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"SOME ASPECTS OF STANDARDIZATION IN ULTRASONIC FLAW-DETECTION"

By

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SYNOPSIS

Industrial applications of ultrasonic detection of internal flaws have now been well recognised in their reliablity and ability to prevent service failures of important engineering components. The acceptance of some materials for critical applications is based on rigid ultrasonic test specification. With the objectives of eliminating personal factors, formulation of rational standards and modes of calibration and test procedure in relation to the material under test have been evolved specially for the pulse reflection technique with electronic instrumentation where several variables are encountered. The parameters of the various elements of the test procedures i.e. the C.R.O. and the ultrasonic transducers have been discussed from basic considerations. A critical examination of the current practice in relation to standard reference blocks for evaluating and calibrating the instrument and probe characteristics has been made with particular reference to the A.S.T.M., British and Dutch test blocks. References have specifically been made to further work required for standardization of test procedures and evaluation of test results.

INTRODUCTION.

Amongst the methods of non-destructive testing, although ultrasonic detection of internal flaws is of comparatively recent growth[1-4a], it offers specific advantages such as (i) very high test sensitivity permitting detection of minute flaws, (ii) great penetrating power,

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allowing examinations of thicker sections, (iii) accuracy in locating the flaws and their areas, (iv) fast instant test response, permitting rapid and automated inspection and (v) need for access to only one surface of the specimen as in pulse-echo-technique. Industrial applications of ultrasonic testing relate to inspection of turbine components, internal combustion engines, aircraft parts, strategic forgings, castings, weldments and rolled products.

Earlier ultrasonic tests were qualititive and required calibration methods to ensure reproducibility of results. Current trends have related to quantitative measurements of the nature, size, shape and orientation of internal flaws, resulting in adequate understanding of the effects of the various parameters & limitations arising out of (i) the nature of material under test, (ii) characteristics of the equipment and probe employed (iii) and the testing techniques. It is in most cases now mandatory to evolve standard test procedures for the ultrasonic inspection of engineering components with a view to reduce personal factors. The use of suitable standard reference block helps in calibration of test equipment.

There are several points of special interest to be taken into consideration for standerdization of test techniques. Some of the basic principles of ultrasonic flaw detection may now be outlined in relation to standardization of test procedures.

FUNDAMENTAL PRINCIPLES:

Basic principle of ultrasonic flaw detection is that very little energy loss takes place (neglecting the attenuation

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loss[5]) when an ultrasonic beam travels through homogeneous material except when it is intercepted or reflected by flaws & discontinuity; based on this principle two techniques have been developed for flaw detection. The earlier technique of "through transmission[3]" or shadow method was based on the diminution in energy of continuous ultrasonic wave transmitted through the material. The "pulse ultrasonic wave technique"[4b,6,7] or reflection method is based on the energy of the ultrasonic wave reflected from the defect as indicative of the internal flaw; the latter offered saveral advantages over the former.

Basic components of Pulse Flaw detector:-

Basic components of a modern pulse flaw detector are shown in Figs la & b. A short electric pulse is applied to the transducer to entrain ultrasonic waves into the specimen which is acoustically coupled with the transducer. The timing circuit through sweep generator then measures the time between transmitted and reflected signals. Distance markers are provided in some instruments. The cycle is repeated at regular periods for continuous indication. The sweep duration is chosen according to the thickness of the sample to cover almost full CRO tube screen for highest accuracy. The synchronizer (Trigger) not only controls the high frequency pulse for the transducer but also ensures desired output for the sweep generator. The pulse repetition rate is so adjusted as to completely extinguish reverberations between successive pulses (Fig.2). The pulses from the generator are damped exponentially and control the "dead zone" below the inspection surface within which no defects are detectable. Similar effect is produced by the long recovery period of the amplifier circuit.

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The transducers and amplifiers used in a typical system tend to ring or to stretch the signals even when initial pulse contains a single cycle. Use of prismatic elements lessens the "dead zone" as compared to that with normal transducer practice (Fig.3).

Combinations of flaw detector elements:

Combinations of the various elements of the ultrasonic flaw detectors are used for different applications. Longitudinal[8], transverse (shear)[9], surface (Rayleigh)[10] and plate (Lamb)[11] waves, the former two being more common, are employed in either through transmission or pulse reflection techniques using single or double, separate or combined (TR) search units[12]. In the U.S.A. single search units and in the U.K. and Europe double transducer techniques are more popular. Again, depending upon the nature of the job either direct contact or angle-beam probes can be used. Various scanning devices viz., A -, B-, or C-scan are followed in direct contact or immersion testing. In the A-scan presentation, depth of the flaw is noted from the horizontal position and the size of flaw from the vertical height of the peak on the CRO screen. The B-scan gives a cross sectional view viz., the depth and extent of flaw in a single vertical plane. The C-scan shows a plan view of the flaw. A combination[13] of B-scan and C-scan can provide an isometric view of the flaw.

Ultrasonic frequency:

Proper selection of frequency is essential as it governs the sensitivity, minimum detectable flaw size, noise level and attenuation etc.

