Ruane & T P O'Neill

Ultrasonic Inspection

ULTRASONIC INSPECTION COURSE

INDEX

INSPECTION AND NDT CERTFICATION SCHEMES

1 – ASNT Examinations
2 – BRITISH GAS Inspection Examinations
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INTRODUCTION TO BASIC CONCEPT

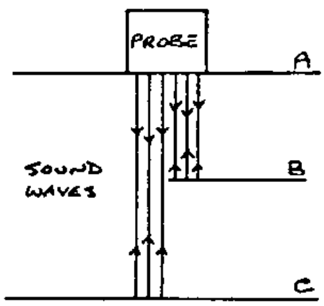
Ultrasonic testing makes use of the phenomenon that sound waves travel in straight lines and are reflected by an obstacle placed in their path.

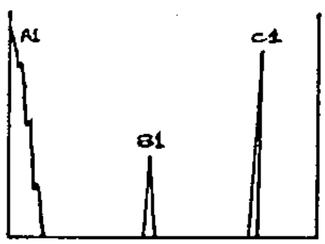
The mechanism is just the same as audible sound waves bouncing off a brick wall and an echo being received. The strength of the echo is controlled by the size of the wall. Also, if the time lapse between sending and receiving the echo is measured, it is possible to determine the distance to the wall.

Given the required instrumentation we can pass sound waves through solid materials and receive echoes from the back wall of the material. If a defect is present in the material, then the sound energy will be reflected back from it and give an echo earlier than that from the back wall, because the sound has not travelled as far. The strength or amplitude of this echo will be an indication of the size of the defect, and the distance travelled by the sound will tell us its depth.

This, then, is the basis of ultrasonic testing.

The instrument which produces the sound energy is called the probe and the echoes are shown on a cathode ray tube (CRT) within a flaw detector.





Sound energy is emitted from the probe into the specimen at surface A producing an echo at A1. Some of the sound is reflected by defect B and the resulting echo appears at B1. The remainder of the sound continues through the specimen to be reflected by the back wall C. The echo from the back wall appears at C1.

If the screen is calibrated from a standard block of known thickness, then the depth of the defect from the specimen surface (A to B) could be read off the screen at the point where echo B1 shows on the screen.

THE NATURE OF SOUND

Sound is caused by mechanical vibrations.

In order for sound to pass, there must be a medium which will support mechanical vibrations.

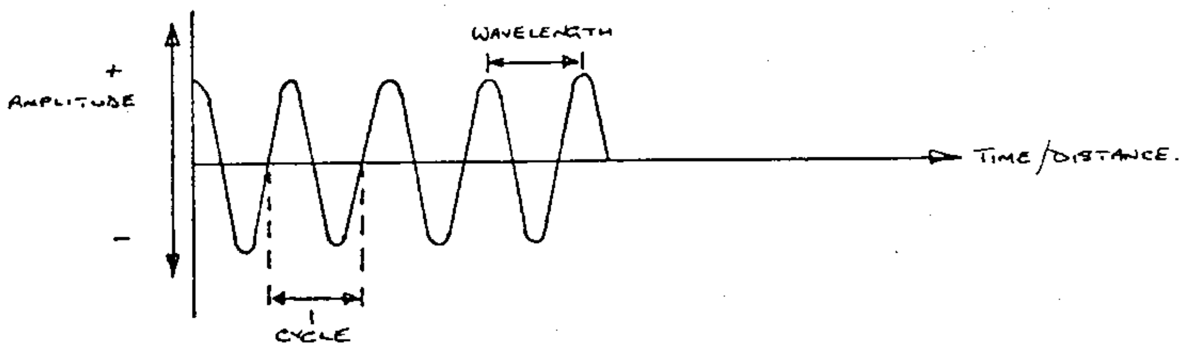
The particles (molecules) within the medium vibrate, passing on energy from one to another giving the effect of sound movement through the material.

The ability of a medium to support sound depends on the elasticity and density of the medium.

Since these properties will vary from one material to another, some materials will pass sound more easily than others.

Sound cannot travel in a vacuum.

Sound follows a waveform:



VELOCITY is the distance moved in unit time

WAVELENGTH is the distance between successive peaks of a wave

PERIOD is the time taken for one complete cycle

FREQUENCY is the number of cycles per second

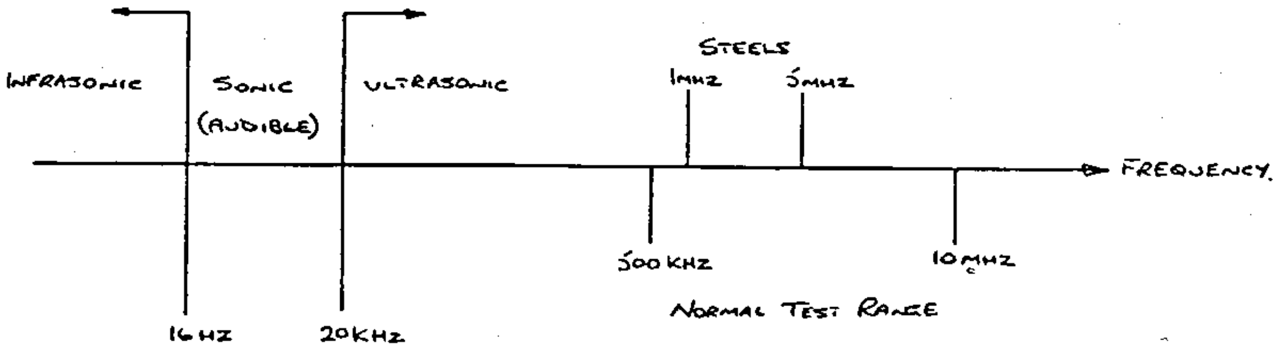
1 Cycle per second	=	1 Hertz (Hz)
1 Kilohertz (KHz)	=	1000 Hertz
1 Megahertz (MHz)	=	1,000,000 Hz

Wavelength is a function of frequency and velocity, thus:-

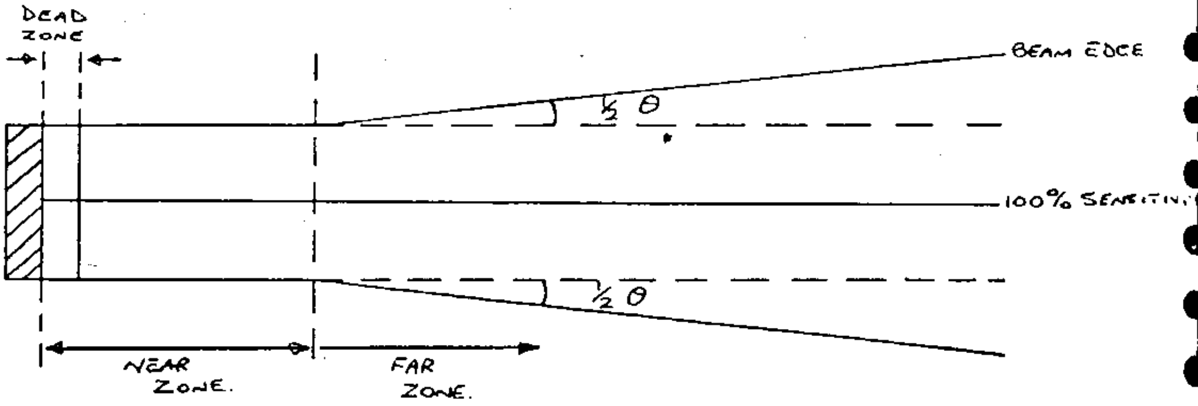
$$\text{Wavelength} = \frac{\text{Velocity}}{\text{Frequency}} \quad \text{or} \quad \lambda = \frac{V}{F}$$

$$\therefore \quad V = F \times \lambda \qquad \text{and} \qquad F = \frac{V}{\lambda}$$

The Acoustic Spectrum



THE ULTRASONIC BEAM



The Dead Zone

Seen on the CRT as an extension of the initial pulse, the dead zone is the Ringing Time of the crystal and is minimised by the damping medium behind the crystal. In the dead zone it is not possible to detect defects.

AS THE FREQUENCY INCREASES, THE DEAD ZONE DECREASES

The Near or Fresnel Zone

The ultrasonic beam remains parallel and has the same diameter as the crystal over a distance known as the near zone.

Within the near zone exist varying intensities of waves at the edge of the crystal, giving rise to unreliable signal amplitudes.

This means that signal heights from the same size of defect may increase when positioned further from the crystal.

The Near Zone can be calculated

$$N = \frac{d^2}{4 \times \lambda}$$

or $$N = \frac{d^2 \times F}{4 \times V}$$

Where d = Crystal diameter (mm)
f = Frequency (cycles/sec)
λ = Wavelength (mm)
V = Velocity (mm/sec)

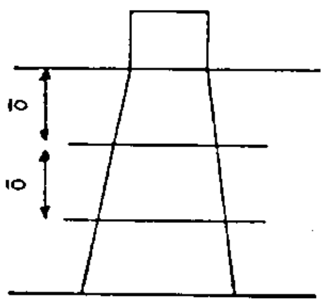
The Far or Fraunhoffer Zone

Beyond the near zone the far zone exists. In the far zone the beam diverges resulting in a decay in sound intensity as the distance from the crystal is increased, just as a beam of light from a torch gets weaker the further it travels.

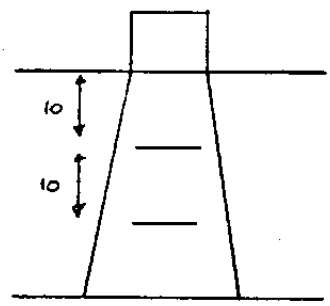
In the far zone, large and small reflectors follow different laws:-

LARGE REFLECTORS (LARGER THAN THE BEAM) follow the INVERSE LAW - the amplitude is inversely proportional to the distance, i.e. 1/d. If the distance is doubled the amplitude is reduced by half, i.e. 6 dB

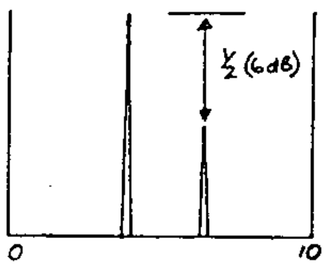
SMALL REFLECTORS (SMALLER THAN THE BEAM) follow the INVERSE SQUARE LAW - amplitude is inversely proportional to the square of the distance, i.e. $1/d^2$. If the distance is doubled the amplitude is reduced to $\frac{1}{4}$, i.e. 12 dB

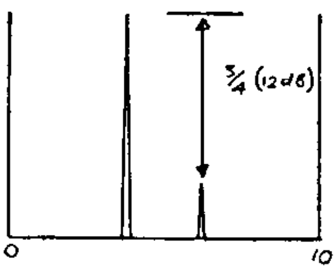


$1/d$

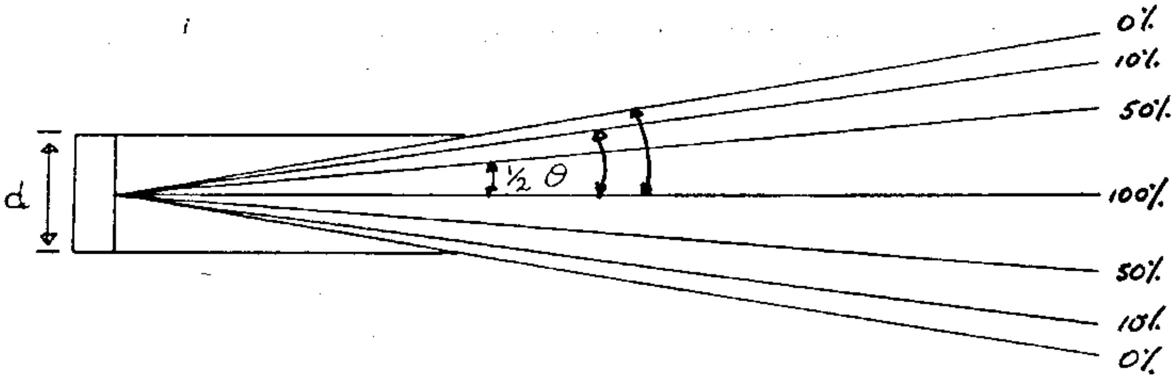


$1/d^2$





BEAM SPREAD CALCULATION



Formula for ½ beam spread

$$\text{Sin } \tfrac{1}{2}\theta = \frac{K \times \lambda}{d}$$

Where λ = wavelength
d = crystal diameter

K Factors	-	Extreme edge	=	1.22
		10% edge	=	1.08
		50% edge	=	0.56

Example: Calculate the half angle of divergence for a 15mm diameter 4 MHz compressional probe for a 90% loss in intensity (v = 5960 m/sec)

$$\lambda = \frac{V}{F} = \frac{596}{400} = 1.49$$

$$\text{Sin } \tfrac{1}{2}\theta = \frac{1.08 \times 1.49}{15} = \frac{1.6092}{15} = 0.10728$$

$$\tfrac{1}{2}\theta = \underline{\underline{6^{\circ}\ 9''}}$$

CALIBRATION EXERCISES

Using V1 Block

1)	Calibrate	time	base	for	100mm	using	25mm	thickness
	"	"	"	"	200mm	"	25mm	"
	"	"	"	"	400mm	"	25mm	"
	"	"	"	"	100mm	"	100mm	"
	"	"	"	"	200mm	"	100mm	"
	"	"	"	"	400mm	"	100mm	"
	"	"	"	"	20mm	"	10mm	"
	"	"	"	"	10mm	"	5mm	"
	"	"	"	"	10mm	"	10mm	"
	"	"	"	"	1000mm	"	200mm	"

Using V2 Block

2)	Calibrate	time	base	for	100mm	using	12.5mm	thickness
	"	"	"	"	50mm	"	12.5mm	"
	"	"	"	"	25mm	"	12.5mm	"
	"	"	"	"	200mm	"	12.5mm	"

3) Thickness measurement

a) Calibrate for appropriate thickness
b) Take thickness readings and enter on full size diagram
c) Enter sample numbers and log

4) Calculation of Unknown Velocity

a) Calibrate time base for appropriate thickness
b) Physically measure sample thickness
c) Observe CRT time base reading
d) Calculate % difference

$$\% \text{ difference} = \frac{\text{recorded measurement}}{\text{ultrasonic measurement}} \times 100$$

$$\therefore \text{Unknown velocity} = \frac{\% \text{ difference} \times \text{calibration standard velocity}}{100}$$

$$\therefore \text{Actual thickness} = \frac{\text{Time base reading} \times \text{velocity of sample}}{\text{Velocity in steel (5960 m/sec)}}$$

Put on drawing and log.

5) <u>Liquid levels</u> Using V1, V2 and STEP wedge

a) Take physical measurement of pipe diameter

b) Take ultrasonic measurement of pipe wall thickness

c) Use formula to estimate time base calibration

$$\text{Time base} = \frac{\text{Velocity in steel} \times \text{physical reading (less } 2 \times \text{wall thickness)}}{\text{Velocity in sample (water)}}$$

Add 2 x wall thickness to result

d) Calibrate for appropriate thickness

e) Locate liquid level

f) Locate obstruction

g) Enter results on drawing and report

h) Enter sample numbers into log

METHOD FOR TESTING MACHINED BLOCKS

1) Measure thickness physically
2) Calibrate for appropriate range (minimum 2 back wall echoes)
3) Apply couplant and set sensitivity, i.e. 2nd BWE to FSH
4) Scan test piece and roughly mark defective areas
5) Assess and size defective areas individually
6) Scan clear areas to confirm absence of any other defects
7) Produce full size report

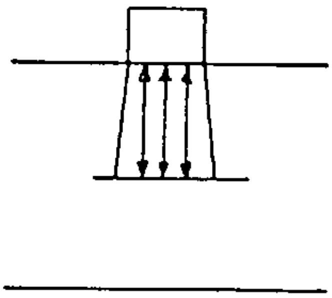
The 6DB drop and equalisation techniques (compressional probes)

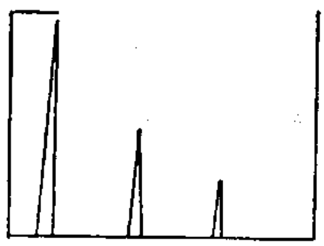
These are methods for sizing laminar defects.

The 6 dB drop

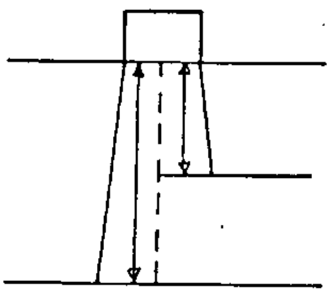
The 6 dB drop is a defect sizing system used to determine the size of large defects.

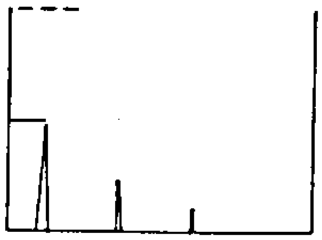
The technique utilises the theory that when a defect occupies the whole beam, the signal received from the defect will be at a maximum. If the probe is then moved to a position where only half the beam is occupied by the defect, the amplitude of the defect signal will be reduced by ½, i.e. 6 dB.





When the first defect echo is at a maximum, its amplitude is set to full screen height.

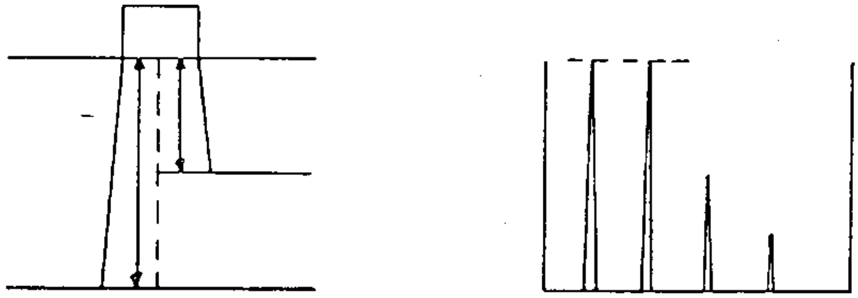




The probe is moved until the signal falls to half its original height. The probe is then vertically over the edge of the defect.

