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Ultrasonic Test in Ferric Steel, Stainless Steel and Welded Ferric Steel, Welded Stainless Steel

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***Abstract*— The aim of this paper is to experimentally comparing the factors those are affected by the grain structure which are responsible for the energy loss of ultrasonic waves and to minimizing the energy loss in the stainless steel. The factors such as, "Scattering of Ultrasonic Waves, Signal to noise ratio, and Beam Skewing. The four materials selected for the experimental comparisons are namely, Ferric (Carbon) steel, Stainless steel (Austenitic) parent material, Welded Ferric steel and Welded Stainless steel material. Stainless steel materials were widely regarded as uninspectable by ultrasonic testing, because of its grain structure, which are large in size and solid as a whole. When the Ultrasonic sound waves travels in such a medium, they get reflected at each grain boundary. Reflections will not be regular but will take the form of scattering in all direction. In order to detect the defect in stainless steel, there exist a lot of limitations. Even today, when Stainless steel material is mentioned the practiced ultrasonic tester also experiences the feeling of uneasiness.**

Keywords*— *Stainless steel, ultrasonic Testing, Beam Skewing

I. INTRODUCTION

Ultrasonic techniques are very widely used for the detection of internal defects in material, but they can also be used for the detection of small surface cracks. Ultrasonic are used for the quality control inspection of part processed material, such as rolled slabs, as well as for the inspection of finished components. Sound waves are elastic waves which can be transmitted through both fluid and solid media. The audible range of frequency is from about 20Hz to 20KHz, but it is possible to produce elastic waves of the same nature as sound at frequencies up to 500MHs. Elastic waves with frequencies higher than the audio range are described as ultrasonic. The range of frequency used in ultrasonic testing is from less than 0.1 to greater than 1.5MHz. For most application the frequency used below 10MHz.

All sound waves both audible and ultrasonic are produced by vibrating bodies. A sound or ultrasonic wave propagates through a medium as waves of particle vibration. The actual particle does not move and it is the wave or the energy that displaces the particle which is moving progressively.

II. WAVE FORMS

If sound waves are measured from trough to trough from crest to crest, the distance is always the same and it is known as the wavelength (λ). The time taken for the travel a distance of one complete wavelength is the same amount for the source to execute one complete vibration. The velocity of sound (v) is given by the equation; where, "f" – is the frequency.

$$V = \lambda f$$

On the basis of mode of the particle, displacement, ultrasonic waves are classified as longitudinal waves, transverse waves, surface waves and limbs waves. All these waves' forms are used in non – destructive inspection of metal to varying degrees.

III. WAVE GENERATION

When a tuning fork is struck with a mallet, it vibrates and produces sound waves by compressing the air. These waves travel through air to the ear of the listener. The tuning fork vibrations soon die out and no longer produce waves. Similarly, in ultrasonic testing, a short pulse of electrical current nits or excites a transducer (crystal) which vibrates as did the tuning fork. The sound beam from the transducer then travels through a couple, which may be water, oil, etc., to the front surface of the test piece. Fig 1.1 Shows the transducer, in contact with the test piece, with the sound, beam pulses travelling through the piece.

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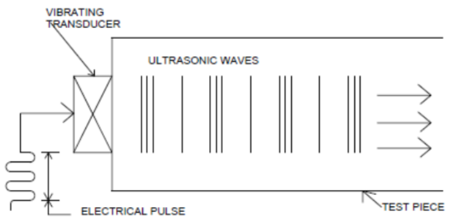

Fig 1.1 Ultrasonic Wave Generation

IV. PIEZOELECTRICITY

In actual practice, a high frequency transmitter applies electrical pulses to a "PIEZO – ELECTRIC" crystal. The prefix "PIEZO" is derived from a Greek word meaning "TO PRESS". Field electricity refers to a reversible phenomenon whereby a crystal, when vibrated produces an electric current, or conversely, when an electric current is applied to the crystal, the crystal vibrates.

This crystal then transforms the electric energy in to mechanical vibrates and transmits them through as coupling medium, such as water or oil, into the test material. These pulsed vibrations propagate through the object with a speed depending on, among other factors, the density and elasticity of the test material. These pulsed vibrations propagate through the object with a speed depending, on among the factors, the density and elasticity of the test material. In many ways high frequency vibrations react in the same way as light. For example when they strike an interrupting object, they reflect most of the sound beam energy. These reflections may then be picked up by a second or, most cases by the same crystal or transducer. Ultrasonic waves are reflected as echoes from the discontinuity and the back surface of the test piece. The echo from the discontinuity is received before the back reflection is received.