Transducers:

The probe design has been the subject of constant

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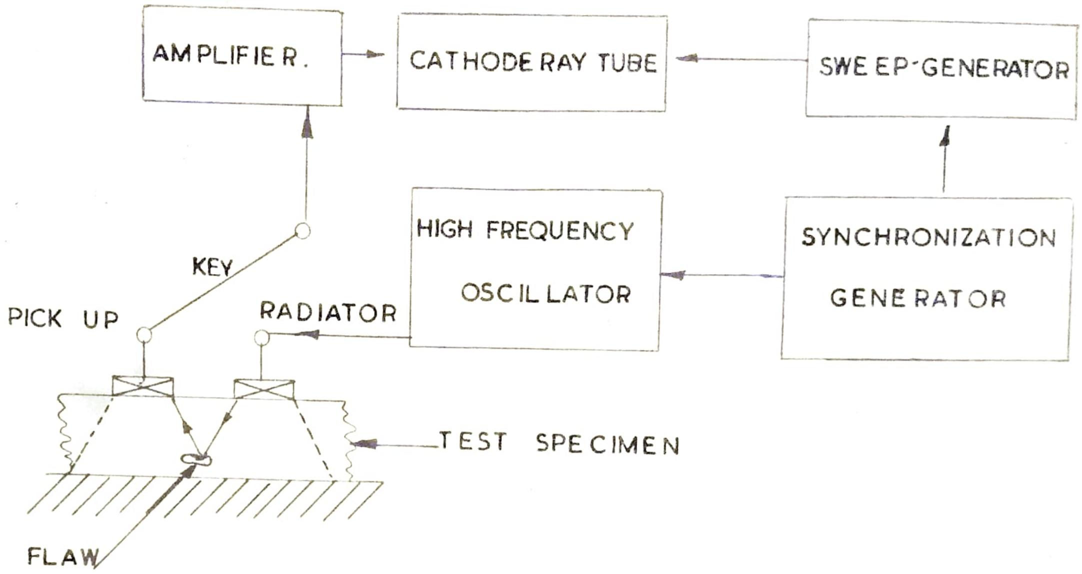

FIG. 1a BLOCK DIAGRAM OF AN ULTRASONIC FLAW DETECTOR.

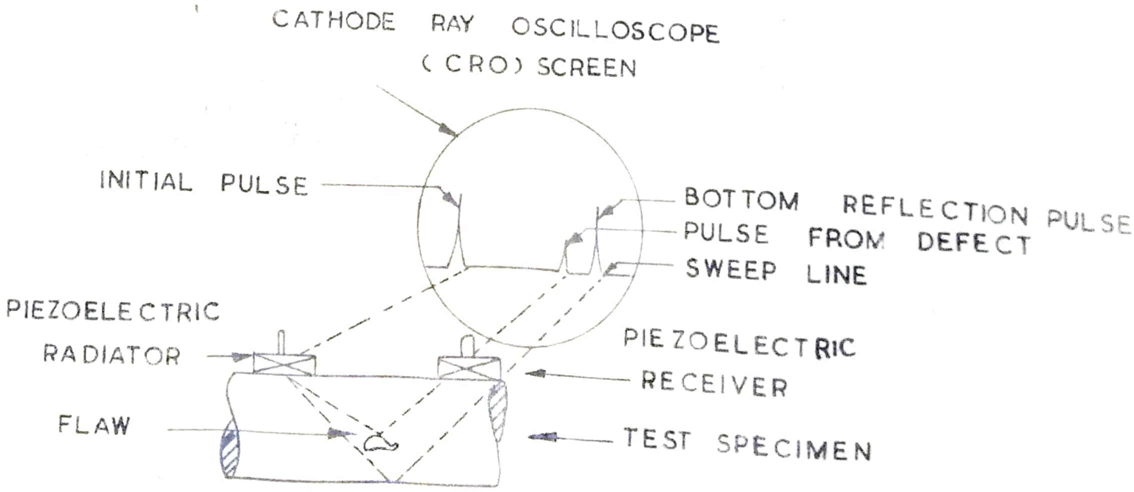

FIG. 1b OPERATION OF AN ULTRASONIC PULSE FLAW DETECTOR.

