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Studies on the Influence of Various Factors in Ultrasonic Flaw Detection in Ferrite Steel Butt Weld Joints

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Abstract Parametric studies have been conducted into the variability of the factors affecting the ultrasonic testing applied to weldments. The influence of ultrasonic equipment, transducer parameters, test technique, job parameters, defect type and characteristics on reliability for defect detection and sizing was investigated by experimentation. The investigation was able to build up substantial bank of information on the reliability of manual ultrasonic method for testing weldments. The major findings of the study separate into two parts, one dealing with correlation between ultrasonic techniques, equipment and defect parameters and inspection performance effectiveness and other with human factors. Defect detection abilities are dependent on the training, experience and proficiency of the UT operators, the equipment used, the effectiveness of procedures and techniques.

Keywords: ultrasonic flaw detection, ferritic steel weld, operator reliability, couplant effect, equipment, transducer

1. Introduction

Ultrasonic inspection is one of the most powerful quality assurance tool used for detection and sizing of serious welding defects. However ultrasonic testing is highly subjective test and several factors influence the performance of ultrasonic test results. Trained and certified personnel are required for performing this test. The test results could vary from operator to operator having the same qualification but different degree of skills and experience. The flaw detectors, the transducer parameters, surface condition of the job, couplant used and type of defects and their orientation significantly affect the detectability and sizing of defects[1-4]. The usual ultrasonic inspection procedures based on echo techniques rely on the determination of the echo or signal amplitude. Detection is obviously dependent on the amplitude of response of any flaw,. whereas sizing is based on equi-amplitude curves (6dB drop techniques) or is performed by comparison with the amplitude of a specified reflector. Thus the amplitude of the received signal is the dominant parameter.

2. The Study

The experiments were carried out on a ferritic steel butt weld with various defects including porosity, incomplete penetration, excess penetration, longitudinal cracks, and transverse cracks of known length at predetermined locations. Both digital and analog flaw detectors

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were used for the experimentation. Equipment parameters like damping etc. were varied to verify the performance of the test results. Ultrasonic transducers both longitudinal and shear wave of frequency varying from 2 to 4 MHz and the angles ranging from 45° to 70° were used during this study. Pulse echo contact technique with single probe, double probes, and focused probes were used. DAC method and DGS scales were used and compared for sizing of defects. Amplitude based sizing techniques (6dB and 20dB drop methods) were used. The effect of coupling on the effectiveness of ultrasonic technique has been studied by varying the couplant. A few exercises were conducted to understand the influence of types of their defects on detection and sizing. In the experimental work Reference Echo (RE) refers to 100% DAC curve plotted with the Side Drilled Hole (SDH) of dia 2.4 mm.

2.1. The Round Robin Test (RRT) on weld pad with intended defects

The test pad with butt weld was fabricated from carbon steel (SA213). The defect free plates were joined together by Single V edge preparation, Manual Metal Arc Welding[5]. By using special techniques, the defects of both voluminar and planar types were introduced at the predetermined locations. These defects included cluster of porosity, incomplete penetration, excess penetration, lack of fusion, longitudinal cracks, transverse cracks etc. The location and the length of the defects were confirmed by Radiography. The position in depth of the defect varies from 3 mm to 17 mm in plate thickness of 18 mm, length of 330 mm. The test pad was finally machined on one surface and left as welded condition on the opposite surface. (Refer Figure 1 & Table 1).

2.2. Procedure used to fabricate the defects

The cluster of porosities was obtained by contaminating the area to be welded with evaporated paint. The hot cracks were induced by using an inconel electrode. Cold cracks were obtained by using electrode with 1.2%C. The Incomplete Penetration (ICP) and Excess Penetration (EP) were induced by deliberately manipulating the current voltage and the speed of welding[6].