V. WAVE TRAVEL MODES:

All materials are made up of atoms (or tiny particles) lined up in straight lines to form lattices as shown in fig 1.2. If we strike the side of this lattice we find that the first column of atoms strikes the second column which in turns the third column and so on in sequence. This motion produces a wave movement in the direction shown. In this case the particle – movement in the direction is the same as wave movement direction. This type of sound wave motion is called the longitudinal or compression wave mode.

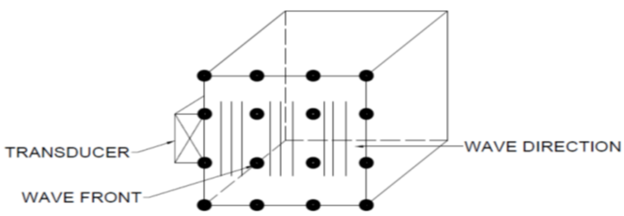

Fig 1.2 Longitudinal Wave Mode

VI. COMPARISON OF LONGITUDINAL & SHEAR WAVES MODES

Fig 1.3 shows two transducers generating ultrasonic waves in the same piece. Note that the transducer on the right is producing a different kind of wave. These waves are called shear waves are called shear waves because the particle movement direction is at right angles to the wave – movement direction. The velocity of shear wave is approximately half of the longitudinal waves. Note, that the right hand transducer is mounted on a plastic wedge so that the ultrasonic waves generated by the crystal enter the material at a specific angle, depending on the velocity of sound beams travel within material.

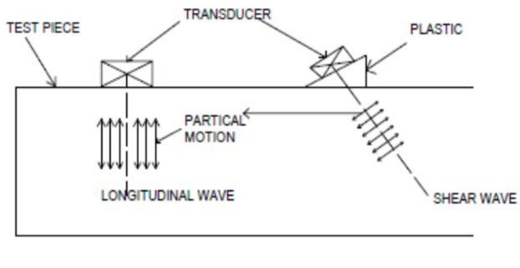

Fig 1.3 Longitudinal & Shear Wave Modes

VII. SNELL'S LAW

When the sound beams velocities in the couple used in lamination testing, on the wedge material used in contact testing, are different than the sound velocity in the specimen, the longitudinal (L) beams passing through the wedge or couple are refracted when the sound beam enters the test material. Incident on refracted angles are computed by a formula developed from Snell's law, after Willebrord Snell or Snellius, C.1621, a Dutch mathematician. For use in ultrasonic, Snell's law has been modified slightly from its original application, which was meant to explain optical refraction.

The following formula may be used to calculate the incident angle the resultant refracted angle, and the mode of materials, including solids immersed in water, oil, or other couplants.

$$\frac{\sin \phi_1}{\sin \phi_2} = \frac{V_1}{V_2}$$

Where, ϕ_1 – Incident angle from normal to the beam in the liquid or wedge

ϕ_2 – Angle of refraction beam in the test material

V_1– Velocity of the first medium, V_2– Velocity of the second medium

VIII. PROPERTIES OF ULTRASONIC WAVES

In many ways respects ultrasonic waves resembles light waves. It travels with a characteristics velocity in a given material depending upon the type of material. It is reflected at surfaces and is refracted when crossing a boundary between two substances and diffracted at edges. They are also attenuated depending upon the acoustic impedance of the material or which they travel.

IX. ACOUSTIC IMPEDENCE:

Wave propagates in solids and depends on the resistance of the atoms of the solid to vibrate when a force is applied; that is the acoustic impedance Z. In ultrasonic testing, cracks, boundaries, or inclusions are detected by the change in Z between the different media, when scattering and reflection in selection of suitable material for effective transfer of acoustic energy between components.