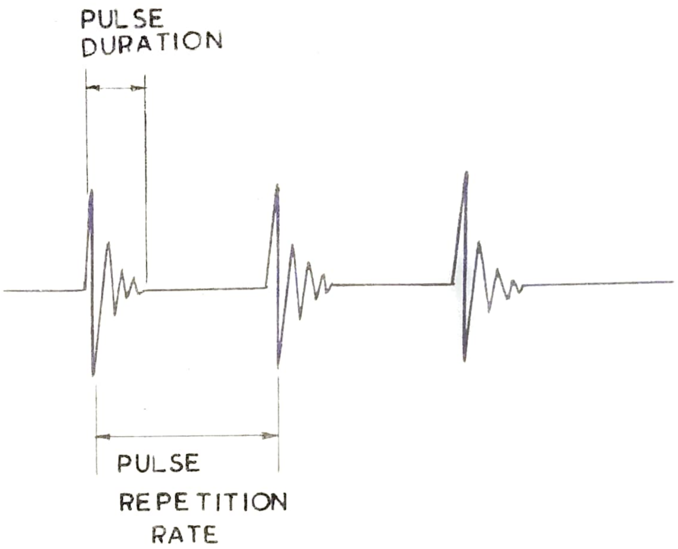

FIG. 2 FORM OF PULSES AT THE OUT-PUT OF THE HIGH FREQUENCY OSCILLATOR

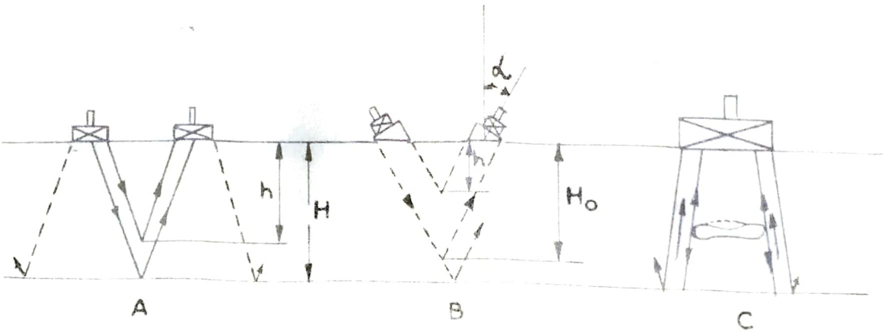

FIG. 3 "DEAD ZONE" (h) FOR DIRECT CONTACT improvements based on its shape, size, frequency, method of mounting and facing, factors affecting the beam characteristics[14] which, have direct bearing upon calibration problems.

Surface finish and Acoustic coupling:

A suitable couplant[15,16] is generally used for proper acoustic contact between transducer and the specimen surface. Presence of loose particles such as scale, inclusion, grit, paint or oil on the surface as well as entrapped air bubble within the couplant cause considerable intensity variations and affect the test calibration. Quality inspection requires good surface finish as surface condition[14,17] affects sensitivity of calibration and its correlation with defect size. The shape effect of the objects with curved surfaces can be eliminated with suitably designed probes.

DEFECT LOCATION AND MEASUREMENT:

The detection of minute flaws such as porosity in casting requires high sensitivity and resolving power (use of higher frequency). Grain boundary reflection[18] (Fig.4) masks signals from minute defects limiting the detectable defect size.

For precise location of the defect, the accuracy of the instrument (checked by proper calibration technique), choice of proper frequency, suitable probe and probe angle (for angle beam probes), pulse length, sweep and other factors affecting the dead zone such as transducer, type and size, ringing of amplifier, damping member of the probe etc. are important. Due care has to be given to eliminate or isolate the false signals arising from edge effects[19] or mode conversion[17] at curved surfaces.

Cont....6.

Under a given instrument setting, magnitude of the energy reflected from a flaw depends in general on the nature, size and orientation of defect. Maximum echo amplitude corresp ds to normal position of the flaw with respect to the beam as in this case maximum area of the flaw is exposed to the beam. Further, the ultrasonic energy or amplitude of vibration of reflected waves is dependent on angle of incidence and the acoustic impedance of the materials at the interface i.e., on their impendance ratio (or mismatch factor) $r = \frac{Z_2}{Z_1}$ where Z_1 (acoustic impedance of one material) $= \rho_1 V_1$ and Z_2 (acoustic impendance of other material) $= \rho_2 V_2$, ρ_1, ρ_2 being the densities and V_1, V_2 being the velocities of ultrasonic wave in the two materials respectively. The reflection coefficient for normal incidence, $R = \frac{\text{Intensity of reflected beam (Wr)}}{\text{Intensity of incident beam (Wi)}}$ is given by

$$R = \frac{Wr}{Wi} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 = \left(\frac{r-1}{r+1}\right)^2$$

The difference of acoustic impedance between gas or vacuum and a metal causes almost total reflection from crack or cavity. Less energy is reflected from metal/ inclusion interface, may be a foreign matter or different phase of the system such as intermetallic compound or grain boundaries. The nature of flaw viz., lack of penetration, voids, cracks or nonmetallic inclusions, as encountered in welds can easily be judged with reference to radiographs.

The above relationship is based on the elementary plan wave theory. In practice, although the ideal condition of plane wave is not realised yet for many purposes when the source size is much larger with respect to the wave length, →

