conventional Pulse Echo Method of Ultrasonic Testing: It is suitable for testing defects which are of small in size and used to detect internal flaws. The amount of total energy which is reflected to the receiver probe is utilised. But this gives poor details about the shape and size of the flaws (Lam and Tsang, 1985).

3. ADVANCED TECHNIQUES IN ULTRASONIC TESTING

Acoustic Holography or Phased sequential array techniques are some of the advanced techniques used in UT for imaging of defect in test sample. This is having limitation in practical applications due to difficult operation and is also less economical in nature. Analysis of diffracted signal from insonified defects brought one more approach where of diffracted signals are analyzed either in frequency (Ultrasonic Spectroscopy) or time domain (Lam and Tsang, 1985). A new algorithm was developed by Corneloup *et al*. (1994) based on ultrasonic image which permits detection of small-sized defects in austenitic stainless steel welds by combining spatio-temporal condition. This Code also permits the detection of large dimension defect and that located outside the weld.

Ultrasonic Time of Flight Diffraction Method (TOFD): TOFD is first discovered by Maurice Silk in 1974 adopted to detect, locate and size the defects. When ultrasonic wave pulse incidents on flaws, a part of the pulse get reflected, transmitted and also diffracted at the tip of flaws. Also the energy of diffracted wave spreads over large angles and can be picked up from test sample's surface. The measurement of time difference between the diffracted waves from the tips flaws results in tofd techniques. Because diffraction takes in space and its reception takes in time, it is known as ToFD (Baskaran *et al*., 2006).

Merits of Time of Flight Diffraction Method (Tofd): It is having high inspection speed. It results in high accuracy in sizing the defects. Subbaratnam *et al*. (2006a) proposed that it has better accuracies of quantitative characterization and faster scanning times.

Advantages of ToFD on X-ray technique (Mondal and Sattar, 2000)

- Higher POD and Cost effectiveness for wall thickness greater than 25 mm.
- Provides safety and is eco friendly due to absence any radiation.

4. DIFFERENCES BETWEEN TOFD AND OTHER ULTRASONIC TESTING METHODS (MONDAL AND SATTAR, 2000)

Diffracted energies are used in place of reflected ultrasonic energies (Mondal and Sattar, 2000) i.e. diffracted energy is considered in ToFD in place of other UT methods where total reflected energy is considered (Charlesworth and Hawker, 1984). A comparison between tofd and Pulse Echo techniques is given in Table No. 2.

Table 2: Comparison between Pulse Echo Ultrasonic Technique and ToFD

S. No.	Pulse Echo Ultrasonic Technique	ToFD
1	Not provide any signs of defects	Provide the signs of defects
2	Precise calibration of the amplitude is mandatory	No mandatory
3	No signal is received from the defect	Signal is received from the defect and measured it
4	With angular probes cannot determine the defect size	It can determine the defect size
5	Defect detection is dependent on defect orientation	Defect detection is not dependant on the defect orientation

Ultrasonic 1-skip ToFD: Shear wave is generated using longitudinal wave in ultrasonic ToFD method, because of mode conversion. Flaws near to surface (<10 mm from the surface) is not easy to be detected. Because lateral waves hide the flaw indication, one Skip ToFD technique and Signal processing is used for near flaws detection.

5. CONVENTIONAL TOFD USING LONGITUDINAL WAVE

Conventional ToFD technique using longitudinal wave uses the pulse transit time for dimensioning the flaw. Roughness of test sample's surface, transparency of flaw as well as orientation of flaw etc. Are used to influence the amplitude of reflected pulse. Taking in consideration the following parameters accurate flaw sizing can be obtained. ToFD was introduce as a suitable ultrasonic NDE technique for sizing defect and ToFD is limited to thickness greater than 15mm & thickness less than 5mm from scanning sample surface. Demerits related to conventional ToFD are (1) It result in overestimation of near Surface defects and (2) Applied for thick sections only.