X. ULTRASONIC BEAM – ZONES:

An ultrasonic beam can be divided into three zones, they are Dead Zone, Near Zone, Far Zone

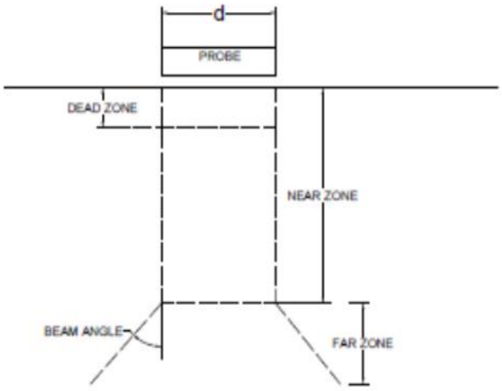

FIG 1.4 ULTRASONIC BEAM SHAPE

A. *The Dead Zone:*

Fig shows that this is the distance below the surface of a material in which a defect cannot be detected .It is not possible to detect a flaw during this ringing time. If the crystal is mounted in a suitably dimensioned block of Perspex that dead zone the dead zone can be wholly contained within the probe back. However, signals from defects close to the surface may still be lost in the interface echo.

B. *The Near Zone:*

The near zone is the zone in which the beam is almost parallel sided. The length N, of the near zone is given by the approximate relationship.

$$N = d^2/4\lambda$$

Where, 'd' is the crystal diameter, and 'λ' is the wavelength. The detection sensitivity is not constant throughout the near zone and is greatest towards the fur end of this zone.

C. *The Far Zone:*

The far zone is the region beyond the near zone where beam spread occurs, and within this zone the sensitivity decreases with the square of the distance from the crystal.

XI. ULTRASONIC TEST

Ultrasonic test equipment comprises of an ultrasound generator, receiver and its amplification and display systems. Each part has got its own role to play to obtain realistic representation of homogeneity of component being tested. The main types of equipment used in ultrasonic testing of metals are

1. Pulse-echo type
2. Resonance type

Pulse –echo type equipment's are used for flaw detection

Fig 1.5 Ultrasonic Testing Equipment

XII. TRANSDUCERS

Transducers are made in a limitless number of sizes and shapes from extremely small to wide paint brushes types. The many shapes are the result of much experience and requirement for many applications. Size of the transducer straighter the sound beam (less beam spread) for a given frequency. The narrow beams of the small high frequency transducers have greater ability for detecting very small discontinuities. The larger transducers transmit more sound energy into test part and so are used to gain deeper penetration. The large single crystal transducers are limited to lower frequencies because the very thin high frequency transducers; are susceptible to breaking and chipping. Depending upon the construction and modes of waves transmitted, the transducers are classified as normal probe, angle beam probes, double probes, focusing probes etc.

XIII. STANDARD REFERENCE BLOCKS

The IIW (INTERNATIONAL INSTITUTE OF WELDING) reference block, and the miniature angle beam field calibration block, shown in fig 3.6(a,b). are reference and standard in common use. For irregularly shaped articles, it is often necessary to make one of test articles into reference standard. In other cases, a special individual technique is developed by careful study of an article ultrasonically, and then verifying the detection of discontinuities, in the article, by destructive investigation. The results of the study then become the basic for the testing standard.