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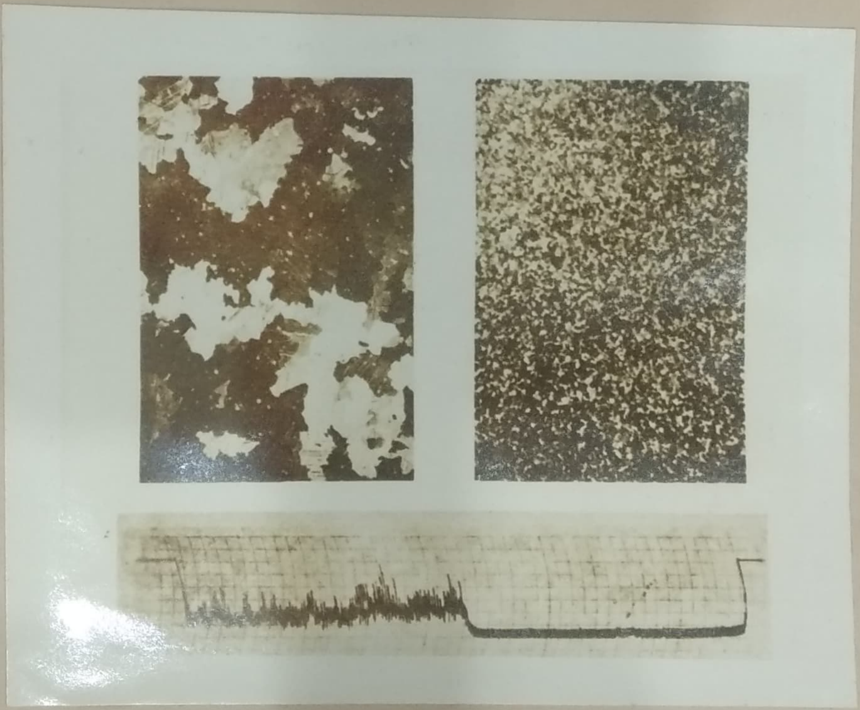

Fig. 4. Grain-boundary Reflections.

the resulting wave may be taken as plane wave. As seen above, the plane wave theory assumes no transmission losses other than interface effects. However, in practice energy losses do occur in all materials to some extent and are of considerable importance in some cases. The following factors have major influence on the reflection peak.

1. Beam spread due to finite transducer size.
2. Beam non-uniformity due to field effects.
3. Transducer loading by couplant or specimen.
4. Attenuation of beam due to such causes as scattering and damping depending upon nature of material.
5. The external geometry and condition of surface of the test object.
6. Defect reflection factors such as those related to its shape, size, surface and impedance.
7. Masking noise.
8. Instrumentation variables.

Thus, in face of these disturbing factors the existing plane wave theory is not adequate to provide quantitative solution of practical problems. An empirical approach is the only way for accurate and reliable quantitative measurement of position, shape and size of the flaw. This approach consists in controlling the various parameters by specifying (1) methods of equipment selection and then calibration and (2) the test procedures both in relation to the nature of the object and defect under examination.

<u>Possible Methods of Equipment Standardization:</u>

Calibration[20] of the instruments and search units by electric measurements alone, although of significant value in equipment maintenance and laboratory studies, is not adequate in practice, since interconnecting cables, couplant, positioner

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and indicator, recorder or alarm, also influence the results. Further since there is no equivalent of X-ray penetrameters (Image Quality Indicators), only indirect calibration for ultrasonic testing is possible by the following means:

i) Producing an artificial flaw in the medium (say water) through inserting a target (say steel ball) in the path of the ultrasonic beam.

ii) Making use of signals from geometrical external discontinuity in the test object, as the back surface, keyway, or bore - hole.

iii) Fabricating a standard discontinuity into a non-critical portion of the specimen which can later be machined away or filled up by welding.

iv) Use of one or more separate reference blocks containing simulated discontinuties or reference surfaces to establish test sensitivity and equipment performance.

First method is practicable only in case of immersion testing and is of importance as 'primary reference standards' to check the ultrasonic behaviour of reference blocks made according to (iv). It may be noted that precise checking of reference block response requires adjustment of test instrument sensitivity to a standard reproducible level prior to obtaining reflection from the bottom of the test hole. In maintaining the sensitivity level, difficulties arise due to fluctuations in vacuum tube performance, internal voltages and component performance. Thus, the easy way to ensure constant instrument sensitivity is to adjust the amplifier gain to obtain predetermined magnitude of indication for some reflecting surface of specified size. The use of steel balls, immersed in water was advocated on the grounds that the

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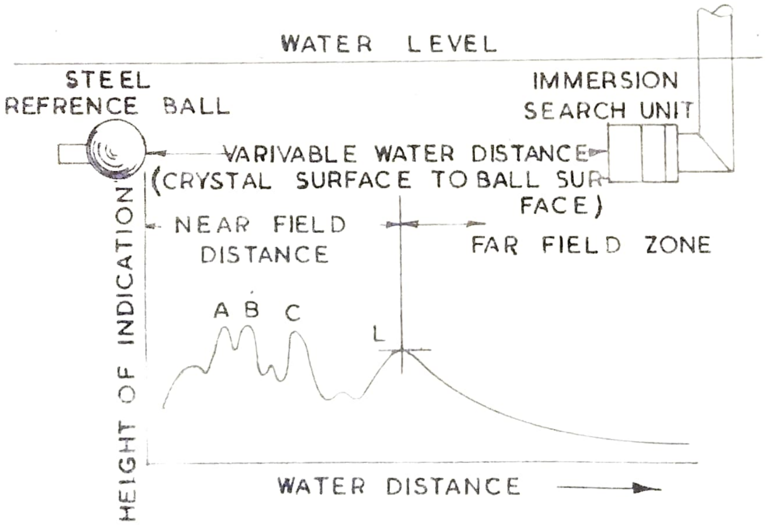

FIG. 5 TYPICAL DISTANCE - AMPLITUDE RESPONSE CURVE, OBTAINED FROM A STEEL REFERENCE BALL, IMMERSED IN WATER.