Apart from these in B-scan image it is unable to detect echo of longitudinal diffracted waves. Since in thin sections the Spacing between Back wall Longitudinal reflected wave and Lateral wave is small .But from flaw the temporal spacing of shear wave signal is to be observed and by B-scan image ToF data is obtained

Shear wave ToFD: whenever a longitudinal incident wave front meets the flaw in the test specimen either longitudinal or compression diffracted wave and transverse diffracted wave will be generated. As the velocity for longitudinal wave (L) is two times the velocity for shear wave (S), L waves reach the receiver first followed by S waves. In s-ToFD, ToF measurements and accordingly flaw sizing are improved because of the smaller velocity of diffracted shear wave. Authors Baskaran *et al.* (2006) have shown the simulated result of surface crack of an aluminium sample using s-TOFD technique. In the process of detection of defect tips, the choice of frequency of transducer plays an important role. Proper probe angles must be maintained to do near-surface inspection.

Merits of s-TOFD: The merit of s-tofd is that longitudinal diffraction may superimpose. Accurate measurements of ToF calculations can be done from the defect's top tip transverse wave-diffraction echo. (Baskaran *et al*., 2006).

Immersion-ToFD: The lateral wave, diffracted waves and the back wall echo will be merged together in thin sections. Because of this, it is very difficult to identify and size the defect. The authors Subbaratnam *et al.* (2006b, 2011) given the new methodology to enhance the application of TOFD sections below to 3 mm. So ToFD is applied in different ways to detect the defects.

6. IMAGE SEGMENTATION CO-OCCURRENCE MATRIX ANALYSIS METHOD (MOYSAN ,1992):

Co-occurrence matrix is a 2d histogram which multiplies possibility and accuracy of image analysis. Authors' moysan et al. (1992) proposed a new type of segmentation method by adopting co-occurrence matrix analysis. Due to continuity in the repartition of amplitude discrimination between defects and noise was not allowed in the histogram of images. Due to the presence of grain noise in austenitic stainless steel welds, the detection of crack tip is very hard. The analysis of the above co-occurrence matrix using threshold makes the defects apart from material noise. The authors found that b-scan image analysis with the above technique will produce excellent outcomes in the form of segmentation of images of cracks in a weld.

7. SSP ALGORITHMS VS WAVELET TRANSFORM SIGNAL PROCESSOR:

SSP is also ultrasonic flaw detection algorithms based on Fourier transform such as STFT (Short Time Fourier Transform). And the signal's frequency spectrum is partitioned into a set of narrow band signals by adopting overlapping Gaussian pass-band filters along different centre frequencies & fixed absolute bandwidth to extract the flaw related information in the processing of Split Spectrum (Abbate *et al*., 1997).

Wavelet Transform is a set of wavelet basis function produced by scaling and translation of a mother wavelet. Wavelet Transform is used to suppress noise and to find flaw. It gives better resolution than STFT because of multi-resolution analysis of wavelet transform. It also better in detection of flaws in noise affected signals. In WT relative bandwidth is constant. MRA property of WT is utilised (Abbate *et al*., 1997) for detecting any flaw echoes from the background noise signal. Sub-band decomposition is also possible in DWT. In DWT, window acts as a set of scales that acts as BPF. Window is equivalent to BPF of split spectrum processing. The authors (Oruklu and Saniie 2004) found good results by adopting higher order kernels. When the measure of flaw-to-clutter ratio is <= 0 dB, using DWT. Authors (Oruklu and Saniie et al.2004) achieved the Flaw-to-clutter ratio enhancement in ultrasonic signal of 5-12 dB.

Signal Matching Wavelet for UFD: In WT domain the energy distributions of the noise and flaw or clean echo are different. To get optimal energy match between the flaw echo and the wavelet basis, two problems of (Concentration and Separation) must be solved:

The relation is: echo pulse signal = clean echo signal or flaw echo signal + Back ground noise.