Equalisation

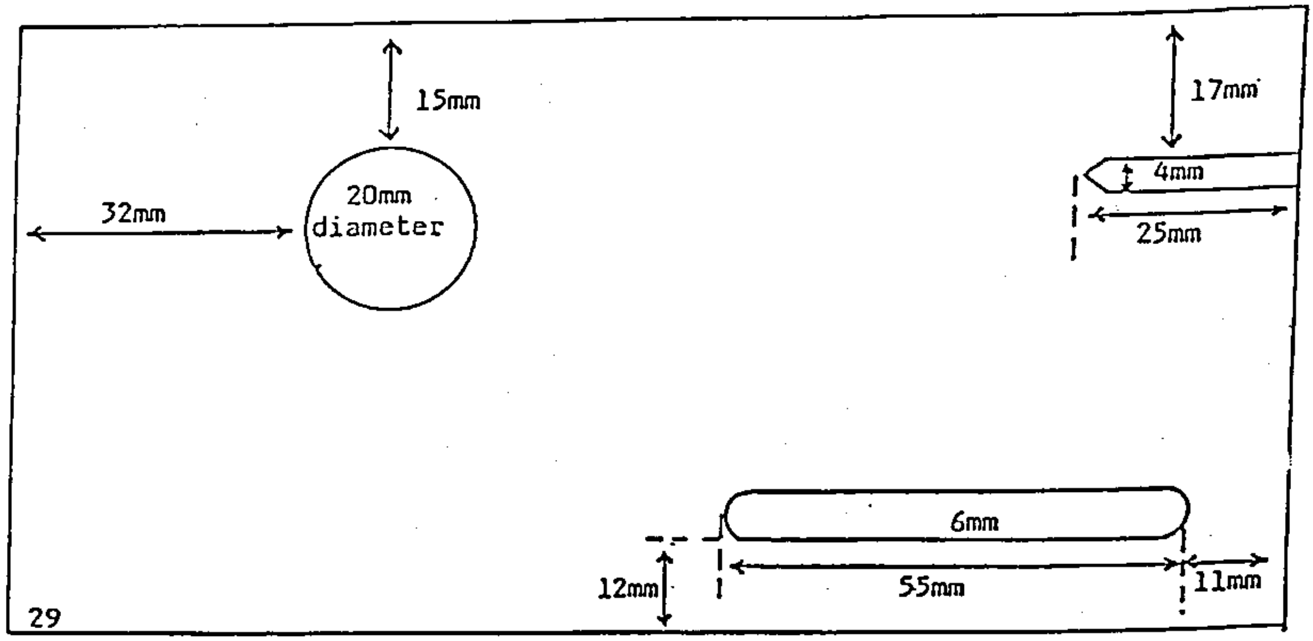
An alternative method is the equalisation technique in which the amplitude of the defect echo and back wall echo are balanced, at which point the centre of the probe is over the edge of the defect.

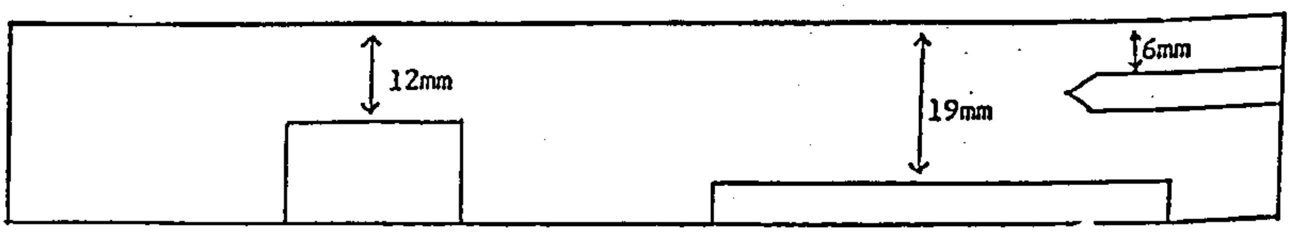


Defect and back wall echo equalised

REPORTING M/C BLOCKS

Sample No.	29
Date	6.5.82
Inspector	G Bloggs
Dimensions	150 x 90 x 20 mm
Equipment	USK 6
Probes used	0^{o} 5MHz 10mm Twin
Sensitivities	2nd back wall echo from parent plate to full screen height.

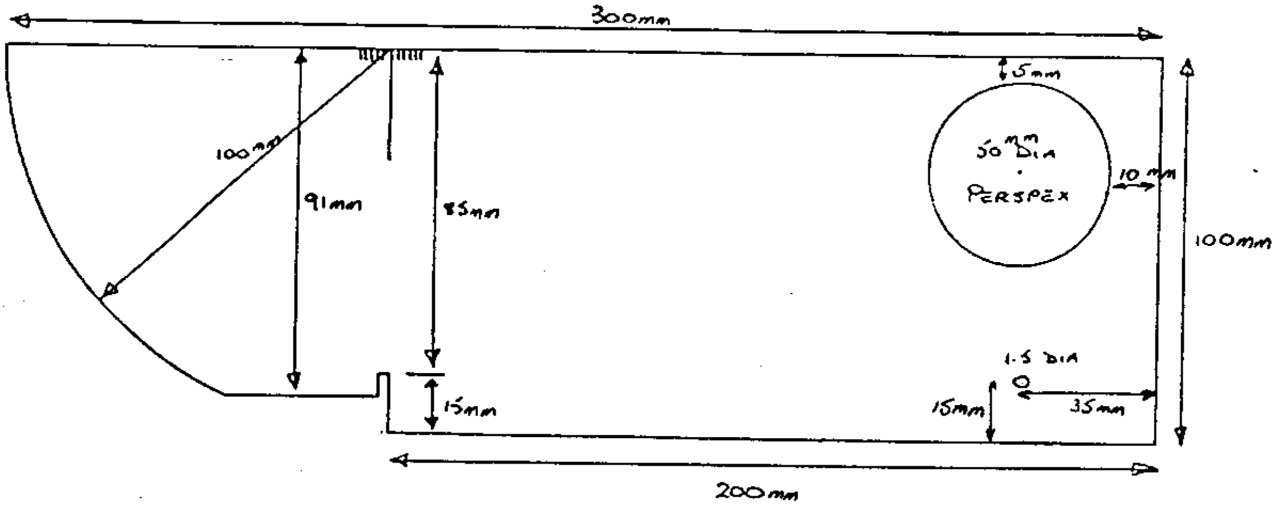




Scale :- Full size

CALIBRATION BLOCKS AND THEIR USES

1) The I.I.W. (International Institute of Welding) Block
V1 or A2 Block



ALL DIMENSIONS IN MM

TOLERANCE ± 0·1 MM

USES

a) Compressional Probes

i) Calibration

Thicknesses available - 5, 10, 25, 100, 200 mm. The perspex insert has a thickness of 23mm which is equivalent to 50mm of steel. This serves as a rough calibration check.

TWO OR MORE ECHOES ARE REQUIRED FOR CALIBRATION

Since 91mm compressional = 50mm shear, it is possible to calibrate the time base for shear velocity using a compressional probe.

91 Comp = 50 shear . . 182mm Comp = 100mm shear

= Ratio of 1:1.82 (i.e. ratio of velocities)

ii) Dead Zone Measurement

Using the 5 & 10mm thicknesses, and 15mm if necessary. Place the probe above the 5mm section, if the response is visible outside the dead zone, the dead zone is less than 5mm. If not visible place the probe above the 10mm section, if the response is now visible, the dead zone is greater than 5mm but less than 10mm.

The above procedure can be done with an uncalibrated screen. If the screen is calibrated, the dead zone length can be read off directly.

iii) Resolution

The ability to separate on the time base, two reflectors which are close together in terms of beam path length.

Place probe above the milled slot (85,91,100) and note separation on time base.

iv) Probe Output

Place the probe on the perspex insert. Increase the gain and note the number of back wall echoes visible above the "grass" level. Three responses is satisfactory.

b) Shear Probes

i) Index Point

Place the probe on the top of the block, aiming at the hundred mm radius. Maximise the signal and mark the probe vertically above the milled slots

The engraved lines either side of the slot are at 1mm intervals and are used to measure the movement of the index point. as the probe shoe wears.

ii) Calibration

Angle probe calibration is carried out using the 100mm radius, repeats being secured by the milled slots at the index point.

iii) Probe Angle

(a) Approximate - maximise on the 50mm diameter hole and measure the angle on the engraved scale.

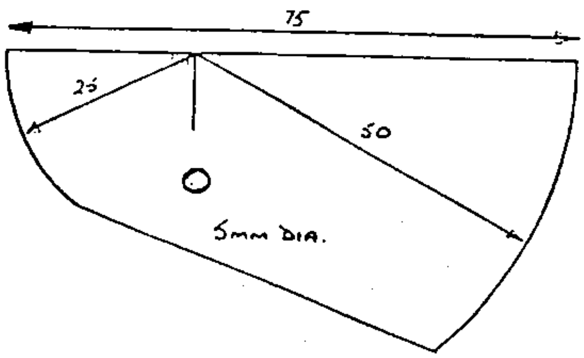
(b) Accurate - maximise on the 1.5mm hole, mark the index position onto the block, draw a line from the index point to the centre of the hole and measure the refracted angle with a protractor.

Probe angle determination is best done on the IOW beam profile block which offers holes at various depths, the average of at least 3 holes being recommended.

iv) Probe Output

Set the response from the 100mm radius to full screen height and note the number of dB's in hand.

2) V2/A4 Calibration Block



ALL DIMENSIONS IN MM

HOLE SIZE MAY BE 1.5MM

COMMONLY USED ON SITE

a) Compressional Probes

i) Calibration

In accordance with BS 2704, this block can be purchased having a thickness of either 12½ mm or 20 mm.

b) Shear Probes

i) Calibration

When aiming at 25mm radius, signals occur at 25, 100, 175, 250, etc.

When aiming at 50mm radius, signals occur at 50, 125, 200, 275, etc.

ii) Index Point

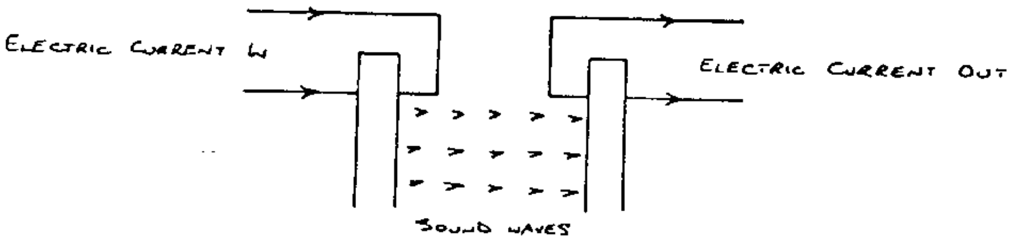
Aiming at 25mm or 50mm radius, maximise signal and mark index.

iii) Probe Angle

By maximising echo from either 1.5 mm or 5 mm dia hole and reading off engraved scale on side of test block. (Limited use as only one hole depth available).

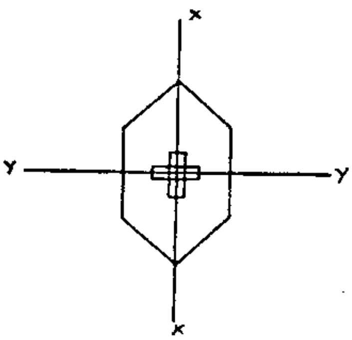
THE PIEZO ELECTRIC EFFECT

The Piezo electric effect is defined as the property of certain crystals to convert electrical energy into mechanical energy and vice versa.



Crystals may be naturally occuring, artificially manufactured, or grown in solution.

They may be x-cut or y-cut depending upon which axis of the crystal they are taken from. The type used in Ultrasonics are x-cut due to the mode of vibration they produce.



The frequency of a crystal is determined by its acoustic velocity and thickness

$$Ff = \frac{V}{2t} \quad \therefore \quad t = \frac{V}{2 \times Ff}$$

e.g. To find the thickness of a quartz crystal required to produce a frequency of 2.5 MHz (V.Quartz = 5760 m/sec).

$$t = \frac{5760,000}{2 \times 2,500,000} = \underline{\underline{1.15 \text{ mm}}}$$

Natural	Artificially grown	Artificially manufactured (ceramics)
Quartz		Barium Titanate ($BaTiO_3$)
	Lithium Sulphate ($LiSO_4$)	Lead Zirconate ($PbZrO_3$)
		Lead Zirconate Titanate (PZT)
		Lead Metaniobate ($PbNb_2O_6$)

Crystal	Advantages	Disadvantages
Quartz	Good wear resistance	Poor Piezo properties
$LiSO_4$	Easily damped/best receiver	Soluble in water
$BaTiO_3$	Best transmitter/good P.E. properties	-
$PbZrO_3$	Good P.E. properties	-
PZT	Good transmitter/good all round properties	Poor silvering

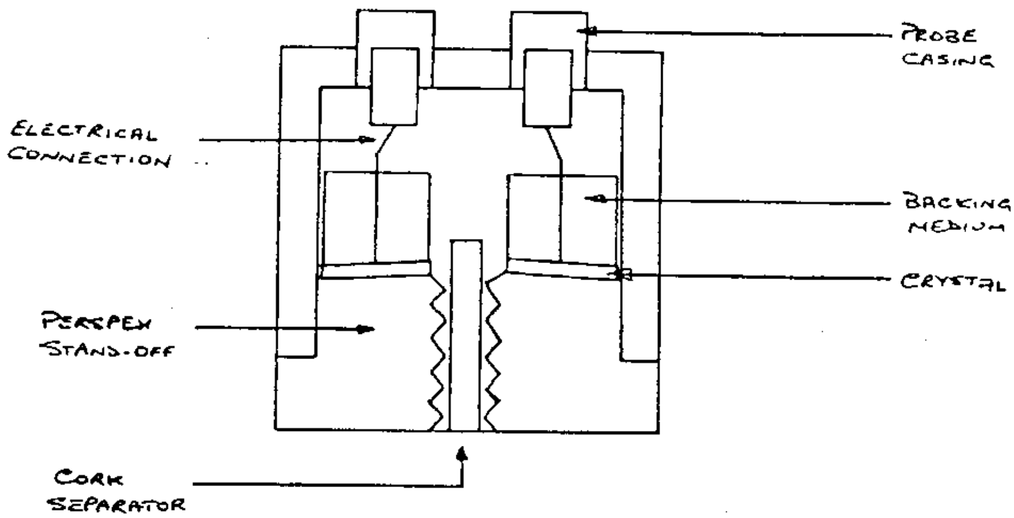
Polarisation of Ceramics

Ceramics made up of tiny crystals are heated up to their curie temperature and subjected to an electrostatic field. The crystals align themselves with the direction of the field which is maintained during cooling. This polarised ceramic behaves as a P.E. transducer until heated to the curie temperature.

$BaTiO_3$ and PZT are the most commonly used

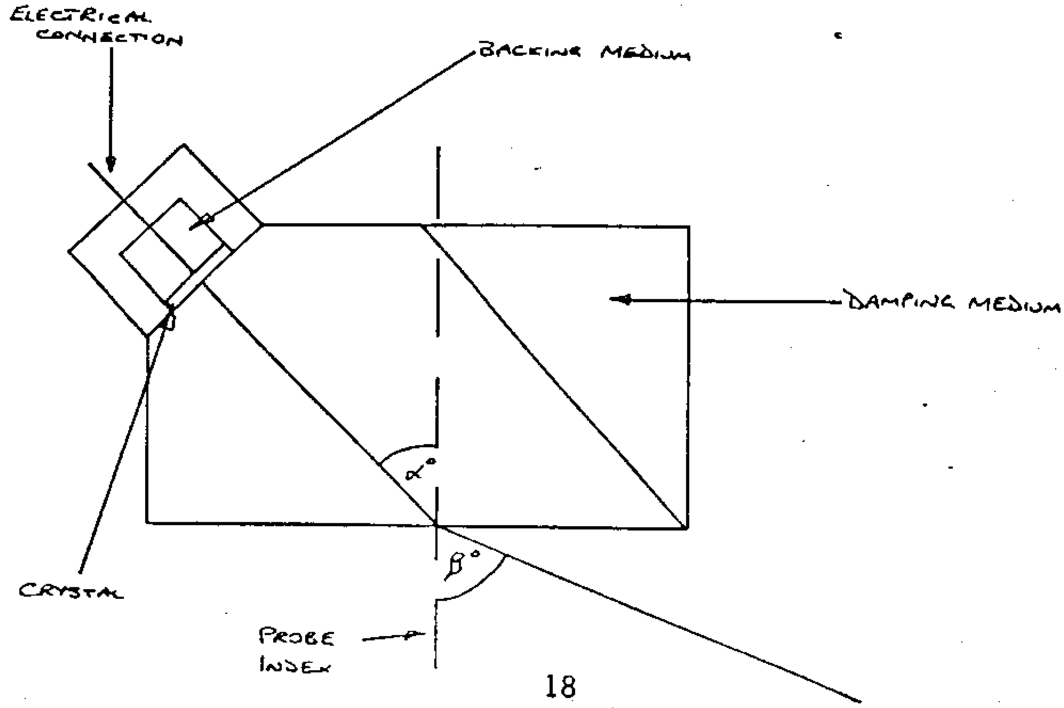
PROBE CONSTRUCTION

Combined Double Probes



The cork separator and corrugations in the perspex reduce the cross-talk or 'chatter' between the crystals. Using oil as a couplant may break down this acoustic barrier and produce standing echoes. Two crystals are used - one transmits, the other receives. This eliminates the dead zone, allowing detection of sub-surface defects. These probes are thus used mainly for testing thin sections. The crystals may be focussed to give a focal point at the approximate thickness range to be examined.