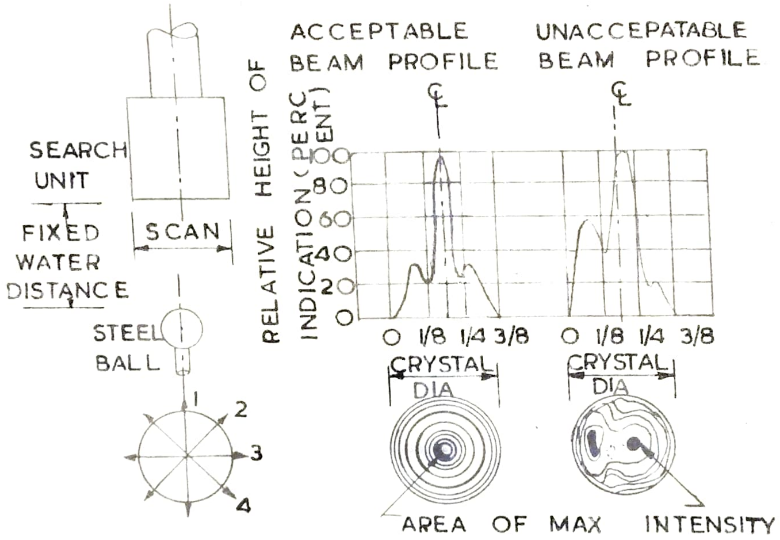

FIG 6 DIAGRAMATIC SKETCH ILLUSTRATING THE GENERAL PROCEDURE FOR CHECKING BEAM CHARACTERISTICS OF 15 MC 3/8 IN DIAMETER QUARTZ SEARCH UNITS TO BE USED FOR CALIBRATING REFERENCE BLOCKS; TYPICAL DIFFERENCES BETWEEN CHARACTERISTICS OF VARIOUS SEARCH UNITS OF THE SAME TYPE ARE INCLUDED.

spherical symmetry of the target rendered the transducer orientation ineffective and that the balls of ball-bearing quality with uniform quality of size, geometry and surface-finish and metallurgical structure will suit the purpose. Other factors needing proper control are water distance, the nature of water as couplant, and search unit characteristics as (i) the ultrasonic field (distance/amplitude curves) (Fig. 5) and (ii) the beam profile (Fig.6).

The fourth method, employing metallic reference blocks of simple shape and convenient size containing discontinuity of known size and shape is widely used. ~~The~~

PRACTICAL REFERENCE STANDARDS

Development of practical reference standards for ultrasonic detection has been undertaken by individual organisations[14,21], Institutions for Standardization at the national as well as the international level. The work of the Society of Nondestructive Testing and ASTM Committee[22] E-7 on Nondestructive Testing is noteworthy. Tentative Recommended practice has been introduced for fabricating and checking Aluminium Alloy Ultrasonic Standard Reference Blocks (ASTM Designation E127 - 58T). A number of valuable contributions came out during the 2nd and 3rd International Conferences on Nondestructive Testing reflecting the related work in the U.S.A.[23], Japan[24] and France[25]. The International Institute of Welding (I.I.W) have considered in detail the various aspects of the standard reference blocks. It is not, however intended to discuss detailed features of all types of reference blocks, used in different countries for different purposes. Only the common features and the basic problems involved will be discussed with illustrations from one or two common

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Reference Blocks with particular reference to its applicatio under Indian conditions.

Simple Reference Blocks:

The simplest type of Reference Blocks for the purpose consists of (i) stepped blocks[14] with holes of same depths, o (ii) uniform thickness blocks with holes of different depths or (iii) separate cylindrical blocks each with a standard hol The shape[26] of the hole bottom exercises considerable effects on energy reflected and the beam profile etc. The position of the peak (for distance calibration) on the CRO tube scree is dependent on the distance of the hole bottom from the scan surface and the magnitude of the peak (used for size calibrat i.e., the sound energy reflected from the hole is roughly proportional to the area of the reflecting surface - the hole bottom. This is true when the sound beam is much larger and wave length is much smaller than the test hole size. Guided the several years of experience in Aluminium and Aircraft Industries in U.S.A., the ASTM adopted a set[27] of 10 aluminiu test blocks (Fig. 7a and b) with holes of the given size and depths (table 1), which are regarded as adequate to define quality of wrought aluminium products.

Practical considerations[20] in arriving at the final shape and size of the ASTM blocks are as follows: limited st size to ensure uniform acoustic noise level in all referenc blocks; cylindrical shape and flat hole-bottom, for ease of machining and precise drilling practice; the 2-inch dimensio for avoiding edge effects from longer blocks; test hole axis along rolling direction of the stock to minimise noise from hole bottom; hole depth of $\frac{3}{4}$" as a practically possible dept drilled for small dia holes and finally, sealing the hole fo preserving the ultrasonic response from the block.