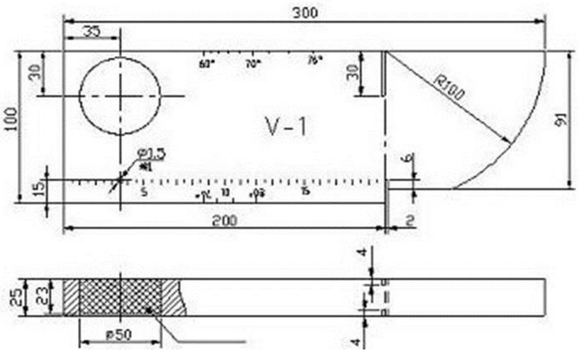

Fig 1. 6 V-I Block

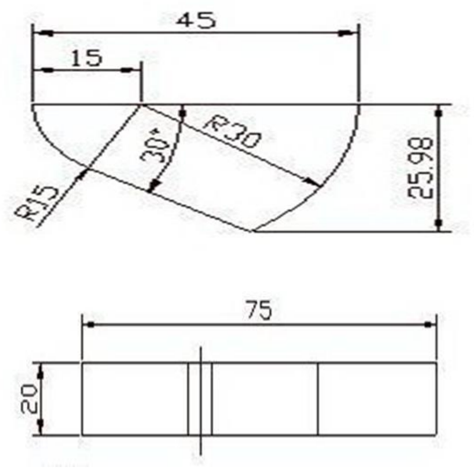

Fig 1.7 V-Ii Block

XIV. STAINLESS STEEL (AUSTENITIC) WELDMENTS

The properties of any metals are affected not only by the character of phase present, but also by the size of grains that are present in the structure. Practically all metals used in everyday life are polycrystalline in their structure. Polycrystalline solid are made up of very large number of grains, having microscopic dimensions of the material. Each of the grains is itself a single crystal and thus in general anisotropic. However, because the grains are oriented at random and because they exist in very large numbers, the solids as a whole, from statistical considerations, displays isotropic properties. When the sound waves travel in such a medium, they get reflected at each grain boundary. Reflections will not be regular but will take the form of scattering equally in all direction.

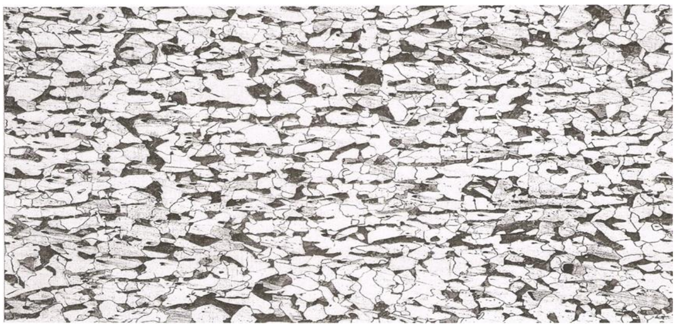

Fig 1.8 Grain Structure of Ferric Parent Steel Material

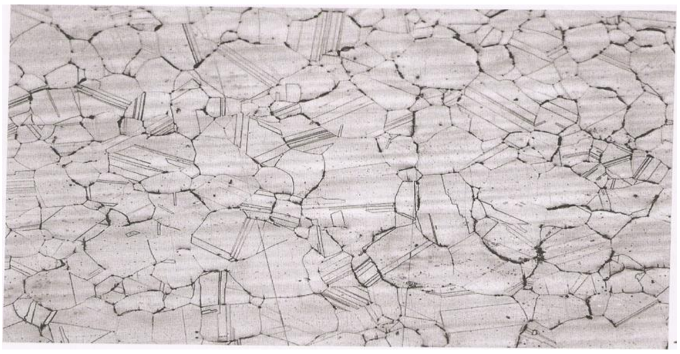

Fig 1.9 Grain Structure of Stainless Steel Parent Material

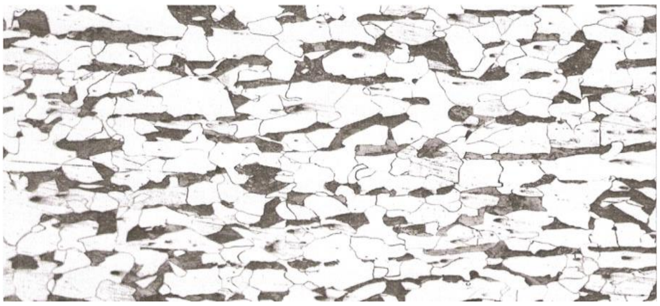

Fig 1.10 Grain Structure of Welded Ferric Material

Fig 1.11 Grain Structure of Welded Stainless Steel Material

The grain size is noted as a number called ASTM (American Society for Testing Materials) number. For example ASTM no 3 represents 64 grains per mm^2
The size, the arrangement and the elastic anisotropy of the different grain result in high scattering associated with mode conversion effects, beam distortion, and a variation of ultrasonic velocity with direction and position in the weld. The scattering energy is observed as a relatively high noise level end high attenuation.

XV. OBSERVATION AND TABULATION

In this paper three major problems associated with ultrasonic testing of austenitic stainless steel is practically studied using reference blocks and test piece. The problems selected are

A. Scattering due to different grain size both Ferrite and stainless steel blocks.
B. Signal –to –noise ratio in Ferrite and different steel blocks.
C. Beam skewing phenomena in Ferrite and stainless steel blocks

TABLE 1 COMPARISON OF BACK WALL HEIGHT BETWEEN THE MATERIALS (EXPERIMENT 1)

Thickness of sample -25 mm

Probe used - Normal probe (4MHz)

Echo type - Back wall echo

MATERIAL TAKEN	FIRSTECHO %	SECONDECHO %	THIRDECHO %	FOURTHECHO %
Ferric parent material	80	58	39	25
Stainless steel parent material	50	34	21	16
Welded Ferric material	60	32	16	8
Welded Stainless steel material	30	20	11	0

A. SCATTERING DUE TO DIFFERENT GRAIN STRUCTURE

Select Ferric steel, parent stainless steel and welded stainless steel, welded ferric steel blocks of same thickness. The probe is placed on the artificial defect created in the blocks. A constant pressure was given to the probe during whole experiment. The differences in dB are noted in four materials.