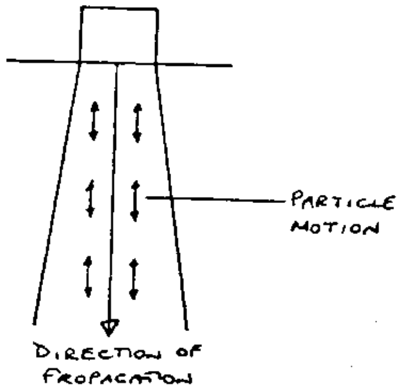
Single Crystal Angle Probes



The perspex wedge on which the crystal sits can be machined to any angle. This angle determines the angle of incidence which controls the angle of refraction according to Snell's Law. The backing medium is a material of high acoustic impedance which absorbs the sound energy behind the crystal, thus damping the crystal to produce short, sharp pulses. This damping controls pulse length which is the major factor in determining resolution. The most common backing medium is Tungsten Araldite.

MODES OF PROPAGATION

1) Longitudinal or Compression

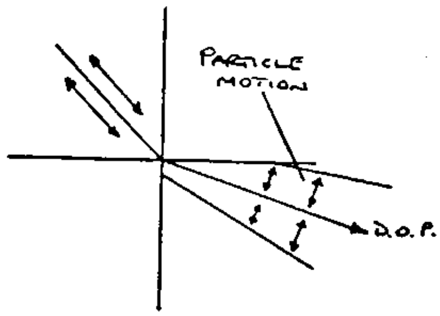


Particles vibrate parallel to the direction of propagation and consist of alternate compression and dilation pressure waves.

Compressional waves can be passed through solids, liquids and gases since rigid particle bonding is not essential

Compressive velocity in steel = 5960 m/sec

2) Shear or Transverse Waves

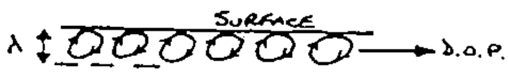


Particles vibrate at 90° to the direction of propagation and have a whip-like action

Shear waves can only be passed through solid materials since a pre-requisite is rigid particle bonding which only exists in solids

Shear velocity in steel = 3240 m/sec

3) Surface or Rayleigh Waves



Particles vibrate in an eliptical motion and have a velocity of about 0.9 of shear waves. They penetrate to a depth of approximately one wavelength and will follow the contour of an object under examination.

Where sharp changes in section occur, reflected energy will return to the probe, e.g. from a sharp corner edge.

However, if a component has surfaces that are rounded off, the waves will continue to follow the shape with no reflected energy returning to the probe, unless of course a discontinuity is present.

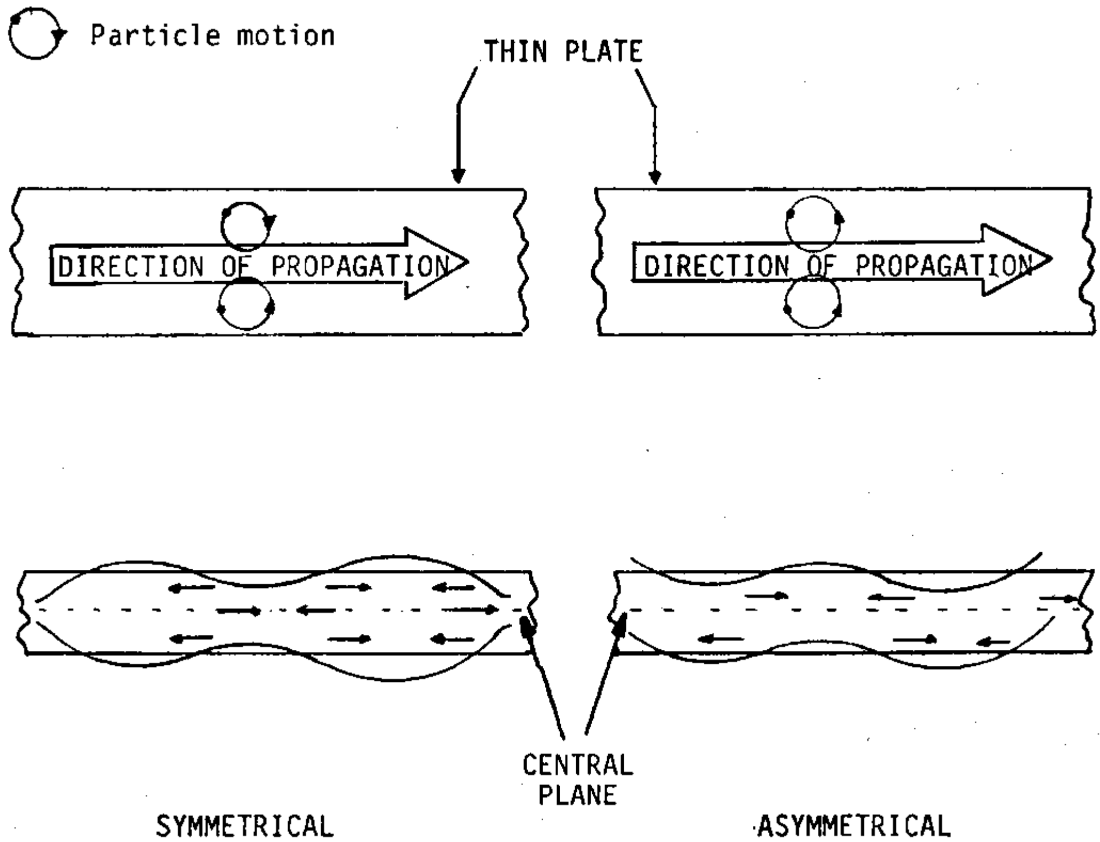
Surface waves also have the characteristic that they are almost completely damped by placing a finger on the surface being examined.

Discontinuities being sought ideally must be surface breaking.

4) Lamb or Plate Waves

These types of wave are rarely used as an everyday mode of propogation and are mainly devoted to the examination of very thin material. They can occur if a surface wave is introduced into a material which has a thickness equal to or less than three wavelengths of the ultrasonic beam. The vibrations that occur within the material cause it to flex, i.e. the wave totally saturates the thickness of the material.

The two types of lamb or plate wave that can be produced is dependent on the way the particles oscillate as the wave moves along the plate and for this reason they are referred to as either symmetrical or asymmetrical bending waves, e.g. see diagram below.



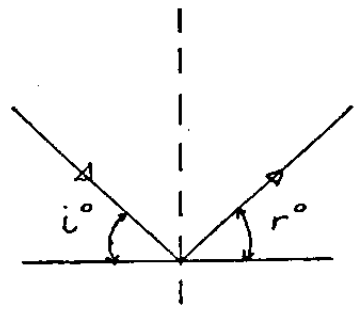
THE BEHAVIOUR OF ULTRASONIC WAVES

When sound waves at an angle from the normal are incident upon an interface between two media, some of the energy is reflected and some transmitted into the second medium.

The ratio of reflected to transmitted energy can be calculated from the acoustic impedance values of the two media and is dealt with later.

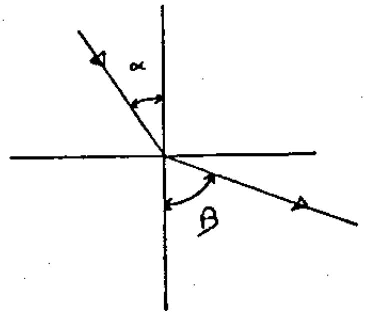
1) Reflection

The reflected energy follows the same laws as light, i.e. the angle of incidence is equal to the angle of reflection when striking a specular reflector, i.e. mirror-like, planar.



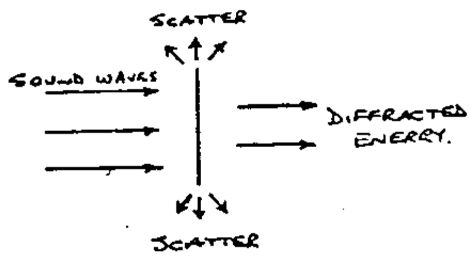
2) Refraction

The transmitted energy is bent as it enters the second medium, just as light waves are bent, demonstrated when viewing a stick dipped in water at an angle. The refraction can be calculated by Snell's Law.



3) Diffraction

Diffraction is the apparent "bending" of sound waves around the tips of a narrow reflector. Diffuse reflection or scatter occurs at these positions resulting in a small amount of energy being "bent" around the defect.



4) Mode Conversion

Ultrasonic energy, when reflected, may change from one waveform to another, i.e. compressional to shear, shear to surface, etc. This mode change is accompanied by the appropriate change in velocity.

5) Attenuation

Attenuation is defined as the loss in intensity of the ultrasonic beam as it passes through a material and is dependent on the physical properties of the material.

Attenuation is caused by two main factors:

(i) Absorption

This is caused by the interaction of the particles as they vibrate during the passage of the sound waves.

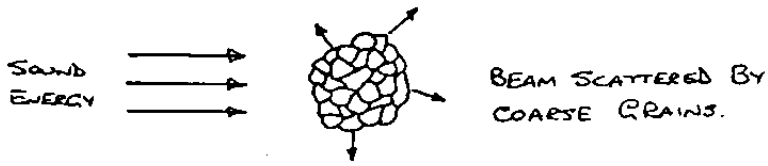
The movement of these particles caused friction, which is dissipated as heat.

As the frequency is increased the absorption becomes greater due to more rapid particle movement.

Absorption accounts for only a small part of attenuation.

(ii) Scatter

This is the major source of attenuation and is the scattering of the ultrasonic beam by grain boundaries, porosity, non metallic inclusions, etc.



The larger the grain size the greater the scatter. Thus coarse grain material will be more attenuative than fine grain material.

Rough surfaces also cause attentuation.

Attenuation can be overcome by using a lower frequency since the wavelength of the energy will be increased and sensitivity to small defects reduced, and the beam will not detect the grain boundaries. Also, particle vibration will be reduced, producing less absorption.

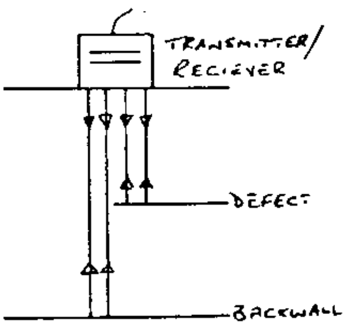
The attenuation factor of a material can be measured and is expressed in dB/mm.

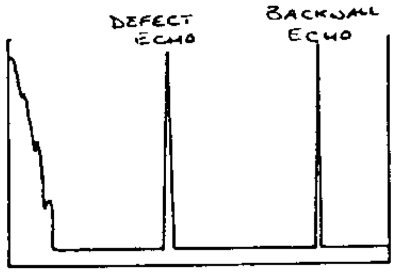
Materials/products such as austenitic stainless, castings, etc. have high attenuative properties due to their coarse grain structures and elastic properties.

It must also be noted that due to the divergence of the ultrasonic beam natural attenuation occurs such that the amplitude of the back wall echo will be halved at twice the distance from the probe.

REFLECTION OR PULSE ECHO METHOD

In this, the most common method used in weld examination, the probe both transmits and receives ultrasound. The probe may have one crystal transmitting and receiving, known as a transceiver. The alternative is a twin probe in which two crystals are mounted, one transmitting, the other receiving ultrasound.





The presence of a defect is indicated by the reception of an echo before that of the boundary signal.

Provided the time base is calibrated, the location of a defect can be read directly from the screen.

Advantages

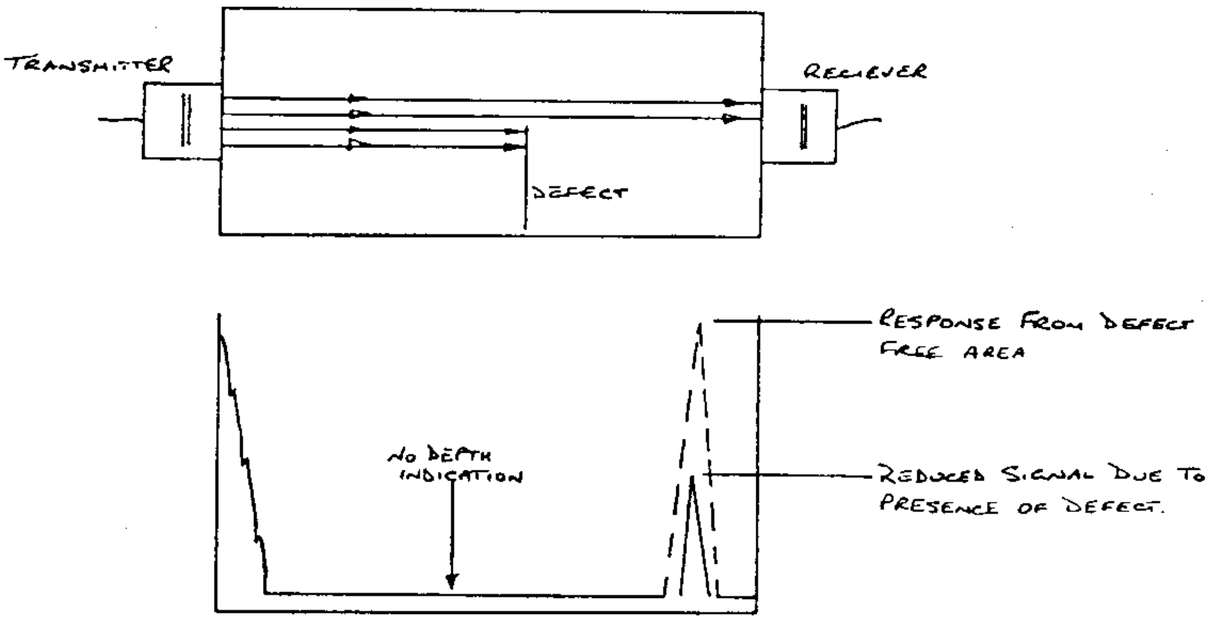
1) It is possible to position defects
2) Access from only one surface is necessary
3) Simpler to operate than angle probes

Disadvantages

1) The sound has to pass through twice the thickness of the specimen.

THROUGH TRANSMISSION TESTING OR SHADOW TECHNIQUE

In the through transmission technique, the transmitting and receiving probes are on either side of the specimen.



The back wall response is set to a pre-determined level and the presence of a defect is indicated by a reduction in amplitude or complete loss of back wall signal.

Advantages

1) It is easier to test material of high attentuation properties.

2) Thicker specimens can be tested as the sound only travels one way.

3) Higher frequency probes can be used for a given thickness.

Disadvantages

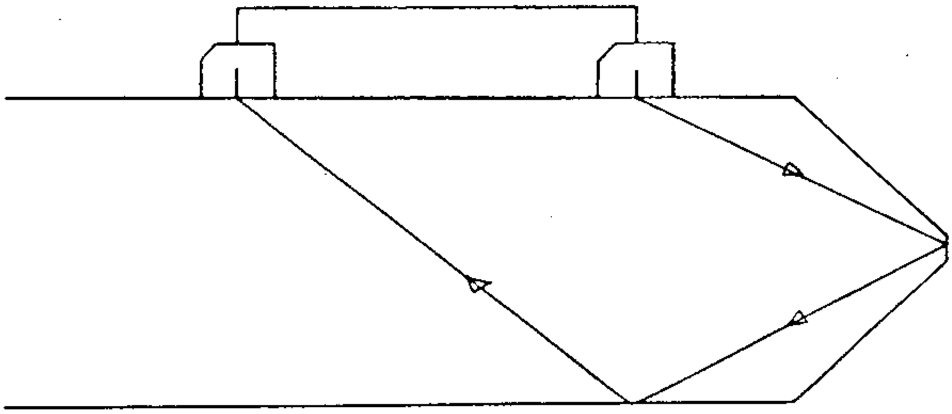
1) No depth indication of defect is given.

2) Access to both sides of specimen is necessary.

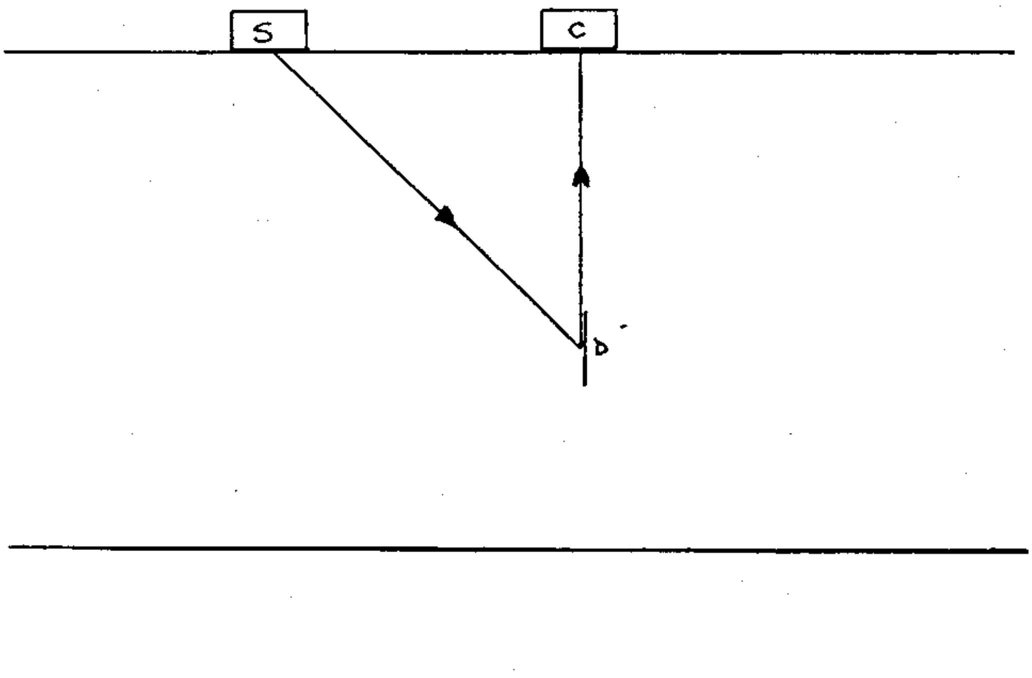
3) Probes must be correctly aligned.

4) Change in coupling conditions could be mistaken for a defect.