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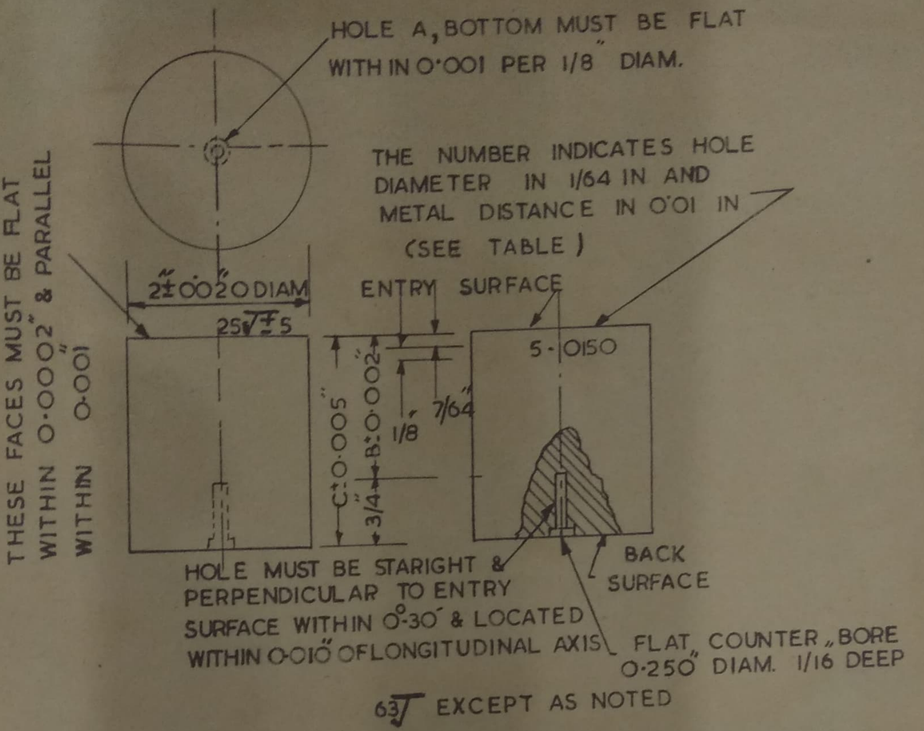


FIG. 7a A.S.T.M. STANDARD ULTRASONIC REFERENCE BLOCK.

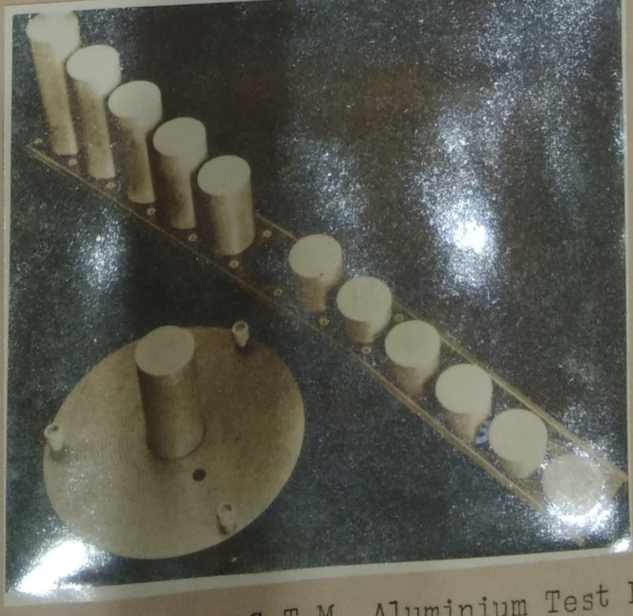


Fig. 7b. The Set of A.S.T.M. Aluminium Test Blocks.

The Dimensions and Primary Reference Ball/Block Composition Data for the A.S.T.M. Basic R.B.Set.

Note:- Couplant is clean deaerated water.

Ref.Block No.	Hole-diameter (A),1/64 in.	Metal Distance (B), in.	Overal length (C), in.	Water distance (Crystal Surface to Block Entry Surface), in.	Equivalent Ball Diameter in.	Water Distance (Crystal Surface to Ball Surface), in.
3-0300	3	3.000	3.750	3	5/8	3
5-0012	5	0.125	0.875	1	25/32	3
5-0025	5	0.250	1.000	1	13/16	3
5-0050	5	0.500	1.250	1	31/32	3
5-0075	5	0.750	1.500	½	1	3
5-0150	5	1.500	2.250	3	2¼	3
5-0300	5	3.000	3.750	3	1½	3
5-0600	5	6.000	6.750	3	½	3
8-0300	8	3.000	3.750	6	1-7/16	3
8-0600	8	6.000	6.750	3	5/8	3

TWO SCALES ENGRAVED IN 0·5 CM DIVISIONS ALONG BOTH EDGES OF ONE FACE AND IN 0·2 IN DIVISIONS ALONG BOTH EDGES OF OPPOSITE FACE