Or, $Y(t)=r(t)+n(t)$

Here localized energy distribution of flaw echoes is given in WT domain, the transmitted signal s(t) is taken as mother wavelet w(t). The authors Shi *et al.* (2011) proved that the flaws efficiently detected using SMW also for SNR_I as low as -20dB.

8. MODEL BASED ENHANCEMENT OF THE TECHNIQUES FOR DETECTION OF FLAW ADOPTING DECONVOLUTION (JUNG *ET AL.*, 2003)

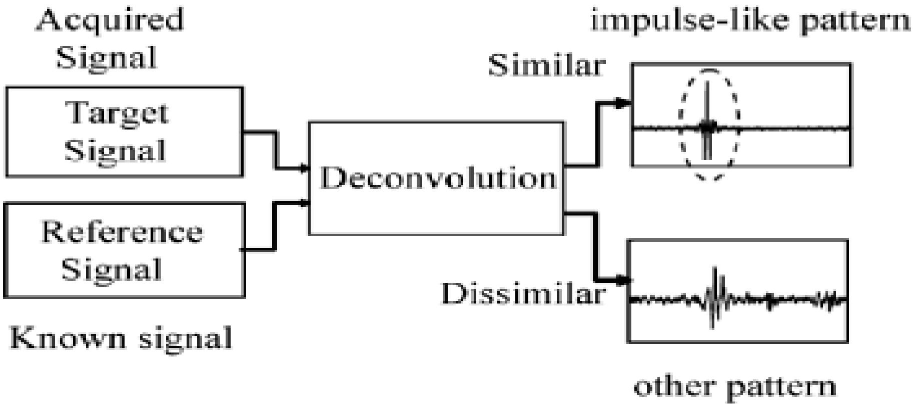

Fig. 2: A Schematic Representation of the TIFD

The traditional methods have considerable ambiguity since they are based on the subjective experience of inspection .However those usually require expensive equipment and time- consuming also expensive scanning. To overcome these difficulties a technique called TIFD was proposed.

The concept is simple. Let g(t) and h(t) be the reference and target signal respectively. Then deconvolution pattern, m(t), also called similarity function was defined as:

$$m(t) = g(t) \otimes^{-1} h(t) \qquad \ldots eq.1$$

where $\otimes - 1$ denotes deconvolution. When the reference and target signal are similar the deconvolution pattern of similarity function become sharp impulse like shape. Otherwise the deconvolution pattern will be quite different in its characteristics. Thus by comparing measured signal with a set of reference signal from non relevant reflectors. The major limitation of this type of TIFD was that various kinds of reference signals had to be obtained experimentally. Also the above approach was costly, time consuming and some time impractical.

Deconvolution is used to define a similarity function m (t) or deconvolution pattern, with target signal as g (t) and reference signal as h(t). Technique for Identification of Flaw Signals using Deconvolution i.e., TIFD is used to find various signals.

9. ACOUSTIC MICROSCOPY (SAM): Acoustic Microscopy or scanning ultrasonic is a type of technique which is able to detect and locate flaws. Here phase of the signal is also used in place of Amplitude and pulse arrival time. Because of which resolution increases and flaws image can be obtained on B, C and D type of scan (Ermolov, 2004).

10. SYNTHETIC APERTURE FOCUSING TECHNIQUE: Synthetic aperture focusing technique is a type of technique which is used to enhance image resolution and also increase SNR; here spatio-temporal correlation of signals is used by SAFT. If a defect which is to be found is at point (x_1, y_1), then the TOF from probe to the defect is given by Eq. 2:

$$t(x) = \frac{2}{c}\sqrt{(x - x_1)^2} \ldots\ldots\ldots\ldots\ldots\ldots eq.(2)$$

Here, c represents sound speed in material. The defects have similar hyperbolic ToF locus with the different depth and location, defect is found at the centre of the locus at every scan. The hyperbolic ToF loci have only one intersection which is known as the location of defect. When the entire 2-D radial images where added from each and every scan, a peak is visible at the region of presence of flaw (Liou *et al*., 2004). The authors Liou *et al*. (2004) for ultrasonic Flaw detection proposed the method of SAFT. The authors Liou *et al*. (2003) successfully detected the defects in solid materials.