TANDEM TECHNIQUE

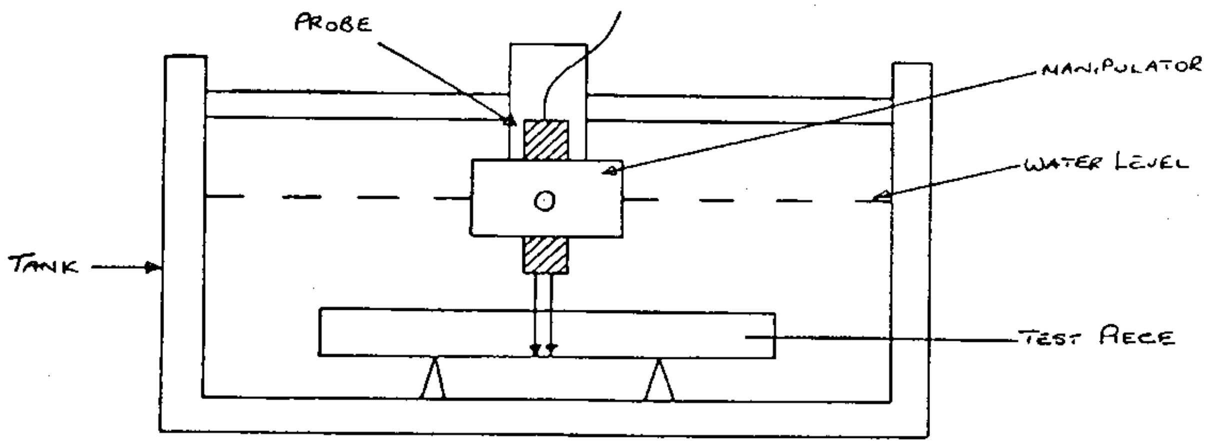


DELTA TECHNIQUE

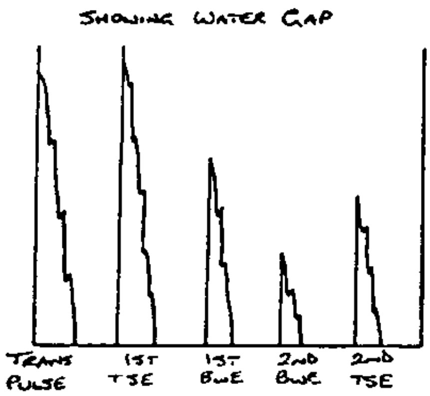


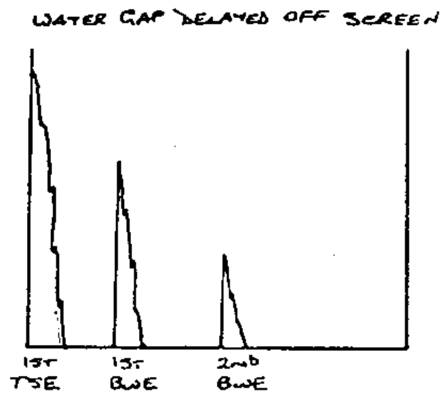
IMMERSION TESTING

Immersion testing is mainly used in laboratory and automatic ultrasonic inspection in factories. Frequencies up to around 25 MHz can be used.



This system uses a compressional probe mounted within a manipulator which can tilt the probe at any angle, thereby introducing sound waves into the specimen at the required angle. By varying the tilt of the probe beyond the critical angles, both transverse and surface waves could be generated within the specimen.

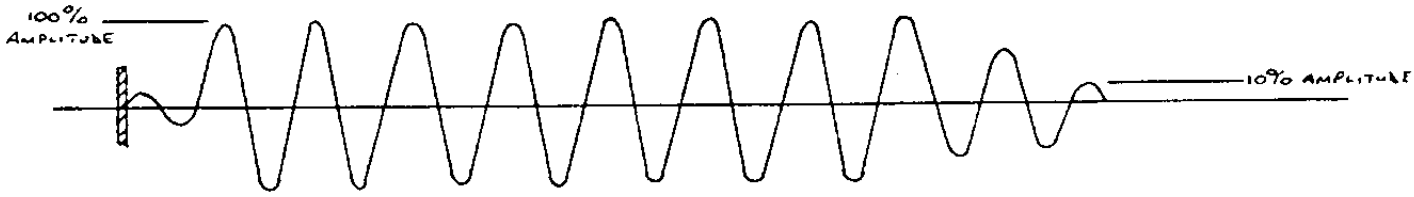




Calibration is done normally with a contact probe from a calibration block. The water gap is then delayed off the screen so that the screen represents only the sound through the spcimen.

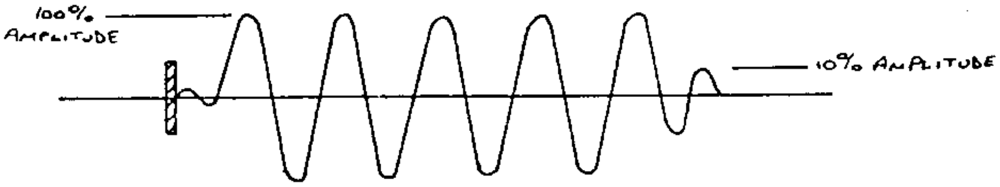
WAVE TRAINS AND PULSE LENGTH

In the pulse echo method, an electrical pulse is fed into the transducer which vibrates with increasing amplitude until a steady value is reached. When the electrical pulse is removed, the oscillations of the transducer do not cease immediately but decrease slowly until they reach zero. The resulting wave train is shown below.



Undamped wave train - long pulse (10 cycles)

This length of pulse is unacceptable since in order to show defects signals clearly and separately on the CRT screen, pulses of sound must be short and sharp. In order to produce these pulses, the crystal must be damped with a backing medium which absorbs the sound energy. In this way the pulse length can be reduced dramatically to a level of 5 cycles.



Damped wave train - medium pulse (5 cycles)

The ideal pulse length would be in the order of two cycles, but such levels are difficult to achieve.

Damping, then, controls the number of cycles (100% down to 10%)

The other factor controlling pulse length is frequency - higher the frequency, the smaller will be the length of one cycle, and therefore the shorter the pulse length.

Pulse length controls resolution

Resolution is the ability to separate, on the time base, two defects which are close together in terms of beam path length.

Consider 2 defects 3mm apart. If the pulse length was greater than 3mm then the response from the 2 defects would be in the same signal envelope, as in (a). If the pulse length was less than 3mm, the defects would show as separate signals, as in (b).

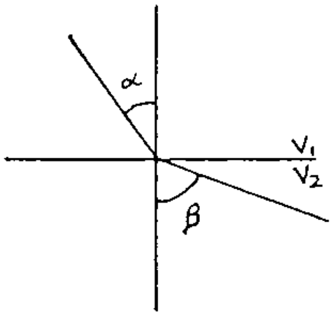
(a) (b)

SNELL'S LAW

Snell's Law determines the angular relationships between the incident and refracted beam on transmission between the media of different acoustic velocities.

SNELL'S LAW STATES THAT:-

$$\frac{\operatorname{Sin} \alpha}{\operatorname{Sin} \beta} = \frac{V1}{V2}$$



Where Sin α = angle of incidence

Sin β = angle of refraction

V1 = velocity in medium 1

V2 = velocity in medium 2

Snell's Law is mainly used when calculating the angle to which the perspex wedge must be machined in order to produce a given refracted angle in the test material.

The standard probes are machined to give refracted angles of 35^o, 45^o, 60^o, 70^o & 80^o in ferritic steel.

Of the above angle probes, the ones commonly used in weld testing are 45^o, 60^o & 70^o.

The formula can also be used to find the angle of refraction that a given probe will produce when examining materials other than steels, e.g. copper and aluminium.

Also, if incident and refracted angles are known, velocities can be calculated.

Example

a) Calculate the incident angle used in the machining of the perspex wedge to produce a 70^o refracted angle in steel.
(Velocity in perspex = 2740 m/s. Velocity in steel = 3240 m/s).

$$\operatorname{Sin} \alpha = \frac{V1 \times \operatorname{Sin} B}{V2}$$

$$= \frac{2740 \times 0.9396}{3240}$$

$$\text{Sin } \alpha = 0.7946$$

$$\therefore \alpha = \underline{\underline{52^{\circ}\ 37''}}$$

b) What would be the new refracted angle if this probe was placed on a copper sample (Velocity in copper = 2325 m/s).

$$\text{Sin B} = \frac{V2 \times \text{Sin } \alpha}{V1}$$

$$= \frac{2325 \times \text{Sin } 52^{\circ}\ 37'}{2740}$$

$$\text{Sin B} = 0.6743$$

$$\underline{\underline{\text{B} = 42^{\circ}\ 23'}}$$

N.B. When velocity V2 is slower than V1, the beam is refracted towards the normal

CRITICAL ANGLES

As the incident angle is increased from the normal, the refracted wave is predominantly longitudinal, although the shear mode exists at an insignificant strength.

When the incident angle reaches the first critical angle, longitudinal eaves are totally internally reflected through 90^{o}, i.e. Blong = 90^{o}.

At this point only shear waves exist in the second medium.

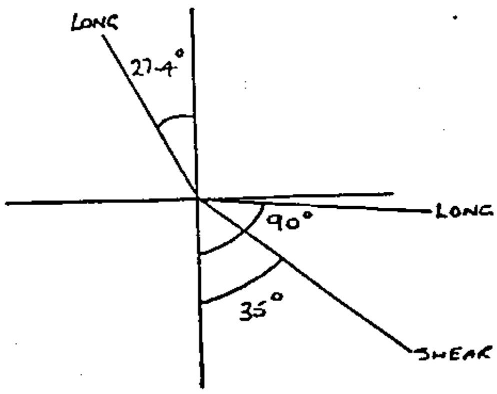
When the incident angle reaches the second critical angle, the shear wave is totally internally reflected through 90^{o}, i.e. Bshear = 90^{o}.

Calculation of first critical angle - perspex to steel

V perspex = 2740 m/s

V steel = 5960 m/s

SinB = 90^{o} = 1



$$\text{Sin } \alpha = \frac{V1 \times \text{SinB}}{V2}$$

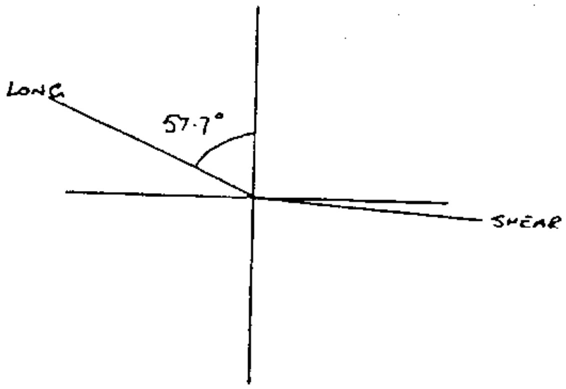
$$\text{Sin } \alpha = \frac{2740 \times 1}{5960}$$

$$= 0.4597$$

$$\alpha = 27.4^{o}$$

Calculation of second critical angle - perspex to steel

V perspex = 2740
V steel = 3240
SinB = $90^{\circ} = 1$



$$\sin \alpha = \frac{V1 \times \sin B}{V2}$$

$$= \frac{2740 \times 1}{3240}$$

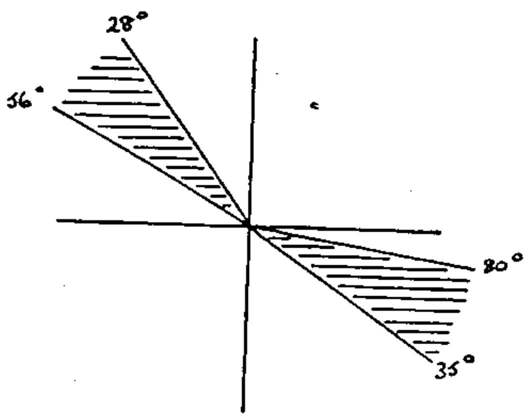
$$= 0.8457$$

$$\alpha = 57.7^{\circ}$$

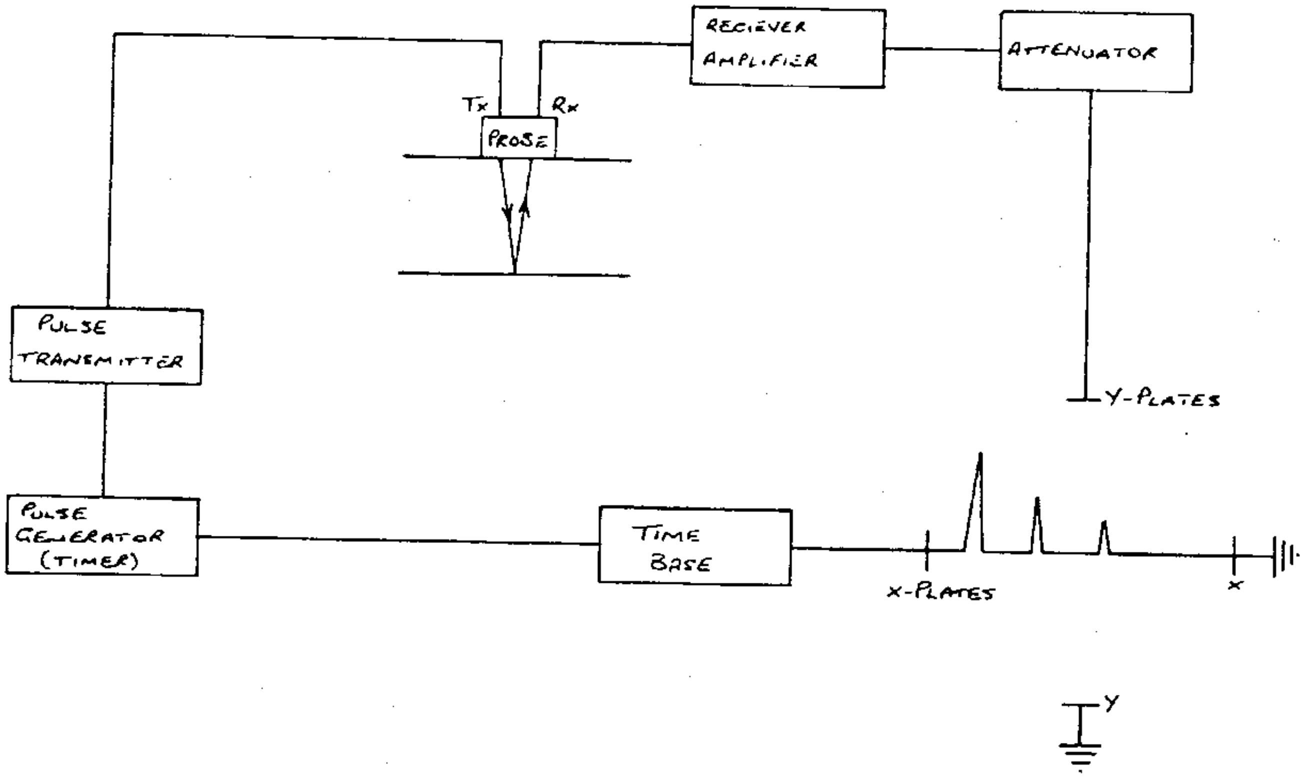
If we calculate the angle of the refracted shear wave at the first critical angle, we get a refracted angle of 33°.

It is for this reason that the steepest angle probe is 35° (α = 28°).

Since surface waves occur at a refracted angle of 90°, the upper limit for shear probes is 80° (α = 56°).



THE ULTRASONIC FLAW DETECTOR



Pulse Generator

Triggers electrical pulses at regular intervals to supply the time base and transmitter circuits.

Time Base

Produces linear travel across the x-plates and relates to time/distance in the test material.

Pulse Transmitter

Delivers the electrical energy to the crystal. (1-2 Kv).

Receiver Amplifier

Accepts and amplifies the returning electrical pulses.

Amplification of 10,000 - 100,000 times is necessary. Must have a bandwidth to accommodate various frequencies. The input/output relationship must be linear.

Attenuator

Controls the relationship of volts in/volts out across the y-plate, thereby controlling signal heights. Does not affect amplifier linearity.

Suppression (Reject) Control

Most flaw detectors have a suppression control in the receiver circuit after the attenuator.

This control reduces the grass level, by effectively raising the time base, but destroys amplifier linearity.

Usually reserved for thickness measurements.

RECOMMENDED CHECKS ON FLAW DETECTOR

BS 4331 1978

Periodically, ultrasonic flaw detection equipment must be checked to ensure that performance characteristics have not deteriorated. The checks recommended in this British Standard are as follows:-

1) Linearity of time base
2) Linearity of amplifier (equipment gain)
3) Calibration of time base
4) Signal to noise ratio
5) Probe index
6) Probe angle
7) Beam spread
8) Resolution

1) Linearity of Time Base

To be carried out over the range(s) to be used. Place the compressional probe on the V1 block and obtain multiple echoes. Place the first and last echoes in their correct places on the time base scale and check that the intermediate signals correspond to their respective positions.

Tolerance - ± 2% of time base range

2) Linearity of Amplifier

Position the probe on a calibration block to obtain a reflected signal 1.5 or 5mm hole. Set the signal to 80% of screen height.
Increase by 2 dB - signal should increase to 100% screen height.
Reduce by 8 dB - signal should fall to 40% screen height.
Reduce by 12 dB - signal should fall to 10% screen height.
Reduce by 6 dB - signal should fall to 5% screen height.
General tolerance - ± 5%

3) Calibration of Time Base

Check the ability to calibrate to ranges to be used.

4) <u>Signal to Noise Ratio</u>

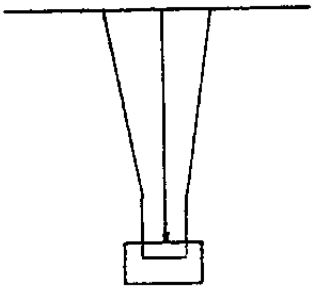
Place the probe on a calibration block and maximise the signal from a transverse hole. Set the response to 20% of screen height. Increase the gain until the grass level reaches 20% screen height on the same time base position. The gain increase is the signal to noise ratio and serves as a comparison between equipments.

Items 5 - 8 have been dealt with earlier.