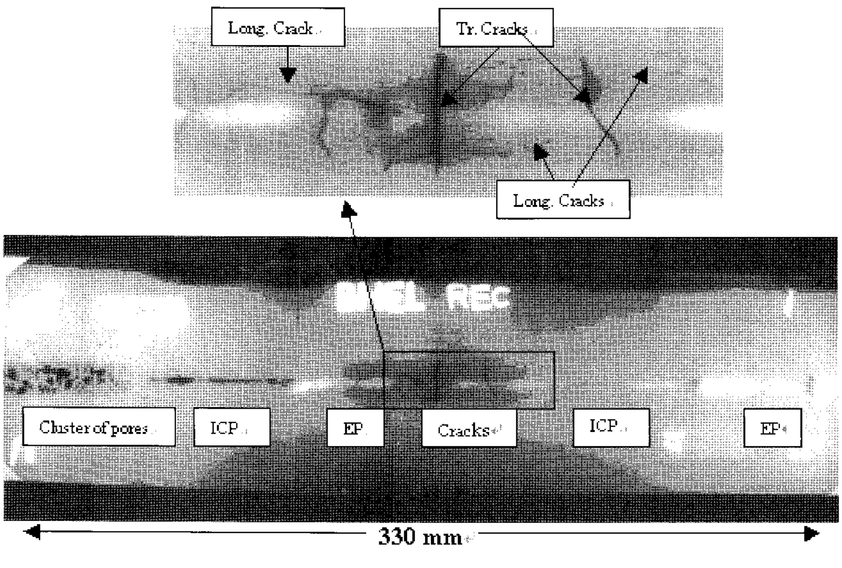

Figure 1 Radiograph showing planar location of different defects in the weld pad

Table 1

Identification of defects	Type of defects	Planar location of defects (mm)	Defect length (mm)
A	Cluster of pores	0 - 40	40
B	ICP	50 - 115	65
C	Excess penetration	115 - 135	20
D	Longitudinal cracks with branches (slightly to the left of center line)	135 - 170	35
E	Longitudinal cracks with branches	170 - 220	50
F	ICP	230 - 250	20
G	Excess penetration	280 - 330	50
H	Transverse crack across centerline	170	20
I	Transverse crack across centerline	195	12

3. Comparative Performance of Digital vs Analog Flaw Detectors

The comparative study was aimed at defect detection, location & sizing using the digital equipment EPOCH-2 (Parametrics) and analog equipment USL-32 (Krautkramer) make. Angle beam 45°, 4 MHz transducer was used for inspection and a calibration block with SDH of dia 2.4 mm was used for arriving at inspection sensitivity. The experimental results have shown that the digital equipment performed better as compared to analog equipment with respect to detection, planar location and cross sectional location of the defects. However the digital equipment used for the study required higher amplification (59.1 dB) as compared to analog equipment (42 dB) for the given sensitivity level. Both the equipment could detect all the defects in the weld. The planar length of defect B (ICP) was equally estimated by both the equipment, but the cross sectional depth was under estimated by the digital equipment. The defects D & E (cracks) were detected by both the equipment but the digital equipment has shown higher sensitivity. With respect to defect A (cluster of porosities), both have shown poor performance in detection and sizing. With digital equipment, the severity of the defect could be measured with an accuracy of 0.1 dB as compared to analog equipment with a minimum variation of 2 dB. The consolidated results are shown in Figures 2 (a) & 2 (b).

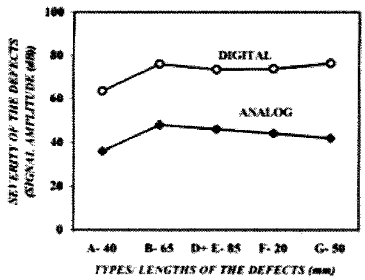

Figure 2(a) Comparison of digital and analog equipt. for detection of defects

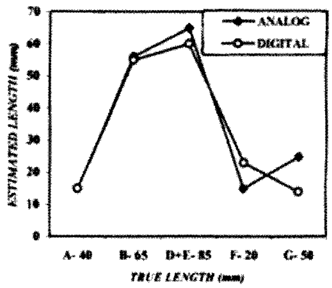

Figure 2(b) Comparison of digital and analog equipt. with respect to sizing of defects