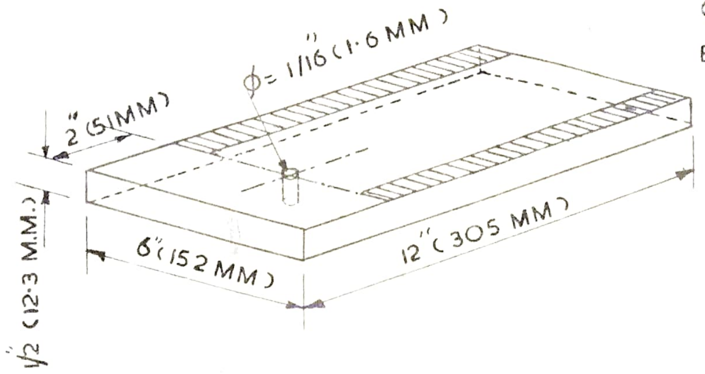
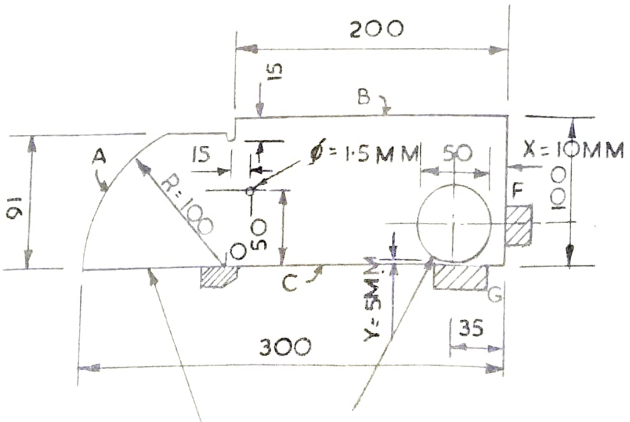


FIG. 8 B.W.R.A. REFERENCE BLOCK FOR ULTRASONIC TESTING



(25 MM THICK) (PERSPEX 24·6 MM THICK)

FIG 9 DUTCH REFERENCE BLOCK

Work of the International Institute of Welding:

The investigations[28] at the International Institute of Welding (I.I.W) regarding the Ultrasonic Reference Block (R.B) have been directed towards the following aims:

1. To determine the characteristics of the instrument and the probe.
2. To determine the level of sensitivity and maintain constancy during inspection.
3. To obtain reproducibility by proper adjustments, determined with the block.

With these ends in view, a comparative study of the British (Fig.8) and Dutch (Fig.9) reference blocks was made.

It is generally realized that the Dutch R.B. although not ideally suited for a two-probe technique calibration, has certain general advantages. With this block, direct measurement is possible without calculations. Further, the measurements are more accurate and the maxima of echos are sharper. The Dutch R.B. is of versatile character as it is suitable for both longitudinal and transverse wave probes. On the other hand, factors in favour of British R.B. are its simplicity and quality, especially for calibration with separate probes for which the Dutch R.B. does not appear to be well suited. For welding problems, using shear wave probes, the British block offers decided advantages. With the proper synthesis of individual merits of the Dutch and British blocks, a better combination could be evolved.

Proposed I.I.W.-R.B:

In view of the merits of the two blocks the International Institute of Welding leaves the question of adoptions of either of these blocks to the user and has suggested a reference block (Fig.10), where additional reflecting surfaces have been introduced for transverse wave calibration by either a saw cut at

Cont..12.

zero point, a saw cut at zero point and a curved surface of radius R = 50 mm, or a circular saw cut. The final choice between these is again left to the user. The steel used for production of the R.B. is suggested to conform to the following metallurgical requirements:

(a) Killed O.H. or Electric mild steel.

(b) Normalized condition.

(c) Grain size Mc-Quaid - Ehn No.8.

Detailed directions[28] for use with the Dutch and Britis Blocks have been issued by the I.I.W. for determining the (1) instrument characteristics (calibration of scale and checking linearity of time base and relative sensitivity, control of dead zone and power of resolution) and (2) the probe characte ristics (Determination and checking of beam index, angle of incidence, zero point and beam characteristics).

The perspex insertion in the Dutch block (Fig.9) is equivalent to 50 mm. of steel and thickness values equal to 25, 50, 100 and 200 mm. of steel for calibration of time bas for longitudinal waves are available. This calibration can be applied for transverse waves through velocity relationshi Distance of 91 mm. of steel for longitudinal waves correspon to 50 mm for transverse waves. The characteristics of trans verse wave probe can be checked by placing probe on surface C (Fig.9) and obtaining the position of maximum reflection from surface A. The mark on the side of probe can then be checked against point O showing the beam centre (Probe Inde Now the beam angle is read off the block from the position (probe along the edges B or C for maximum reflection from th perfex surface. The angular width of beam may be determine by moving the probe along edge B or C till the indications