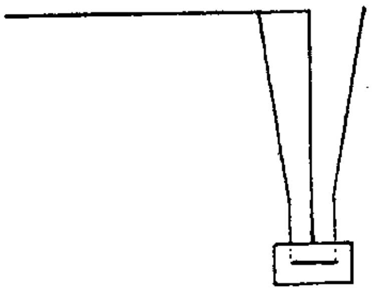
DEFECT SIZING - THE 6 dB DROP METHOD

This is a sizing system which can be used to determine the length of large reflectors both with compressional and angle probes. Compressional probes have been dealt with earlier.

This system is dependent on the principle that when the signal from a large defect is at a maximum, the defect covers the whole beam - as in (a).



(a)



(b)

If the probe is moved laterally until the signal falls to half its original height (amplitude drop of 6 dB) then only half the beam will contain the defect - as in (b) and the centre of the beam will correspond to the end of the defect.

In practice, the signal from the defect is maximised by probe traversing. The probe is then moved laterally until the signal disappears. At this point the probe is moved laterally until the signal reaches the first maximum, then finally in the opposite direction until the signal falls to half the amplitude. The probe centre now corresponds to the end of the defect.

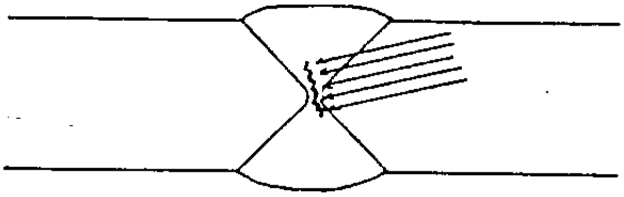
The above procedure is repeated at the other end of the defect to give the defect length.

It is useful during this exercise to use a backing strip behind the probe to maintain the probe stand-off during lateral movement of the probe.

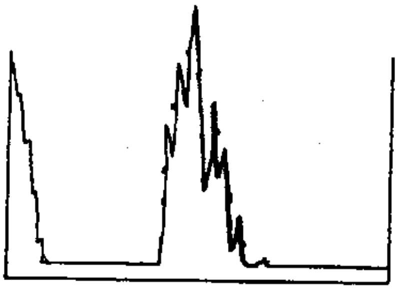
N.B. THIS METHOD ONLY HOLDS FOR LARGE REFLECTORS AND WILL GROSSLY OVERSIZE SMALL REFLECTORS.

DEFECT SIZING - THE MAXIMUM AMPLITUDE TECHNIQUE

This technique utilises the fact that most defects do not have perfectly flat, smooth surfaces but are ragged or multi-faceted. Thus, for angle probes, most defects will have one or more of these facets favourably orientated to the beam.



Because of the spread of the beam, the signals from these facets will usually be in the same envelope, representing a series of overlapping signals since they are too close together to be resolved as separate signals.



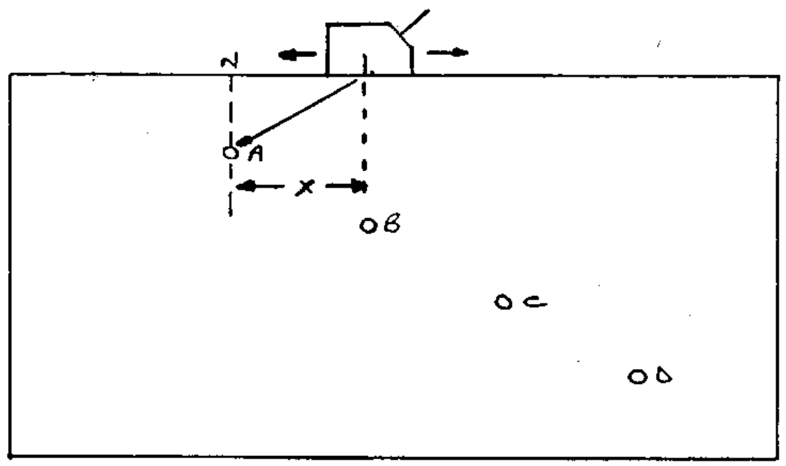
In the maximum amplitude technique, each of these signals is maximised in turn and plotted using the centre of the beam, thus giving an indication of the size of the defect in the vertical plane. An added advantage of this technique is that where other sizing systems only give the extremities of the defect, the maximum amplitude technique also gives intermediate points which is useful information for interpreting the defect type.

This technique can also be used to determine defect length. As the probe is moved laterally along the defect, the signals rise and fall as the centre of the beam hits the facets of the defect. Probe movement is continued until the signal from the defect is lost. The beam is then moved back onto the defect until the signal from the first facet is maximised. The centre of the probe at this point corresponds to the end of the defect. This procedure is repeated at the other end of the defect to give the total length.

PRODUCTION OF 20 dB BEAM SPREAD (VERTICAL PLANE)

As the distance from the probe increases, the ultrasonic beam diverges. It is necessary that the operator is aware of the extent of this beam spread and can use it for sizing purposes.

The method plots out the 10% edges of the beam in the vertical plane at various positions down the beam. This sampling of the beam is carried out using the 1.5mm holes at various depths on the I.O.W. beam profile block.



Method

1) Maximise signal on hole A. Mark index pt onto block. Note surface distance x (index pt to N).

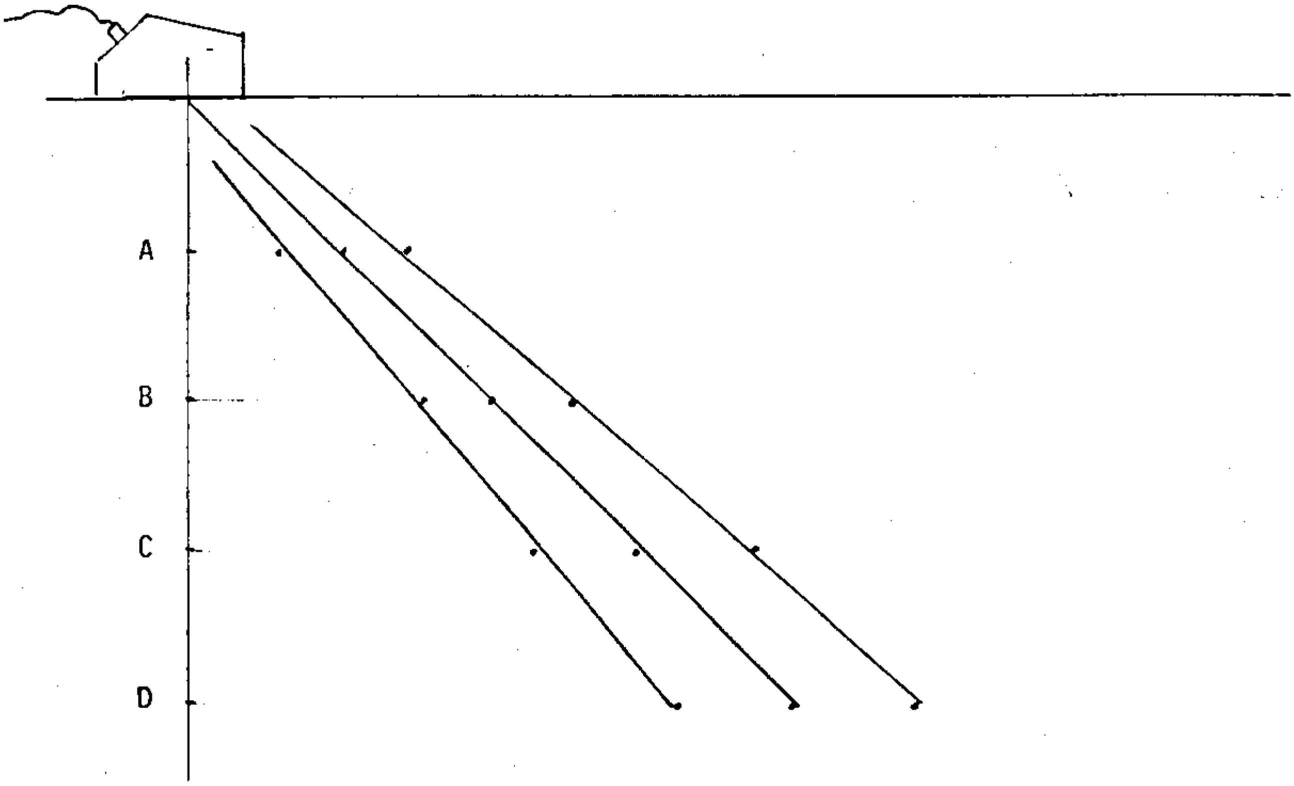
2) Adjust signal to FSH. Move probe forwards until signal falls to 1/10th original height. Mark index pt on block and note distance to N.

3) Move probe back to position 1. Adjust signal to FSH. Move probe backwards until signal falls to 1/10th of original height. Mark index on block and note surface distance to N.

4) Repeat for holes B, C & D.

5) Transfer measurements onto paper so that distances recorded in 1. 2 & 3 are projected from the left hand edge along horizontal lines corresponding to hole depths. Draw best lines through the points, beam centre passing through corner.

EXAMPLE

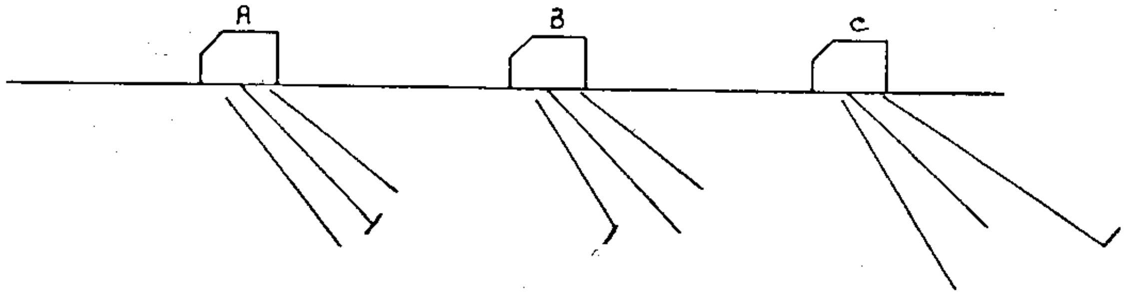


The above is a typical 20dB drop average beam spread that would normally be transferred onto acetate sheets or direct onto beam profile characteristic cards prior to ultrasonic measurements or defect sizing.

DEFECT SIZING - THE 20 dB DROP METHOD

The 20 dB drop is a method used mainly for sizing the face value or width of a defect. The method utilises the 10% edges of the beam (plotted from the I.O.W. block) and is used for sizing defects which are smaller than the beam.

Method



1) Maximise signal from defect (A). Set response to FSH.

2) Move probe forward until response falls to 1/10th original height (20 dB drop) and note both screen reading and distance of probe index from weld centre line (or ref point).

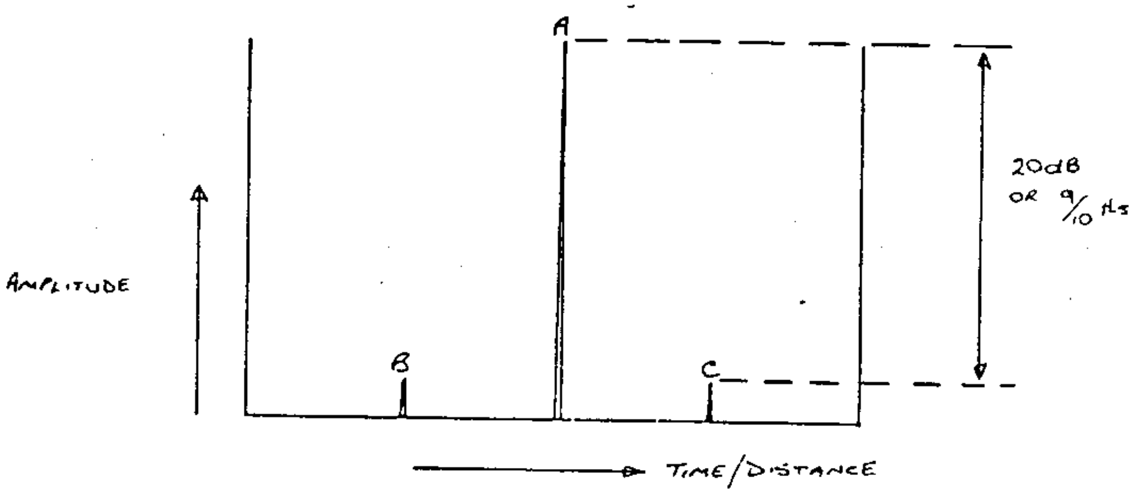
   At this point the trailing edge of the beam is impinging on the top of the defect (B).

3) Return probe to (1).

4) Move probe backwards until response falls to 1/10th original height and note readings as in (2).

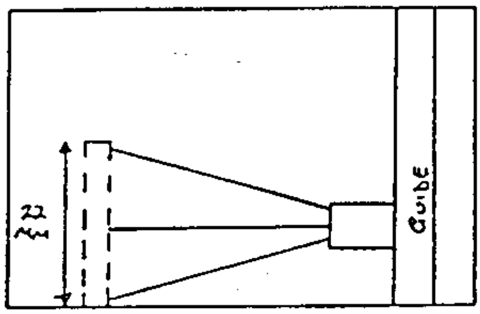
   At this point the leading edge is impinging on the bottom of the defect (C).

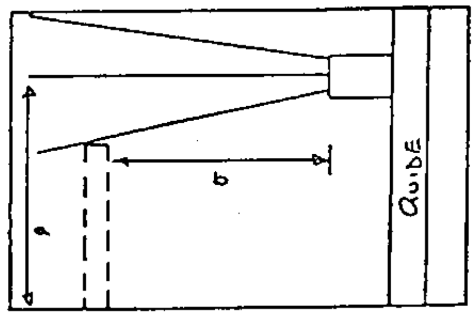
5) Using 20 dB beam spread, plot results noted in (2) and (4) to give position and size of defect.



HORIZONTAL BEAM SPREAD

It is possible to size defects in the horizontal plane (i.e. length) using the 20 dB drop method. To do this it is necessary to produce a horizontal beam spread plot. This is done using the flat bottomed holes in the IOW beam profile block.





1) Select a hole and maximise the signal from it.

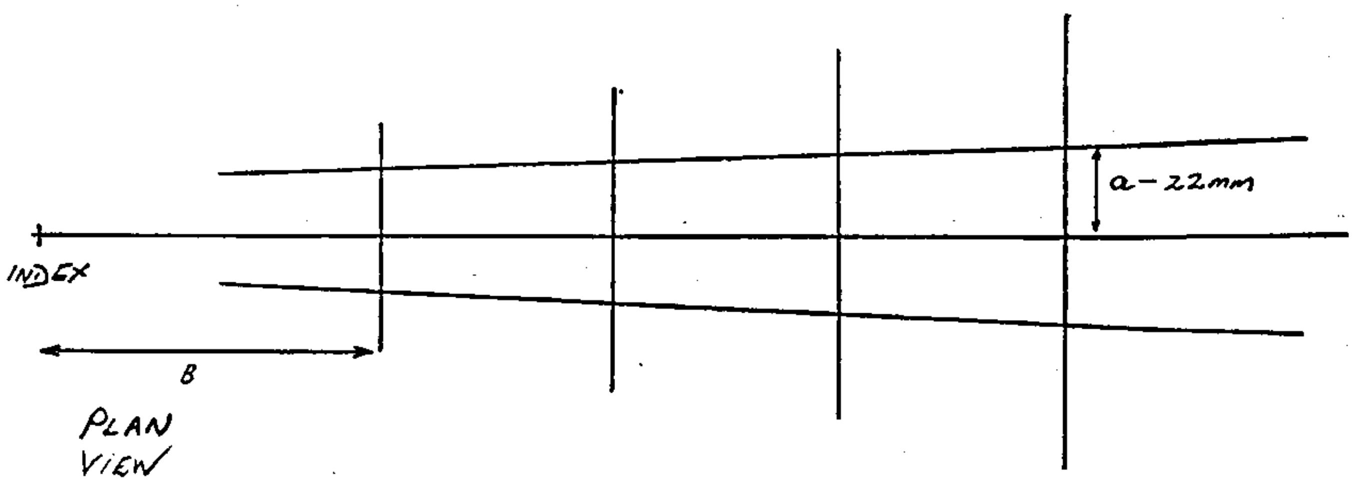
2) Using a probe guide, move the probe off the hole until the signal falls 20 dB.

3) Measure distances a & b.

4) Subtract horizontal depth of hole (22mm) from (a) to give half the spread.

5) Position the probe on other side of hole and repeat for other half.

6) Repeat steps 1 - 5 for further holes of different depths and plot the results as shown.



PROCEDURE FOR ULTRASONIC TESTING BUTT WELDS

1) Obtain appropriate weld details, ie. edge preparation prior to welding process and heat treatment stage.

2) Thorough visual inspection, ie. surface condition, misalignment, mismatch, etc. Mark off centre line if none marked.

3) Compressional check parent plates for laminations and inclusions, thickness of parent plates particularly adjacent to weld. Make a note of any variations in thickness and the areas involved.

4) Draw up cursor(s) ready for angle probe inspection using a mimic gauge where misalignment is apparent.

5) Mark off half-skip and full-skip positions onto parent plate.

6) Perform critical root scan with probes on half-skip position from both sides of weld using a backing guide, marking the approximate extent of suspect areas if any.

7) Assess suspect areas individually (changing probes where necessary) and note lengths, depths and positions of defects onto rough report.

8) Scan between half-skip and passed weld centre line if flush (or weld reinforcement if not ground) from both sides, marking suspect areas.

9) Assess suspect areas and note length, depth and positions of defects onto rough report.

10) Scan between half-skip and full-skip positions from both sides of weld, marking suspect areas.

11) Assess suspect areas individually (changing probes where necessary) and note length, depth and positions of defects onto rough report.

12) Perform transverse scan and assess any transverse defects located.

13) Produce neat, concise, report giving details of any defects located and their position in the weld both by plan view and cross section.