4. Variation of Transducer Parameters

4.1. Angle variation

Most of the critical weld defects are planar in nature and are oriented at an angle to the test surface. The selection of the appropriate angle for detection of these defects depends on the thickness and the geometry of the weld[7-9]. Generally, three angles 45°, 60° & 70° should be good enough to detect most of the weld defects. However it is essential to study the effect of particular angle with respect to detection and sizing of the defects[10]. The experiments were carried out using digital equipment EPOCH-2 (Panametrics) in combination with Krautkramer 4 MHz probe. The experimental observations revealed that all the three angles could detect the cluster of porosity, to an extent of 1/2 the length of area occupied by the pores (40 mm). However 70° probe could estimate the length and depth of the pores better than 60° & 45° probes. Sensitivity of the porosity varied from (RE-6) for 70° to (RE + 4.7) for 45° . All the three angles (45°, 60° and 70°) revealed ICP fairly accurately ranging from 64 mm for 60° to 68 mm for 70° and 45° as against the actual length of 65 mm. Severity varied from (RE + 6) for 70° to (RE + 14.7) for 60° and (RE + 13.4) for 45° . Hence 6 0° probe found to be most effective for the detection of ICP for the given thickness. The cracks were detected to different degrees by all the three probes. 70° and 45° probes could detect around 35 mm length of crack as against 85 mm length of longitudinal crack with the branches whereas 60° could detect only 15 mm length. The 70° probe has shown the highest sensitivity to cracks with (RE+ 14.4) as against (RE + 5.6) for 45° and (RE + 5.5) for 60° . Figures 3(a) & 3(b) shows the performance of different angle beam probes.

4.2. Frequency variability

Generally for the examination of ferritic steel welds, ultrasonic frequency in the range of 2 to 4 MHz is recommended. Variation in frequency affects the sensitivity and resolution of flaw detection[9,11]. Hence the experiment was carried out to compare the performance of 2 & 4 MHz transducers. The digital equipment used for the detection and sizing was EPOCH-2 (Panametrics) in combination with the angle beam MWB 45° probe. The experimental results revealed that most of the defects were detected using 2 & 4 MHz probes but there is a marginal variation with reference to location and sizing. Using 4 MHz, the cracks and ICP were detected with high amplitude as compared to 2 MHz. Porosity was detected by both, but the planar length of the area occupied by the defect was underestimated. The 2 MHz probe required lesser gain i.e., 49 dB as against 59.1 dB for 4 MHz probe for the given sensitivity with respect to SDH of dia 2.4 mm. Defect C (excess penetration) was detected only by 2 MHz. The performance of these probes is shown in Figures 4(a) & 4(b).

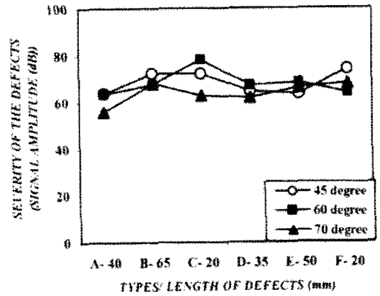

Figure 3(a) Comparison of different angle proves with respect to detection of defects

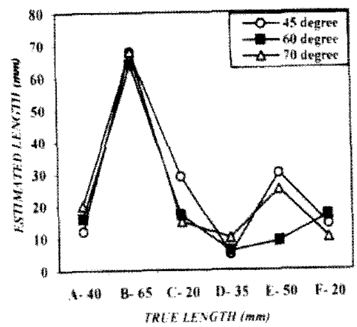

Figure 3(b) Comparison of different angles of probes with respect to sizing of defects