TABLE 2 SCATTERING DUE TO DIFFERENT GRAIN SIZE (EXPERIMENT 2)

PROBE USED		HOLE DEPTH mm	dB REQUIRED TO DETECT THE HOLE DEPTH			
			PARENT MATERIAL		WELDED MATERIAL	
			FERRIC MATERIAL dB	STAINLESS STEEL MATERIAL dB	FERRIC MATERIAL dB	STAINLESS STEEL MATERIAL dB
NORMAL (4 MHz)		15	45	50	50	58
ANGLE (4 MHz)	45°	15	46	52	52	59
	60°	15	52	54	61	61

B. SIGNAL –TO –NOISE RATIO

We have selected four blocks of two Ferric steel type and two Stainless steel type. The probe is placed on the blocks and the whole echo or back wall echo is identified. Then the signal is raised as 100%. The noise level is noted before the signal. This experiment is done on the parent material and welded material side and the differences are noted. The difference in signal height and noise height gives the signal –to –noise ratio.

TABLE 3 SIGNALS-TO-NOISE RATIO (EXPERIMENT 2)

Probe Used- Normal Probe (4MHz)

MATERIAL	HOLE DEPTH mm	HOLE DIAMETER mm	AT 100% OF SIGNIFIED ECHO HEIGHT (S)		SNR (S-N) %
			NOISE(N) %	GAIN REQUIRED dB	
Ferric Parent material	Back wall echo	-	0	36	100
	15	3	9	50	91
Stainless Steel Parent material	Back wall echo	-	5	41	95
	15	3	12	52	88
Welded Ferric material	Back wall echo	-	7	45	93
	15	3	15	53	85
Welded Stainless steel material	Back wall echo	-	20	58	80
	15	3	28	54	72

C. BEAM SKEWING

Ferric steel, parent Stainless steel material and Welded Ferric, Welded Stainless steel material are selected. We are using only angle beam probes to study the beam skewing. The probe is placed on the material after applying couplant and the signals of the oscilloscope screen are noted. For particular distance of hole the beam path was noted on the basis line of the oscilloscope. We have the actual whole depth. Using this, calculated Beam path is related to the observed beam path. The differences are obtained in the whole depth for different blocks at different depths. The calculated beam path is given by the formula as beam path = $t/\cos\theta$.
Where, t –thickness of the specimen.

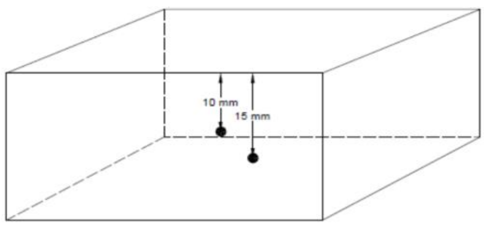

Fig 1.12 Ferric, Stainless Steel Parent And Welded Ferric, Welded Stainless Steel Material

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TABLE 4 BEAM SKEWING (EXPERIMENT 4)

Material : Ferric parent material
Probe used : Angle Probe
Size of crystal: 8*9
Hole diameter: 3mm

Probe (Angle θ) 4 MHz	Probe Index mm	Hole depth (t) mm	Calc. Beam path B.P= t/cosθ	Obtained distance (t1) mm	Obtained Beam path mm	Difference (t1-t) mm
45°	10	10	14.14	10.5	14.4	0.5
		15	21	15.3	20.8	0.3
60°	12	10	20	10.2	20	0.2
		15	30	15	30	0

TABLE 5 BEAM SKEWING (EXPERIMENT 4)

Material : Stainless steel parent material
Probe Used: Angle Probe
Size of Crystal: 8*9
Hole Diameter: 3mm