ULTRASONIC TEST REPORT PROCEDURE

ULTRASONIC INSPECTION REPORT

IDENTITY	TP 27
DATE	5.10.83
INSPECTOR	J Smith
MATERIAL	Mild steel
DIMENSIONS	32 mm x 240 mm
WELDING PROCESS	M.M.A.
EDGE PREPARATION	Single 'V' 60° included angle. 2mm root face and gap.
WELD SURFACE CONDITION	Unground
PLATE SURFACE CONDITION	As rolled
PLATE THICKNESS	32 mm
EQUIPMENT	USK6

PROBES		Angle	Frequency	Size	Type
	1	0°	5 MHz	10mm	Twin
	2	45°	4 MHz	10mm	Single
	3	60°	4 MHz	10mm	Single
	4	70°	4 MHz	10mm	Single

SENSITIVITIES

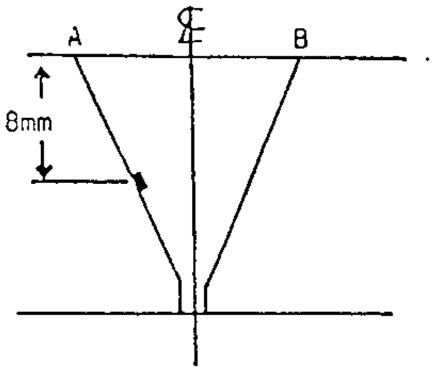
Compressional. 2nd BWE to FSH from parent plate.
Angles response from 1.5mm hole at test depth to FSH.

REPORT

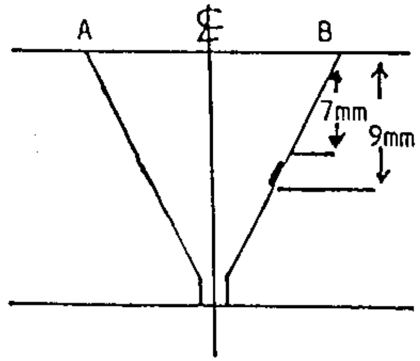
Parent plate compressional scan - Plate A clean. Plate B - isolated inclusions (small) throughout. Not affecting Shear

Weld - Defects as shown.

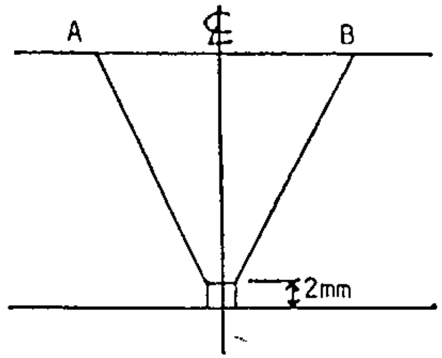
Transverse scan - No transverse defects.



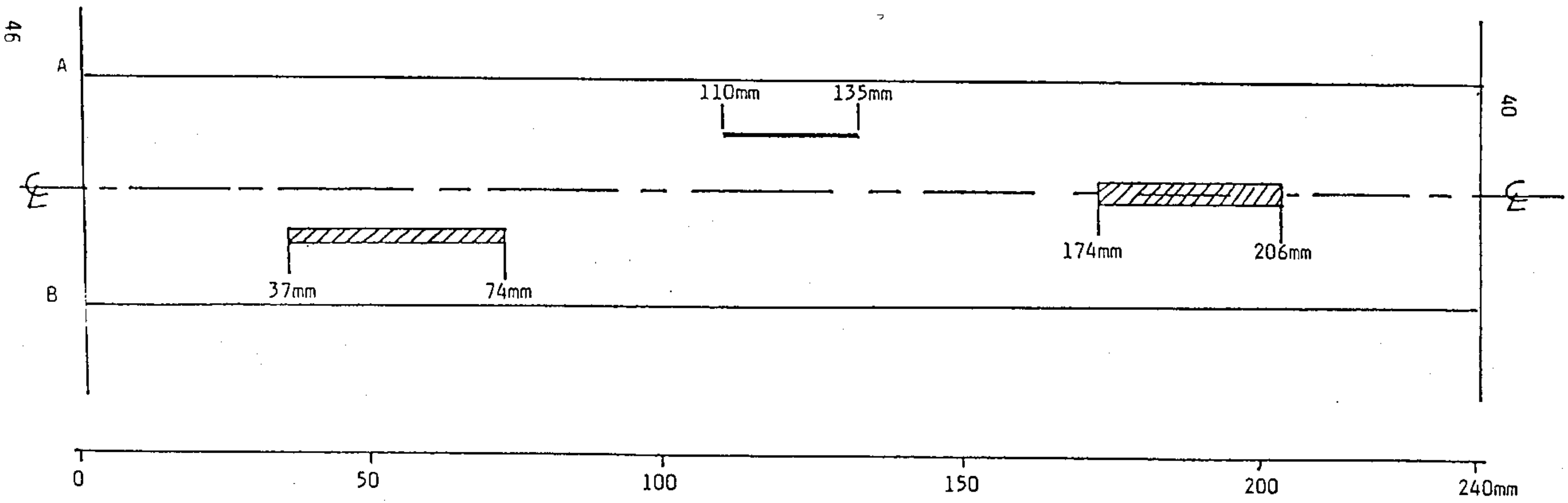
Through section at 120mm
slag on sidewall 110-135mm
60^{O} & 45^{O} probes



Through section at 45mm
lack of sidewall fusion 37-74mm
60^{O} & 45^{O} probes

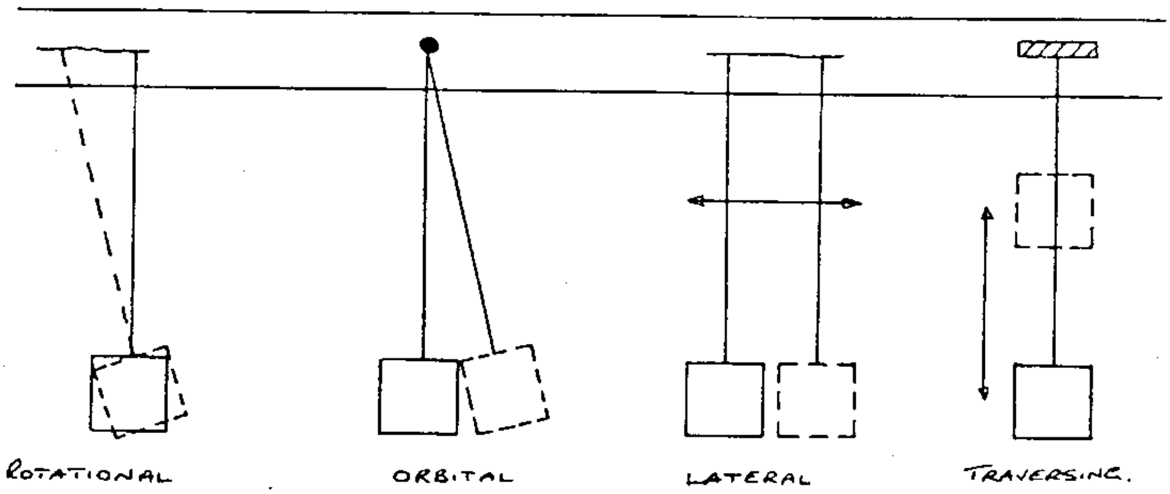


Through section at 195mm
lack of penetration 174-206mm
60^{O} & 70^{O} probes



Scale - full size

ANGLE PROBE SCANNING TECHNIQUES



ROTATIONAL

To distinguish between lack of fusion defects and crack-like defects (multi-faceted). Lack of fusion defects give a signal which dies off quickly on rotational scan where crack-like defects continue to rise and fall.

ORBITAL

Interpretation of spherical defects, i.e. porosity. Orbital scan retains a similar signal on this type of defect.

Lateral

Mainly used to determine defect lengths. Lateral scan is also used when performing a critical root scan.

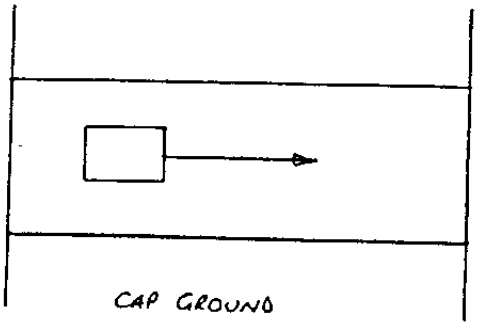
Traversing

Mainly used to determine through section or depth of defect.

During weld body scanning, a combination of lateral and traversing techniques is used.

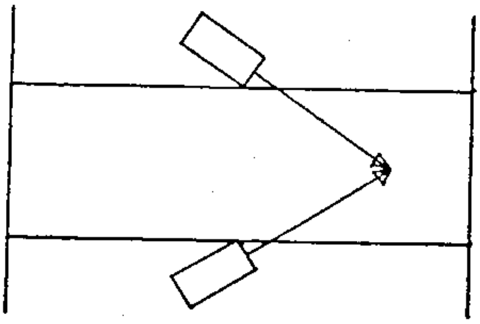
Transverse Scan

A further technique used to locate defects is the transverse scan. As the name suggests, this scan is carried out with the probe parallel to the weld. If the cap is unground then the transverse scan is limited.



CAP GROUND

PLAN VIEW OF WELD CAPS



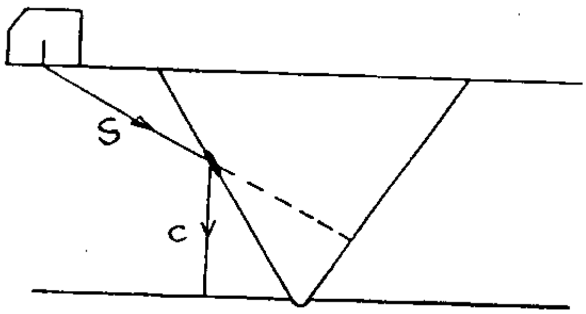
CAP UNGROUND.

SPURIOUS INDICATIONS

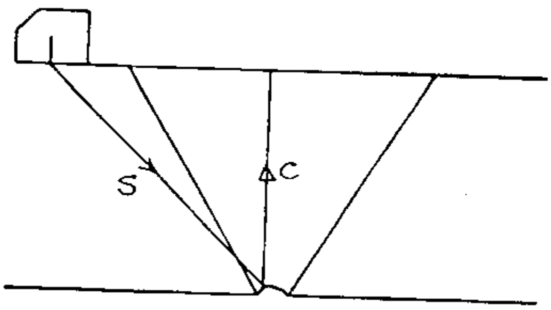
Spurious indications can be summarised simply as unwanted echoes. They are signals on the CRT screen which are irrelevant to the geometry of the material under test, and unless understood, may be misinterpreted as defects.

1) Mode Conversions

The form of spurious indication is the most troublesome since, in many cases, the resulting signals plot within the weld area. Mode conversion is the transformation of ultrasonic energy, usually due to reflection, causing a change of waveform and velocity, i.e. compression to shear and vice versa, shear to surface, etc.



Mode change off sidewall defect. Shear to compression and back to shear. Would plot as defect on opposity sidewall.



Mode change off concave root. Shear to compression and back to shear.

Where mode conversions are reflected to an accessible surface they can be damped with an oily finger.

They cannot be prėdicted but appear to occur more regularly at an incident angle of around 30°. For this reason the 60° beam tends to be more prone than other angles.

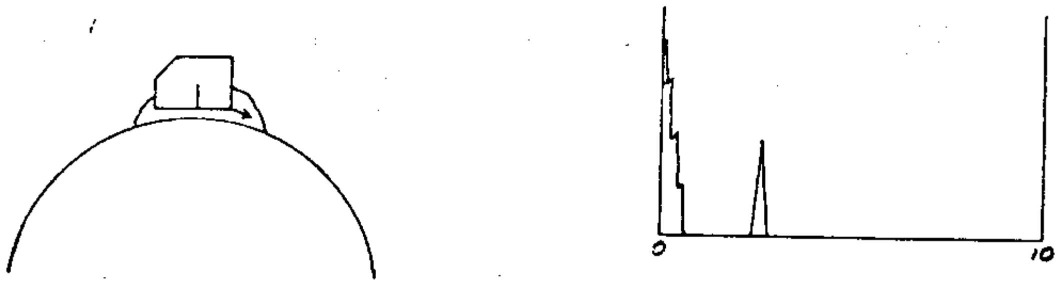
2) Ghosting

Electronic interference causing echoes to run across the screen.

3) Transmission Pulse

The transmission signal is a spurious indication.

4) Grease Build-up



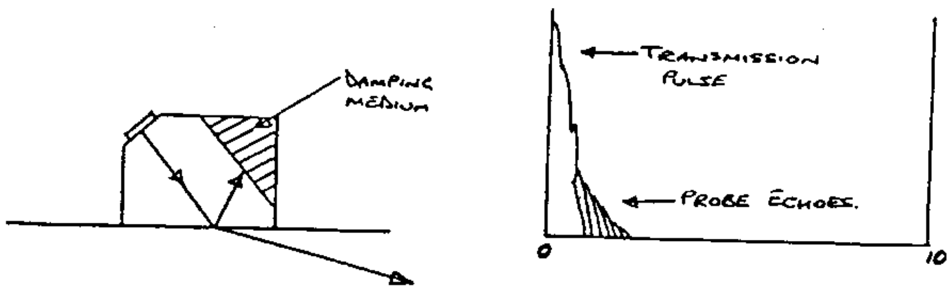
A spurious indication can occur due to grease build-up at the front of the probe, particularly on curved surfaces.

5) Cross-Talk or Chatter

This occurs in twin-crystal probes and is due to the breakdown of the acoustic barrier (cork separator) allowing the passage of sound from the transmitter to the receiver without leaving the probe.

Breakdown of the separator often occurs due to oil impregnation of the cork.

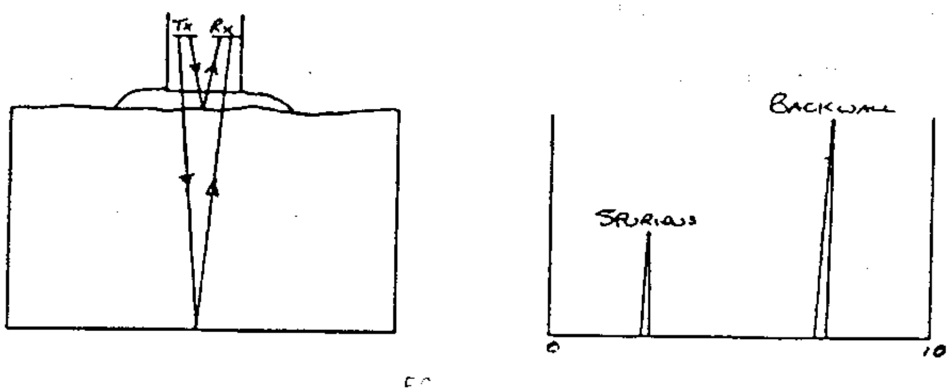
6) Probe Echoes (Standing Echoes)



Probe echoes occur after the transmission pulse and are due to reflection from the perspex which the damping cannot absorb. This very small amount of energy is reflected back to the crystal.

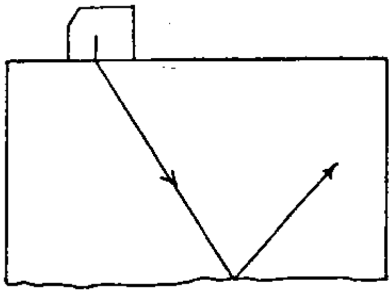
7) Reflection Grating

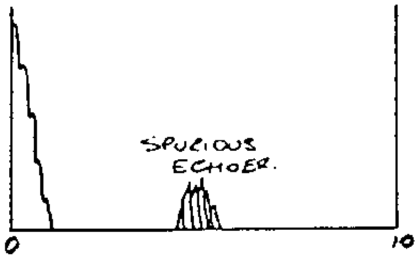
This occurs when using twin crystal probes on a rough surface. The transmitted ultrasound reflects from the surface back to the receiver without entering the material under test. This spurious indication could easily be mistaken for a defect.



8) Rough Backwall

Fairly high amplitude signals can be obtained from a rough uneven backwall with steep angle probes, i.e. 45°. These echoes give a rolling affect as the probe is moved.

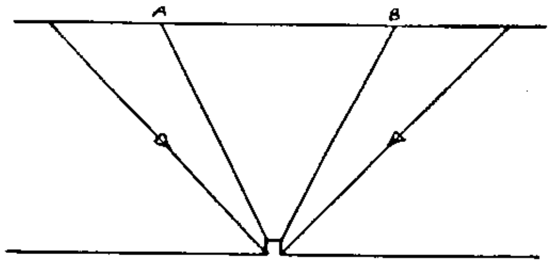


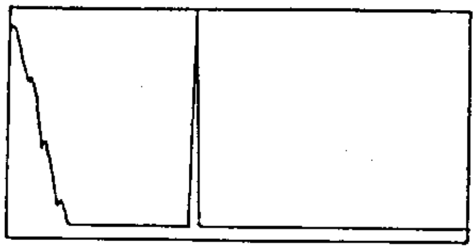


ASSESSMENT OF DEFECTS IN SINGLE 'V' WELDS

ROOT CONDITION

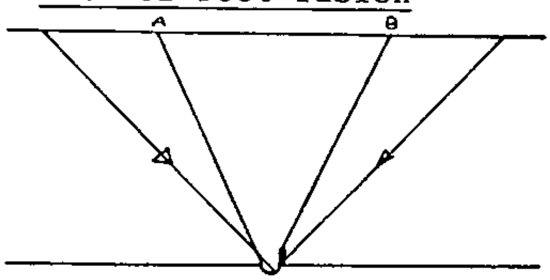
1) Lack of penetration

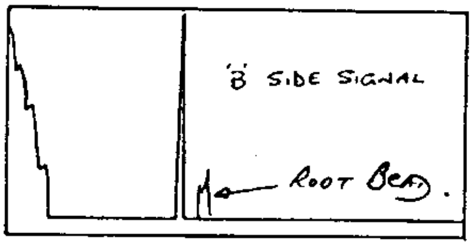




High amplitude corner reflectors from both sides plotting at plate thickness. No cross-over. Projected vertically = root gap. Lack of fusion signals dying off rapidly on rotational scan.