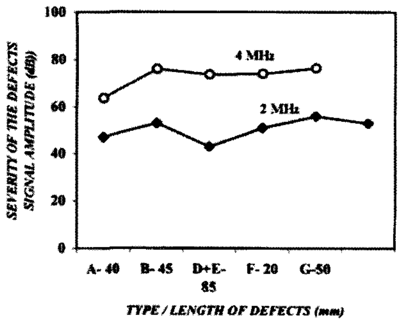

Figure 4(a) Comparison of 2 and 4 MHz probes for detection of defects

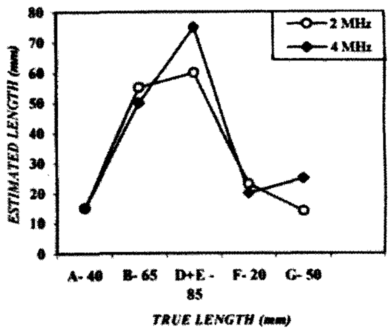

Figure 4(b) Comparison of 2 and 4 MHz probes with respect to sizing of defects

5. Defect Detection and Sizing Techniques

5.1. DGS vs DAC

The DGS technique uses curves which represent the echo amplitude that could be obtained from an ideal smooth disc reflector (FBH) placed at normal incidence to the probe beam at various ranges. The probe is scanned over the defect of interest to obtain the peak echo amplitude and the equivalent size of the defect is found by reading off from the curves, the size of disc reflector at the same range at normal incidence. The equivalent defect size will approximate the true size if the defect is smooth and at normal incidence to the probe beam. Most real defects will deviate from this ideal and give weaker echo amplitudes. The DGS sizing technique will thus considerably underestimate the true size of such defects[12], whereas the DAC method makes use of standard reference blocks with artificial discontinuities such as SDH and notches. The diameter of the SDH and the percentage of notch depth in terms of the job thickness govern the sensitivity of the test. The gain required to set the signal amplitude (80% of FSH) from the nearest reflector determines the sensitivity. However to compensate the attenuation of energy, a curve is plotted by joining the signal amplitude received from SDH at different depths. This curve acts as a reference curve for accepting the defects and flaw size determination by dB drop methods (6 dB and 20 dB drop methods) is used[13].

In flaw size determination, one must first determine whether the flaw is a "large reflector" i.e. larger than the sound beam or a "small reflector" i.e. smaller than the sound beam. The size of a large reflector is determined by scanning the borders of the flaw with the ultrasonic beam. Small reflectors although scanned with the beam, their sizes are estimated by comparing with the maximum echoes of flaws of known sizes. The experiments were carried out using Krautkramer equipment (USL-32) in combination with MWB 45° transducer. A reference block with a SDH of 2.4 mm was used for determining the sensitivity for DAC method and for DGS scale, D/E series- MAD 4424 with a FBH of dia 3 mm was used for DGS method. The experimental results revealed that, with the given sensitivity, DGS & DAC methods could detect the presence of cluster of pores and the planar defects. The defects ICP were underestimated by DGS method. So far as cracks are concerned, both the methods detected & sized fairly accurately. DAC method is found to be more operator friendly as compared to DGS method. Figures 5(a) & 5(b) show the performance of DAC & DGS methods with respect to detection & sizing.

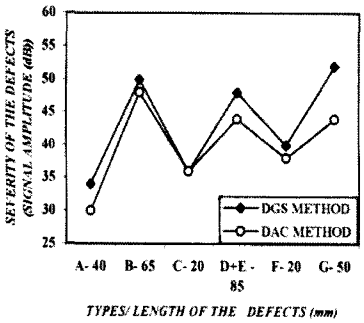

Figure 5(a) Performance of DGS & DAC methods for detection of defects

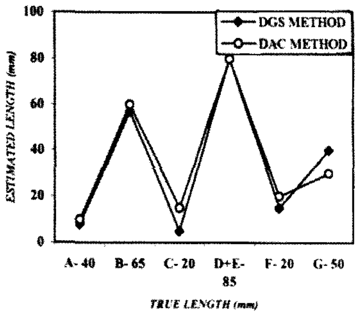

Figure 5(b) Performance of DAS & DGS methods for sizing of defects

5.2. Single Probe vs Tandem Probe Techniques

Experiments were carried out using digital equipment Panametrics (EPOCH-2). The transducer used for tandem probe technique was KBA Krautkramer 45° / 5 MHz. MWB 45° / 4 MHz probe was used for single probe technique. Tandem probe technique has not shown much advantage with reference to detection and planar location of defects[14]. It slightly overestimated the defects like ICP, whereas it has shown less sensitivity in detection and sizing of cracks (D & E). However it has precisely detected and sized defects (C & G) like excess penetration. It also responded better for voluminar defects like cluster of pores (A). The transverse cracks H & I could be detected only by tandem probe technique. Figures 6 show the performance of detection sizing of tandem & single probe techniques for detection and sizing of defects.