11. ULTRASONIC PHASED ARRAY TESTING: Ultrasonic Phased Array uses number of probes each at different angle put together in single unit .Because of less sizes of probe elements its cost is high. The output pulse of every probe element is time delayed to produce interference at specific depth and at a specific angle. To sweep the beam over the preferred angular range the time delays can be incremented over the range of angles (Birring, 2008). Birring (2008) have found that PA has ability to detect the discontinuities of weld samples. And 100% of detection of discontinuities is done by him.

Discussions: By considering the changes in backscattering noise and ultrasonic velocity measurement , micro structural change in stainless steel can be detected(Kawashima *et al*, 1996).Also Ido *et al*. (2004) for detecting the flaws in the material whose thickness is 10 mm .i.e. Near surface inspection used the technique known as one skip ToFD. The authors (Lee and Furgason, 1983) used the s-ToFD to find the flaws which are very close to the scanning surface with this technique an improvement of 20-35% is observed in comparison to conventional time of flight diffraction technique. The authors (Baskaran *et al*., 2006) stated that near-surface defects can be found using 5 MHz transducer frequency and with probe angles of 40-50°. Abbate *et al*. (1997) found improvement in detection using steel samples with simulated flaws. The authors (Dijkstra and Bouma, 1996) discussed the ToFD technique for weld defect detection also some authors have found ToFD to be more. The authors Shi *et al*. (2011) proposed ToFD technique to be more probable for detecting weld defects and thick layers of steel. ToFD can be utilised for testing fabricated pressure vessel components in place of traditional NDT methods is concluded by Prabhakaran *et al*. (2004) .The authors Sinclair *et al*. (2010) and Chen *et al*. (2005) proposed the a technique of signal processing based on empirical mode decomposition (emf) and hilbert transform (HT) to obtain better time resolution of the ToFD signal, exact sizing along with location of deeper flaws. The authors Lalithakumari *et al*. (2011) have worked for improving the efficiency of defect detection by multiple scans of materials in SAFT technique; Liou *et al*. (2004) with the help of hyperbolic TOF loci found the images with better resolution and located the defect. The authors Ahmed *et al*. (2005) stated the new technique for detecting flaws in ToFD type ultrasonic images based on 2D Gabor functions and Fuzzy c_mean clustering classifier. Bossuat *et al*. (2006) proposed the application of ToFD for mechanical engineering for detection and dimensioning of mechanical component. One of the authors Birring (2008) also concluded that the output of PA image was easy in interpretation for discontinuity detection and characterization in comparison of A-scan ultrasonic testing. The usage of ToFD to inspect materials than that of other NDT procedures was proposed by Charlesworth and Temple (2001) .The authors Cao *et al*. (2010) proposed that ToFD (B-scan ultrasonic image) based on edge detection was accurate to detect the defects. Chang and Hsieh (2002) proposed ToFD imaging for double-probe reflection to process the image and to detect the non-horizontal flaws.

Conclusion: From above review we can point out that many ultrasonic techniques and algorithms are used to detect the defects in weldments. The defects can be detected based on (A scan, B scan, C and D scan, Phase of signals or Diffracted signals, also on SNR. Each and every technique has some advantages and limitations Such as in SMW flaws even from input SNR is -20 Db the defect can be detected. Whereas Acoustic Holography takes high equipment cost thus is not suitable for practical application. On the other hand ToFD involving longitudinal wave is suitable for thick sections only. To overcome the difficulties Shear wave-ToFD is used to inspect near surface and thin sections defects. i-ToFD gives better result in thin weldments. SAFT is a technique used to enhance image resolution and improve SNR, and the technique of using Phased Array us to detect the defects using multi element transducer is growing concern in now a day because of its easy and good accuracy in minimum time.

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