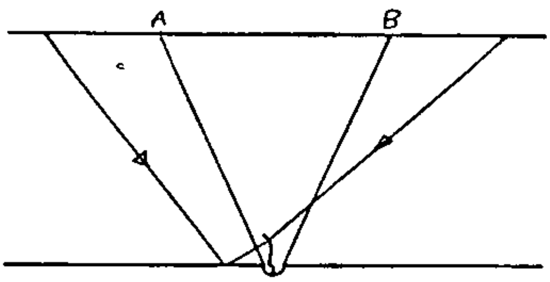
2) Lack of root fusion

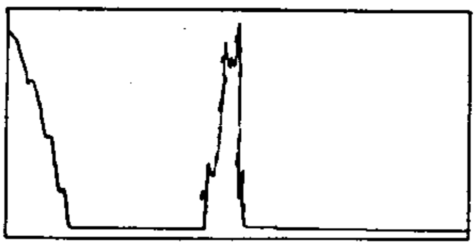




High amplitude signal corner reflector 'B' side plotting at plate thickness. Low amplitude signal 'A' side from bead crossing over centre line and plotting below plate thickness.

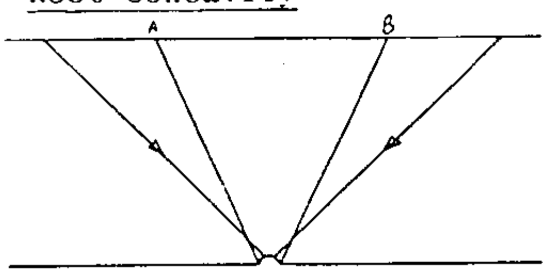
3) Root crack





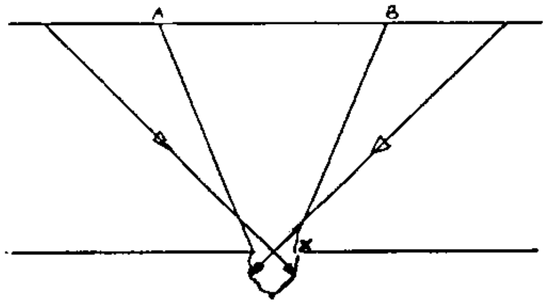
Multi-faceted response usually of high amplitude. Signals continue to rise and fall on rotational scan.

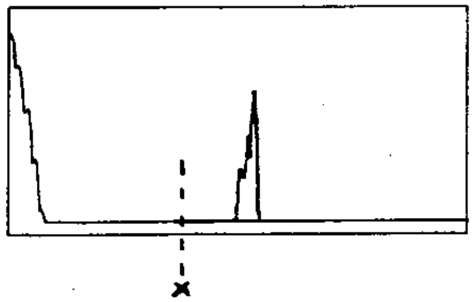
4) <u>Root concavity</u>



Usually low amplitude signal from both sides, plotting short of plate thickness. No cross-over.

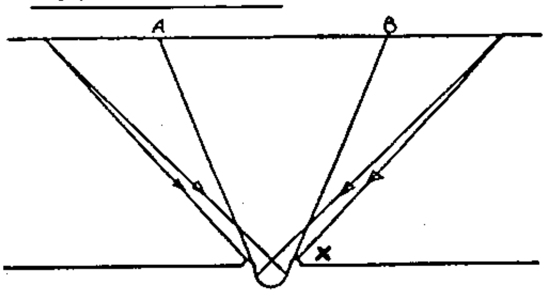
5) <u>Excess penetration</u>

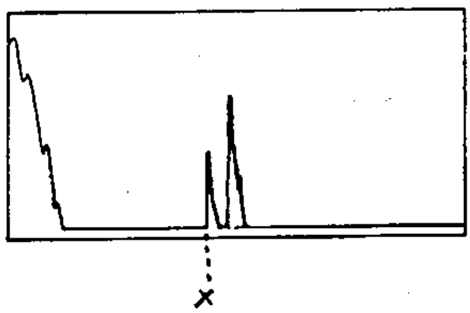




Root bead signal from both sides coming up at a beam path much longer than expected beam path length. Steep angle probe subject to parent metal thickness and width of weld cap would give best results.

6) <u>Root undercut</u>

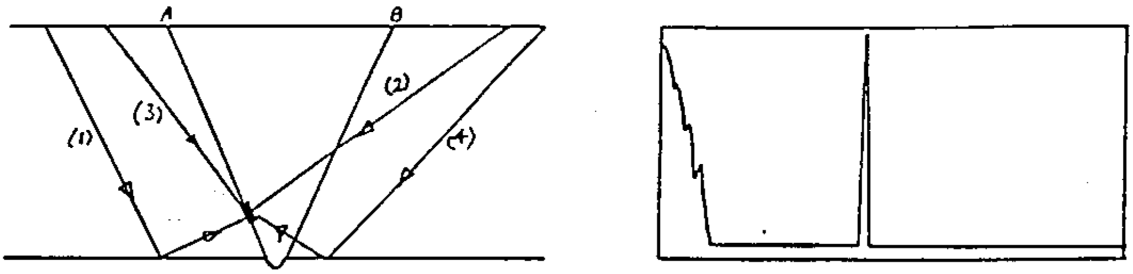




Twin peaked signal from both sides due to beam spread hitting both the defect and the bead. This depends on the severity of the defect.. Defect signal plots short of plate thickness with no cross-over.

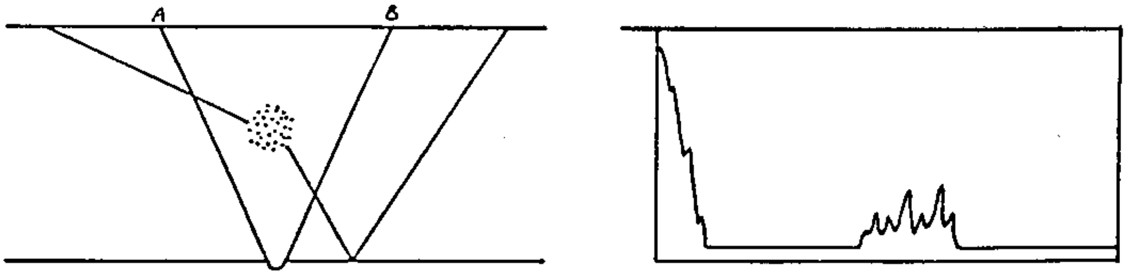
WELD BODY DEFECTS

1) Lack of sidewall fusion



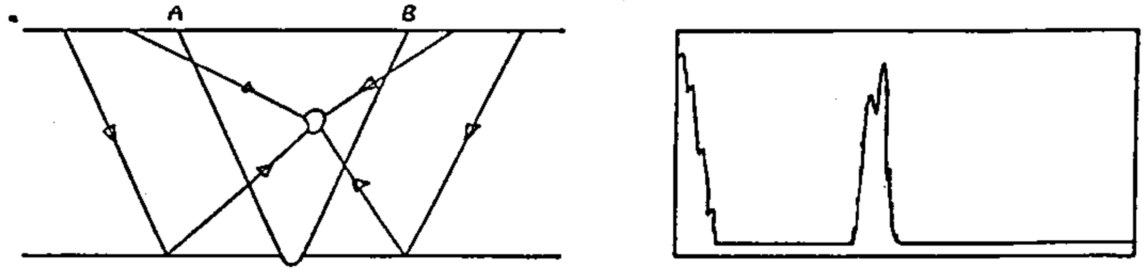
High amplitude lack of fusion signals from (1) and (2). Low amplitude signals from (3) and (4) if any signal at all. This is dependent on slag entrapment which is common in this type of defect.

2) Porosity



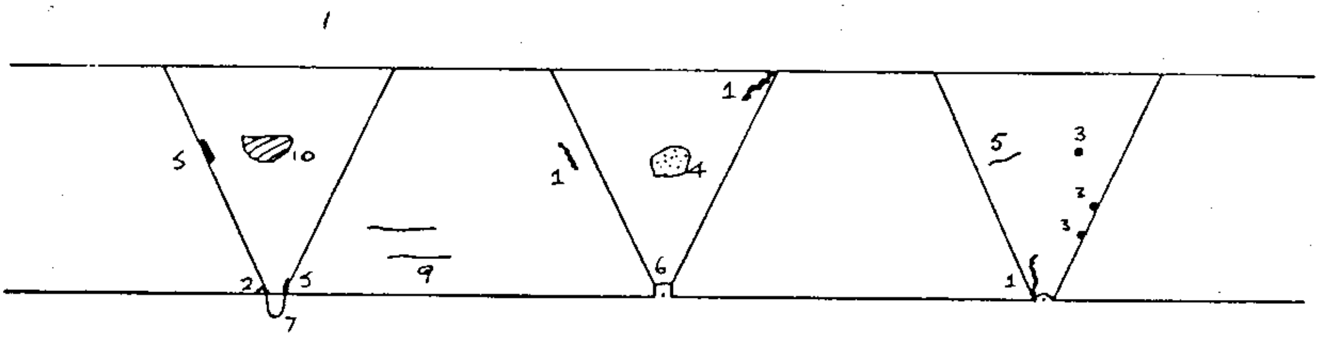
Detectable from all directions. Porosity is a very low amplitude signal with a wide time base. Orbital scan retains the same signal.

3) Slag inclusion



Detectable from all directions. Slag inclusions are volumetric defects. The signal has numerous half-cycles and often a "rounded" tip or peak.

DEFECTS ARISING IN BUTT WELDS

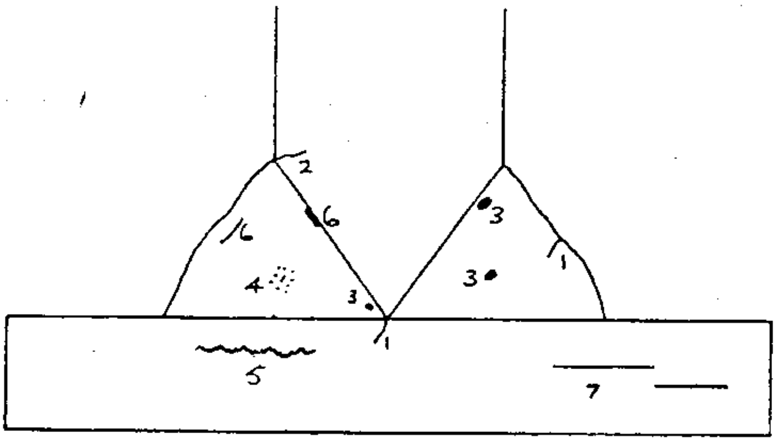


1) Cracks (underbead, root, HAZ).
2) Undercut
3) Slag (root, sidewall, body)
4) Porosity
5) Lack of fusion (root, sidewall, inter-run)
6) Lack of penetration
7) Excess penetration
8) Root concavity
9) Plate laminations
10) Transverse cracks

Double V Welds

Defects possible in double V welds are the same as those for single V's but for excess penetration and root concavity which are not possible due to the geometry of this type of weld

DEFECTS ARISING IN T - JOINTS AND NOZZLES



The diagram shows a full penetration T-section or set-on nozzle and illustrates the defects one might expect to find in this type of weld. These defects could also be found in partial penetration welds.

1) Cracks (toe, underbead, HAZ).

2) Undercut

3) Slag (root, sidewall, body)

4) Porosity

5) Lamellar tearing

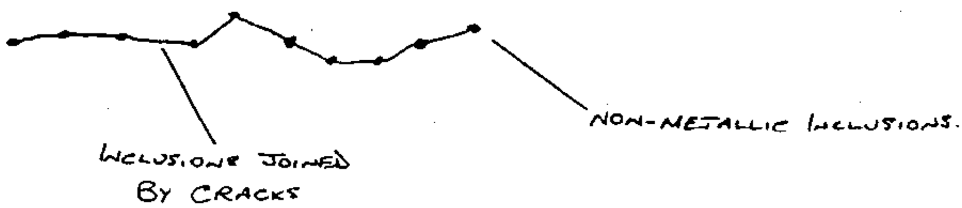
6) Lack of fusion (root, sidewall, inter-run)

7) Plate laminations

Lamellar Tearing

This defect is common only to branch type welds and is due to contraction or mechanical stresses.

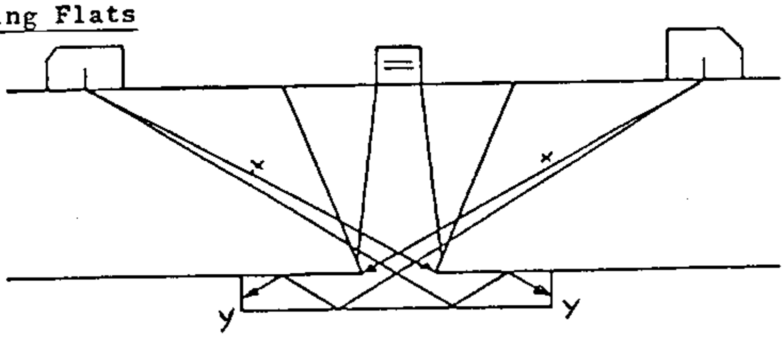
Materials with poor transverse ductility are susceptible to lamellar tearing, often due to a high non-metallic inclusion content. These inclusions are joined together by cracks when stresses become high, producing a step-like defect which runs parallel with the plate surface and gives crack-like ultrasonic responses.



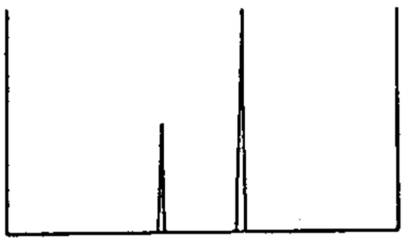
BACKING FLATS AND E.B. INSERTS

Backing flats and E.B. inserts are sometimes used in butt welding to enable better control of root condition. Fusion in the root area is checked in the following way.

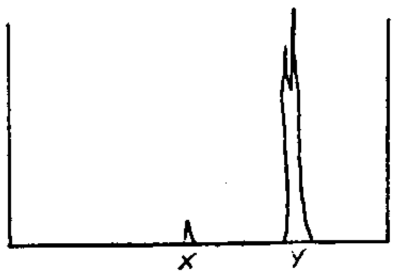
Backing Flats



SCREEN PRESENTATIONS



Compressional Probe



Angle Probe

If the root is fused, a strong signal from the backing flat is received. Due to the beam spread a small signal will be received from the parent plate.

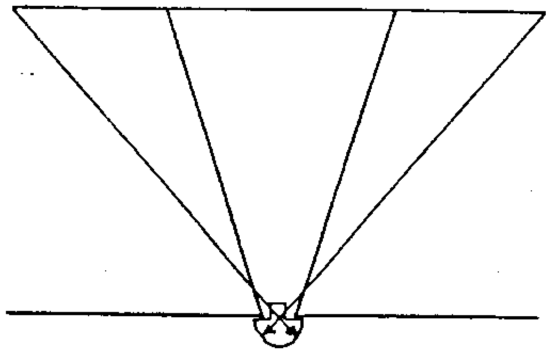
If the root is fused, a signal from the backing flat will be received at a distance well in excess of that for the root. This is usually a series of signals due to the sound ringing in the backing flat.

N.B.

The junction between the parent plate and the backing flat presents NATURAL REFLECTORS at positions x above and low amplitude signals can be expected at these positions when the probe is on the opposite side of the centre line.

E.B. Inserts

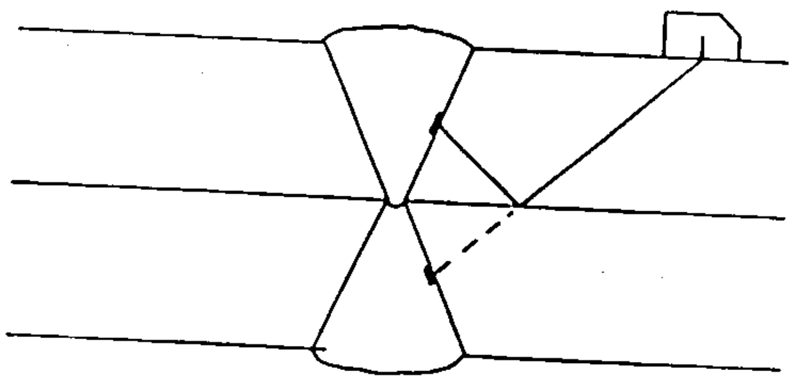
Welds with E.B. inserts can be treated as normal single 'V' welds. A fused E.B. insert gives the affect of a perfectly machined bead which can give high amplitude signals.



THE MIRROR IMAGE TECHNIQUE

When examining welds from the full-skip position, projection of the beam from the reflecting surface (plate bottom) can lead to inaccuracies in defect plotting.

To overcome this problem it is possible to produce a mirror image of the sample and read directly down the straight beam.



This technique can also be used on welds of variable geometry where access to testing surfaces is limited.

ACOUSTIC IMPEDANCE

The acoustic impedance (Z) of a material is a measure of the resistance of that material to the passage of ultrasound. It is a product of density (P) and velocity (V).

Thus $$Z = PV$$

When a beam of ultrasound arrives at a boundary between two media of different acoustic velocities, part of the energy is reflected and part transmitted into the second medium. The amount of energy reflected can be calculated from the acoustic impedance values of the two materials.

Thus $$\text{REFLECTED ENERGY} = \left(\frac{Z1 - Z2}{Z1 + Z2}\right)^2 \times 100\%$$

Consider a water/steel interface:- Z steel = 45, Z water = 1.5

$$\%\ \text{reflected energy} = \left(\frac{45 - 1.5}{45 + 1.5}\right)^2 \times 100$$

$$= \left(\frac{43.5}{46.5}\right)^2 \times 100$$

$$\therefore = \underline{\underline{87.5\%}}$$

This means that 87.5% of the initial energy is reflected and only 12.5% transmitted into the sample. This 12.5% will be totally reflected at the steel/air interface (backwall) but on returning to the probe will suffer a further 87.5% loss at the steel/water interface. The intensity of ultrasound returning to the probe is therefore only 1.5% of the original incident energy and, for this reason, high amplification in the receiver circuit is necessary.