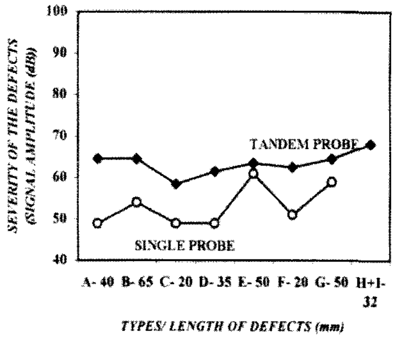

Figure 6(a) Performance of tandem & single probe techniques for detection of defects

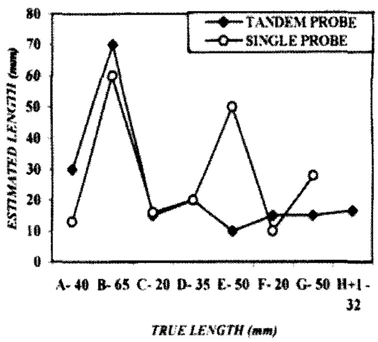

Figure 6(b) Performance of single & tandem probe techniques for sizing of defects

6. Importance of the Couplant

Studies on the effect of human factors have shown that couplant effects are very important. It has been observed that loss of coupling can correspond to half of the inspected surface. Coupling maintains the stability of response to within 3 or 6 dB otherwise there is the risk of a serious loss of information (1). In the case of the contact testing the amplitude of the echo depends on the type, amount and uniformity of the pressure exerted on the probe as well as on the characteristics and the thickness of the couplant medium and the roughness of the surface of the test piece (15). Different types of couplants were used to carry out the experimental work using the digital equipment Panametrics (EPOCH - 2) in combination with MSEB 4H 10mm dia probe using FBH of 2 mm dia as the reference block. Experimental observations revealed that for a fixed gain of 71.6 dB, the echo amplitude from 2mm flat bottom hole (FBH) was recorded. Glycerin is found to be the best couplant with maximum echo amplitude among the couplants used (Glycerin, Water, Grease, Grease + Oil and Oil). Though water has shown second best performance in terms of echo amplitude, in practical situation, for contact testing it is difficult to apply water uniformly on the surface. However grease or grease + oil are the most practical alternatives to glycerin in terms of coupling efficiency and cost. Figure 7 shows the performance of different couplants used.

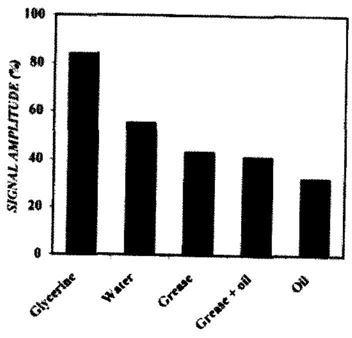

Figure 7(b) Performances of different couplants for contact testing

7. Operator Reliability

One of the main sources of error in ultrasonic contact inspection arises from the human element, and one way of increasing confidence in reliability is to minimize human errors[10,16]. However in many cases it is not feasible to fully automate, and the inspection has to be performed manually, in which case, the skills, knowledge and reliability of the operator are crucial to the effectiveness of the ultrasonic inspection. Results from the round robin trials carried out have shown the wide range of variations that can occur between different operators[17,18]. There are several possible causes for the observed variations, these ranging from different manipulator skills, data interpretation and operators concept of the requirement of the task. A limited study on the operator performance was carried out with four operators with different educational qualifications, NDT experience and the time devoted to ultrasonic test. (Refer Table 2). The equipment used for this study was Panametrics (EPOCH-2) in combination with MWB 45° / 4 MHz probe. Figures 8(a) & 8(b) show the performance of the operators with respect to detection & sizing of the defect.