Probe Angle θ 4 MHz	Probe Index mm	Hole Depth(t) mm	Calc. Beam Path B.P= t/cosθ	Obtained Distance (t1) mm	Obtained Beam Path mm	Difference (t1-t) mm
45°	10	10	14.14	10.7	15.2	0.7
		15	21	17.1	21.96	2.1
60°	12	10	20	10.2	19.6	0.2
		15	30	15.2	30.4	0.2

TABLE 6 BEAM SKEWING (EXPERIMENT 4)

Material : Ferric welded material
Probe used : Angle Probe
Size of crystal: 8*9
Hole diameter: 3mm

Probe (Angle θ) 4 MHz	Probe Index mm	Hole depth (t) mm	Calc. Beam path B.P= t/cosθ	Obtained distance (t1) mm	Obtained Beam path mm	Difference (t1-t) mm
45°	10	10	14.14	10.8	14	0.8
		15	21	15.5	21.6	0.5
60°	12	10	20	10.6	22.8	0.6
		15	30	15.4	30.8	0.4

TABLE 7 BEAM SKEWING (EXPERIMENT 4)

Material : Stainless steel welded material
Probe used : Angle Probe
Size of crystal: 8*9
Hole diameter: 3mm

Probe (Angle θ) 4 MHz	Probe Index mm	Hole depth (t) mm	Calc. Beam path B.P= t/cosθ	Obtained distance (t1) mm	Obtained Beam path mm	Difference (t1-t) mm
45°	10	10	14.14	11.8	11.6	1.8
		15	21	17.5	22	2.5
60°	12	10	20	11.6	21.6	1.6
		15	30	15.8	30.4	0.8

Probe used: Angle – Longitudinal probe

Material	Probe Angle (θ) 4 MHz	Probe Index mm	Hole Depth mm	Calc. Beam Path B.P=t/cos θ	Obtained distance (t1) mm	Obtained Beam Path mm	Difference (t1-t) mm
Ferric parent	45°	12	10	14.14	10.35	14.12	0.35
			15	21	15.3	20.8	0.3
	60°	10	10	20	10.15	20	0.15
			15	30	15	30	0
Stainless steel Parent	45°	12	10	14.14	10.21	15.12	0.21
			15	21	14.83	21.52	0.17
	60°	10	10	20	10.1	19.3	0.1
			15	30	15	30.1	0

Material	Probe Angle (θ) 4 MHz	Probe Index mm	Hole Depth mm	Calc. Beam Path B.P=t/cosθ	Obtained distance (t1) mm	Obtained Beam Path mm	Difference (t1-t) mm
Ferric welded	45°	12	10	14.14	10.6	14.11	0.6
			15	21	14.6	21.4	0.4
	60°	10	10	20	10.5	21.8	0.5
			15	30	15.2	30.5	0.2
Stainless steel welded	45°	12	10	14.14	9.7	14.13	0.3
			15	21	14.75	20.88	0.25
	60°	10	10	20	9.1	19.28	0.9
			15	30	14.5	28.9	0.5

XVI. CONCLUSION

A. *Experiment 1:*

In the first experiment it is evident that for the same amount of energy the amplitude is different for different materials. Noticeable energy loss is taken place in Parent Stainless material and welded Stainless steel material.

B. *Experiment 2:*

As a result of grain structure is different in stainless steel material the scattering is studied in the experiment. The increase in grain structure in a welded stainless steel block shows that the energy loss is more in Stainless steel welded material. Therefore the energy is last in the material then that is evidence of high scattering is taking place in grain boundaries of austenitic weld materials.

Experiment 3:

In the third experiment it shows that there is no noticeable noise in Ferric steel. Whereas in stainless steel the noise in very much noted. This noise may completely obscure the important test indications affecting the results.

In the observation we also saw that the ratio is different for different blocks either parent or welded material. This may be due grain orientations in the particular direction.

C. *Experiment 4:*

The difference in hole depth that as calculated from beam path and actually in block shows noticeable beam skewing is taken place in the welded Stainless steel material. We also noticed that as the distance increases the skewing contributes to more different in depth values.

The dB drop methods used for finding flaws of length are not suitable for austenitic welds. Because the dB drops method is used only in the principle of constant amplitude variation.

The reference standard selection is very much important in case of Stainless steel testing. To standardize the equipment the reference block is selected as the same material as which is under test.

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