COUPLING

Because of the difference in acoustic impedance between a gas and a solid, all of the energy is reflected - the basis of flaw detection.

We therefore have to exclude the air between the probe and the specimen. This is done by introducing a substance with a higher acoustic impedance than air. This substance is known as couplant.

Common couplants are - water, oil, grease, polycell, swarfega, glycerine.

THE DECIBEL (dB)

The decibel is a unit of comparison.

It is the measurement of changes in sound intensities and has a logarithmic base.

It is possible to calculate the dB difference between signals from two reflectors whose size ratio is known.

Example

If two reflectors, equidistant from the probe, have a size ratio of 10:1, what would be the dB difference in their echo heights?

From the formula

$$dB = 20 \log_{10} \frac{h1}{h2}$$

Where h1 & h2 are echo heights

Then $dB = 20 \log_{10} \frac{10}{1}$ (log 10 = 1)

$= 20 \times 1$

$= \underline{\underline{20\ dB}}$

For a 2:1 ratio :- $dB = 20 \log_{10} \frac{2}{1}$ (log 2 = 0.3010)

$= 20 \times 0.3$

$= \underline{\underline{6\ dB}}$

By transposing the formula it is possible to determine the ratio of sizes of the two reflectors whose dB difference is known.

Example

Two reflectors, equidistant from the probe, have a dB difference of 14 dB between their echo heights. What is the ratio of their reflective areas?

$$dB = 20 \log_{10} \frac{h1}{h2}$$

$$14 = 20 \log_{10} \frac{h1}{h2}$$

$$\frac{14}{20} = \log_{10} \frac{h1}{h2}$$

$$\text{Antilog } 0.7 = \frac{h1}{h2}$$

$$5 = \frac{h1}{h2}$$

$\therefore$ **Ratio = 5:1**

DETERMINATION OF ATTENUATION FACTOR

The attenuation factor of a material is the loss in intensity suffered by the ultrasonic beam passing through the material - expressed as dB/mm.

To determine this factor we must consider the distance along the ultrasonic beam, beyond which loss in intensity becomes constant. The distance is equal to 3 near zones from the crystal. If we then practically determine the attentuation loss of the beam travelling between two surfaces beyond this point, and subtract the loss due to natural divergence of the beam (i.e. 6 dB - Inverse Law), the remainder will be due to the attentuative properties of the material.

Method of Determination

a) Determine the near zone of the probe.

b) Note the distance of 3 near zones.

c) Select a backwall echo greater than 3 near zones from the probe and the BWE which represents the repeat echo of this distance.

d) Using the calibrated gain control, find the difference between the two signals.

e) Subtract 6 dB from (d) because of the Inverse Law.

f) Divide the result of (c) by twice the distance on the time base between the two signals (i.e. there and back). This result is the attentuation factor in dB/mm.

Example

a) For a 5 MHz 10mm compressional probe.

$$N = \frac{d^2 \times F}{4 \times V} = \frac{100 \times 5{,}000{,}000}{4 \times 5{,}960{,}000} = 20.97 \text{ or } \underline{\underline{21\text{mm}}}$$

b) 3 near zones = 63 mm

c) Screen calibrated for 200mm on 25mm thickness = 8 signals.

3rd BWE = 75mm (i.e. over 63mm)

∴ select 3rd & 6th BWE's (i.e. 2 x 75mm)

d) dB difference = 10 dB

e) 10 - 6 = 4 dB

f) BWE's selected = 75 & 150 mm ∴ time base difference = 75mm

∴ 2 x distance = 2 x 75 = 150mm (there and back)

∴ attenuation factor = $\frac{4\text{dB}}{150\text{mm}}$

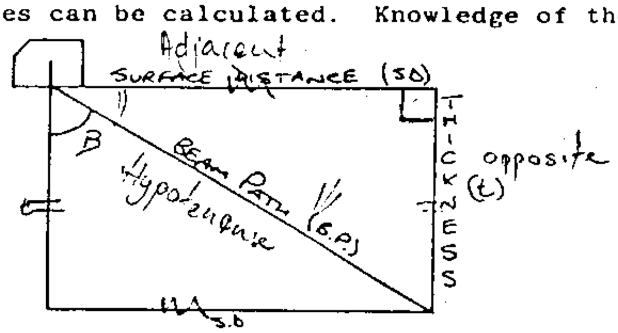
$$= \underline{\underline{0.026 \text{ dB/mm}}}$$

SOHCAHTOA.

Sin = $\frac{\text{Opposite}}{\text{Hypotenuse}}$ Cos = $\frac{\text{Adjacent}}{\text{Hypotenuse}}$ Tan = $\frac{\text{opposite}}{\text{Adjacent}}$.

CALCULATION OF BEAM PATHS AND SURFACE DISTANCES

In ultrasonic weld examination, plotting systems are used for speed of reference to beam path and surface distances. The system is controlled by right-angled triangles, thus by trigonometry the relationship between probe angles, plate thicknesses or defect depths, beam paths and surface distances can be calculated. Knowledge of these calculations is necessary.



Since the probe angle, B, is measured from the normal, the lower triangle will be considered, both triangles being equal.

Beam Path Calculation

t = thickness
BP = Beam Path.

$$\text{Cos}B = \frac{\text{Adjacent}}{\text{Hypotenuse}} = \frac{t}{BP} \quad \therefore \quad \text{Cos}B = \frac{t}{BP} \quad \therefore \quad BP = \frac{t}{\text{Cos}B}$$

Example

Calculate the ½ skip beam path distance for a 60° probe in a plate of 20mm thickness.

$$BP = \frac{t}{\text{Cos}B} = \frac{20}{\text{Cos}60} = \frac{20}{0.5} = \underline{\underline{40\text{mm}}}$$

Surface Distance Calculation

$$\text{Tan}B = \frac{\text{Opposite}}{\text{Adjacent}} = \frac{SD}{t} \quad \therefore \quad \text{Tan}B = \frac{SD}{t} \quad \therefore \quad SD = t \times \text{Tan}B$$

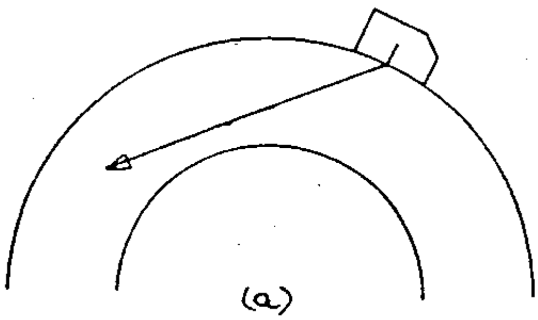
Example

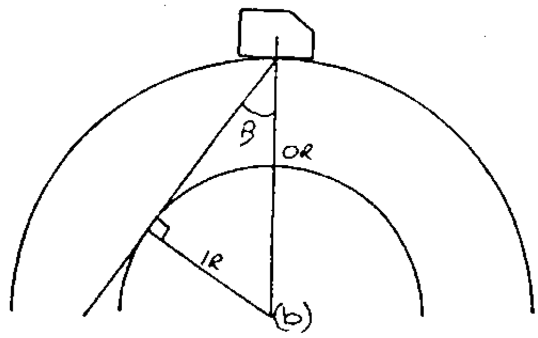
Calculate the ½ skip surface distance for a 45° probe on a plate of 30mm thickness.

$$SD = t \times \text{Tan}B = 30 \times \text{Tan } 45^{\circ} = 30 \times 1 = \underline{\underline{30\text{mm}}}$$

THE IRRADIATION FACTOR

When ultrasonic testing horizontal welds in thick-walled pipes it is possible, due to curvature, that the beam will not reach the inside bore of the pipe as illustrated in (a) below.





To ensure that this does not happen we can calculate the maximum angle that we can use, i.e. the angle which will create a tangent to the inside bore.

Consider the pipe shown in (b).

In the right angled triangle, B = probe angle
IR = inside radius
OR = outside radius

By trigonometry: $\mathrm{Sin}B = \dfrac{\text{Oposite}}{\text{Hypotenuse}} = \dfrac{IR}{OR}$

Since pipe measurements are normally expressed by diameter we can convert the equation to diameters simply by doubling both the top and bottom of the equation.

Thus:

$$\mathrm{Sin}B = \frac{ID}{OD}$$

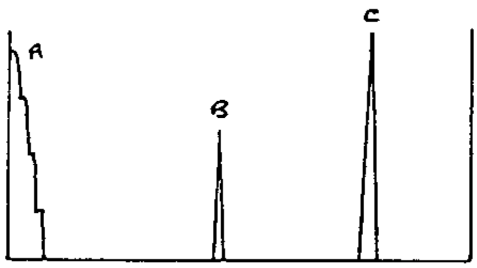
Where ID = inside diameter
OD = outside diameter

SCANNING SYSTEMS

A- Scan

A-scan is a data presentation method to display the returned signals from the material under test on the screen of an oscilloscope. The horizontal base line on the CRT indicates elapsed time and the vertical deflection shows signal amplitude.

The chief advantage of this equipment is that it provides the amplitude information needed to evaluate the size and position of the discontinuity.



A-SCAN PRESENTATION

A - Initial pulse

B - Discontinuity

C - Backwall echo

B-Scan

The B-scan equipment, in addition to the basic A-scan unit, provides these functions:

a) Retention of the image on the oscilloscope screen by using a long-persistence phosphor coating.

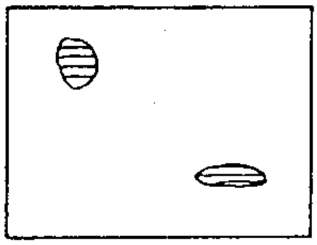
b) Deflection of the image-tracing spot on the oscilloscope screen in synchronism with the motion of the transducer along the sample.

c) Image tracing spot, brightening in proportion to the amplitude of signal received.

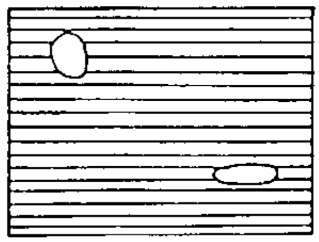
The chief advantage of the B-Scan technique is that a long persistence cross-sectional view of the sample and the discontinuities within it are displayed. In high speed scanning, the cross-section image is retained long enough to evaluate the entire sample and to photograph the oscilloscope screen for a permanent record.

C-Scan

C-Scan is intended to provide a permanent record of the test when high speed auto-scanning is used in ultrasonic testing. C-Scan displays the discontinuities in a plan view but provides no depth or orientation information.



Plan view of specimen



Printout representation of defects

INSPECTION & NDT CERTIFICATION SCHEMES

1 ASNT EXAMINATIONS

1.1 Overview

ASNT (American Society for Non-destructive Testing) examinations are usually held at the Rotherham training centre and conducted by Terry O'Neill (ASNT level III RT, UT, ET, MT, PT, certificate number LM 964).

Examination content is determined by an employers *written practice*, i.e. employers who do not have a written practice cannot have their NDT personnel certified under the ASNT system.

All companies who wish their NDT operators to be qualified to ASNT requirements must hold a written practice in accordance with the ASNT document *SNT-TC-1A - Recommended Practice*; this document is intended as a guideline for employers to establish their own written practice for the qualification and certification of their non-destructive testing personnel. It is not intended to be used as a strict specification.

Written practices are available via T P O'Neill at the Rotherham Training Centre.

A self-employed individual may hold his own written practice, but it should be appreciated that he may be re-examined in accordance with a different written practice when employed by another employer.

1.2 Written practice

A written practice is not a set of NDT procedures. A written practice is for the **control and administration of NDT personnel** and is written specifically for a companies needs, e.g. related to welds only, for welds and castings, for forgings only etc.. Also the document may relate to specific British Standards, American standards, in-house procedures etc., and may cover one NDT method or say four or five.

A written practice typically consists of 20 - 25 pages and includes the following:

- Minimum training and experience requirements for personnel wishing to be certified.
- The methods which may be relevant, e.g. UT, MT, PT, RT, ET.
- The syllabus for the training related to each method.
- The number of examination questions and number of practical test points. Theoretical questions are usually of the multi-choice type.
- Minimum examination pass marks.

Although it is common practice for ASNT examined level III personnel to produce written practices, it should be noted that it is the employer who is responsible for the document, i.e. it is the employer who is responsible for his own qualification system for NDT personnel.

1.3 Examinations

The examinations are divided into three parts:

1. **General**: Typically 30-40 multi-choice questions related to the relevant NDT method.
2. **Specific**: Typically 15-20 questions related to the test equipment used, product/process, and specifications/procedures used by the employer.
3. **Practical**: Typically 10 check points which may relate to one or more test samples.

All candidates would also have to undertake physical tests applicable to the test method, e.g. eyesight, and in some cases, colour differentiation.

Examination duration is typically less than a day.

1.4 Examination results

Examination results are normally available within 48 hours of the examination; the employer is forwarded a sheet detailing examination results and certificates of achievement for successful candidates, normally within 5 days.

ASNT certificates are normally valid for 3 years.

2 BRITISH GAS INSPECTION EXAMINATIONS

2.1 General

The British Gas Approval Scheme (BGAS) for inspectors and NDT technicians is primarily related to pipe and pipeline applications. The examinations deal with the theory and practice related to the NDT or inspection method, relevant British Gas specifications and pipemill or pipeline operations.

British Gas examinations are held at the following location:

British Gas plc,
Ripley Road,
Ambergate,
Derbyshire.

Do not send examination fees to this address.

Examinations should be arranged with British Gas:
Contact Jean Grice; tel. Hinckley (0455) 251111 Ext: 2287.

Details regarding payment, accommodation etc. will be issued by British Gas.
The examination fee is £169 inc. VAT at 17.5%.

The duration of an examination is approximately half a day, usually commencing at 8.45 a.m. Each examination consists of three specific parts:

1.	Question papers:	Time limit approximately 2 hours
2.	Practical:	Typically 30 minutes to 3 hours
3.	Interview:	Up to 30 minutes

2.2 Question papers:

Question papers consist of approximately 30 questions similar to the following examples:

a. **Welding inspection**
What are the dimensions of a tensile test specimen in accordance with BGC PS P2?

b. **Painting inspection**
What is a Pfund cryptometer used for?

c. **Magnetic particle inspection**
What is a Burmah-Castrol strip used for?

d. **Ultrasonic inspection**
State the formula for calculating the near zone of an ultrasonic beam.

The questions are NOT multi-choice.

2.3 Practical:

The practical content of the examination is carried out on a one to one basis with the examiner; this may consist of:

- Identification of equipment relevant to the subject.
- Demonstrating the correct use of inspection gauges likely to be used on site.
- Identification of consumables, e.g. electrodes, paints etc..
- Assessment of acceptable/non-acceptable samples.

The candidate may be requested to explain actions/decisions plus answer additional verbal questions given by the examiner.

2.4 Interview:

The final part of the examination is again conducted on a one to one basis in an interview room. Any queries relating to the theory paper or practical examination will now be discussed. Additional questions may also be asked.

2.5 Examination results:

There is no *pass mark* in percentage terms for the examination; it could be regarded as a technical interview in which an overall assessment of the candidate is made.

The results of your examination will be available within 24 hours; contact Jean Grice.

A report summarizing the attempt will be normally be received within 5 days. If successful the candidate will also receive an approval *ticket* which is valid for 5 years. If unsuccessful the candidate may apply for a re-test; there is no time limit for this.

3 PCN/CSWIP EXAMINATIONS

3.1 General

The PCN (Personnel Certification in Non-Destructive Testing) certification scheme has been introduced to provide a *European* recognised level of competence for NDT personnel. PCN is being conducted by the British Institute of Non-Destructive Testing and is structured to cover most of the current CSWIP (Certification Scheme for Welding Inspection Personnel) qualifications; PCN is also actively involved in the transition arrangements of other UK certification schemes who wish to be part of a joint approach into Europe.

The introduction of the open European market in 1992 will require the British non-destructive testing industry to work in accordance with European recognised certification schemes. All the member countries will have to comply with this requirement even though the certification schemes will have different names.

3.2 Levels of qualification

The PCN/CSWIP approvals scheme covers a wide range of non-destructive testing methods and applications for both technicians and supervisors.

Most PCN examinations are at available at three levels:

- Level 1: for trainees or new candidates who have attended relevant courses and have attained practical experience.
- Level 2: for more experienced technicians.
- Level 3: for supervisors who need a thorough knowledge of all NDT techniques.

Application areas for the PCN/CSWIP certification scheme include welding, castings, forgings, and aerospace.

Most examinations are available at The Northern Test Centre for personnel who require certification in the category of *fusion welding*; these are also available at other examination/test centres.

3.3 Pre-examination requirements

It is recommended, and for certain levels of certification, a requirement to have attended PCN/CSWIP approved courses before taking examinations; practical experience is also required prior to taking examinations. These and other requirements are laid down in the *PCN/CSWIP Requirements Booklets* which can be obtained from the test centres; also available are specimen questions and syllabuses on which the candidate will be examined.

3.4 Examinations

The examinations consist of theory, practical, and, in certain cases, oral parts. The examination parts must be completed within specified time periods which are stipulated in the PCN/CSWIP documents.

3.5 Results and certification

The candidates will be informed of his results by mail from the Welding Institute if the examination has been conducted at either Abington or Rotherham. Part retests are allowed after the initial examination, with up to two attempts being the maximum, dependent upon the specific examination, before the complete examination has to be re-attempted.

On successful completion of examinations the candidates will be issued with a certificate of competence which is valid for five years, subject to various clauses. Depending upon the level of certification there may be a re-sit required to maintain certification at the end of the five year period.

3.6 Useful addresses

Northern Test Centre,
TWI-Ruane Ltd,
Psalters Lane,
Rotherham,
South Yorkshire,
S61 1DL.

Telephone: (0709) 560459
John Moody
Martin Dawson

PCN/CSWIP Bookings,
c/o The Welding Institute,
Abington Hall,
Abington,
Cambridge,
CB1 6AL.

Telephone: (0223) 893482
Bookings Office