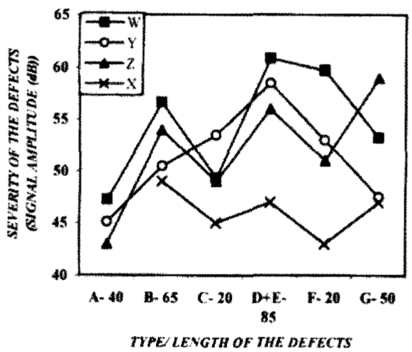

Figure 8(a) Operators performance with respect to detection of defects

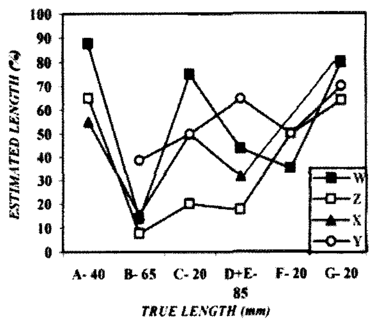

Figure 8(a) Operator performance with respect to sizing of the defects

Table 2 Operator performance on NDT Experience

Operators	Qualification	Experience	Time devoted to UT(%)
X	B.Sc UT Level-I	5 years	25
Z	M.Tech (NDT) UT Level - II	20 years	50-60
Y	M.Tech (NDT) UT Level - II	7 years	10
W	M.Sc	3 months	5

8. Conclusion

The parametric study has revealed that ultrasonic test results are influenced by several factors and it is essential to understand the causes of variability so that changes and improvement can be made to promote a more uniform standard of inspection.

Digital flaw detectors have shown definite advantages over the analog flaw detectors in terms of precise detection, location and sizing of weld defects. With digital equipment, the severity of the defect could be measured with an accuracy of 0.1 dB as compared to analog equipment with a minimum variation of 2 dB. The use of supplementary techniques such as Tandem and Special probes has a very important influence in determining the capability of a procedure. The appropriate angle and frequency of the probe has got significant influence on detection and sizing of weld defects. A defect can be more reliably characterized and sized if it is inspected by more than one probe. Use of a range of beam angles can help distinguish

Table 3 Analysis of operator performance

Operators	Number of defects detected	Types of defects	Detect size underestimated (%)		Defect size overestimated (%)		Error in planar location of defect (%)	Severity	Remarks
			Length	Depth	Length	Depth			
W	7	Voluminar defect	87.5	–	–	50	5	Low	Cluster of porosity was poorly detected. Length of planar defects underestimated. High amplitude has been recorded for ICP & crack.
		ICP	22.5	13.89	–	–	–	High	
		Crack	43.5	10	–	–	5	High	
X	6	ICP	38.4	10	–	–	–	Low	Could not detect volumetric defect. Defect length grossly underestimated. Low amplitude recorded for crack & ICP.
		Crack	64.7	10	–	–	5	Low	
Y	7	Voluminar defect	75	3.8	–	-	5	Low	Overestimated the length of ICP & underestimated cracks. Location of defect fairly accurate.
		ICP	–	6.1	15.38	–	5	Low	
		Crack	31.8	-	-	60	5	High	
Z	7	Voluminar defect	67.5	-	-	-	25	Low	Slightly underestimated the length of ICP & cracks. Location of defect is fairly accurately marked. High amplitude has been recorded for ICP & cracks.
		ICP	8.3	20	-	-	-	High	
		Crack	17.6	5	-	-	-	High	

volumetric from planar defects: a volumetric defect will tend to give similar echo amplitudes for each probe, while a planar defect will give much stronger echoes with those probes which interrogate it close to normal incidence. The choice of a suitable and accurate technique and its correct application are essential for effective sizing. DAC method is found to be more operator friendly compared to DGS method. The qualification, training and hands on experience of the ultrasonic test operators have got tremendous influence on the reliability of the test results. On an average, during weld evaluation, undersizing occurs more frequently than over sizing of rejectable defects. Glycerin is found to be the best couplant for contact testing.

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