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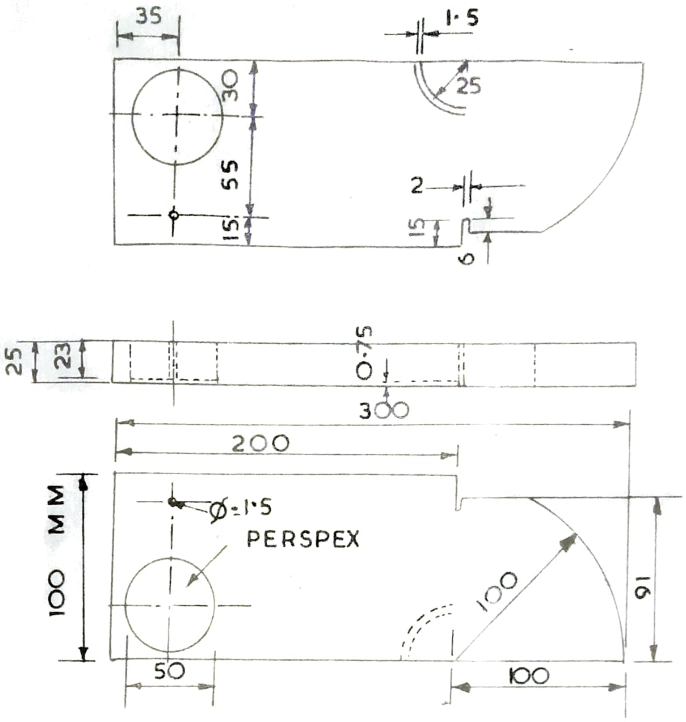


FIG. 10 ADDITIONAL REFLECTING SURFACES
(I.I.W. – R. B.)

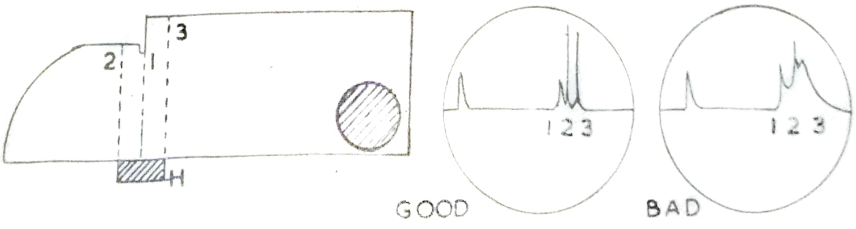
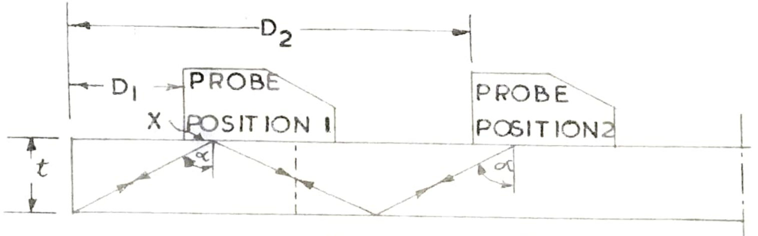


FIG. 11 CHECK OF RESOLVING POWER



$$\left[X = \frac{D_2 - 3D_1}{2} \right]$$

FIG. 12a PROBE INDEX (X) DETERMINATION.

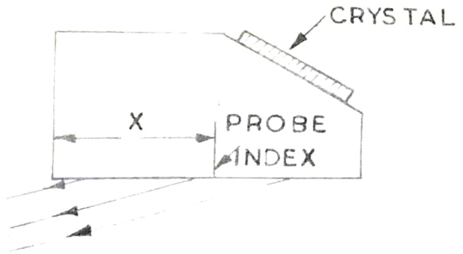
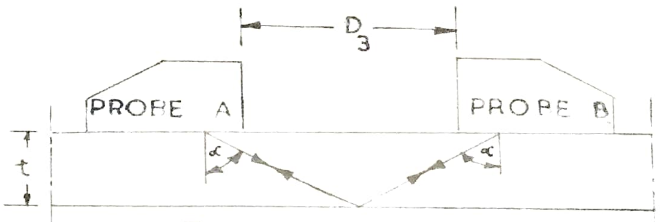


FIG.12b ENLARGED VIEW OF PROBE INDEX



$$\left[\mathrm{TAN}\ \alpha = \frac{D_3 + 2X}{2t} \right]$$

FIG. 12c DETERMINATION OF PROBE ANGLE(α) FOR DOUBLE PROBE SYSTEM WITH PROBE INDICES KNOWN.

drop by one half in magnitude and the corresponding angles noted. The small hole is used for checking sensitivity of transverse waves. Dead zone can be determined from the indications with probes in positions F and G (Fig. 9). Resolution is measured from reflections obtained with longitudinal wave probe at position H (Fig. 11).

The British block (Fig.8) is well suited for separate two probe systems, permitting control of linearity of time base, checking of probe index (Fig. 12a, b), angle of refraction of beam (Fig.12c), (with or without the knowledge of beam index), zero error correction for the distance covered by perspex mount of the probe and beam spread.~~are measured accurately~~.

Limitations of the Reference Blocks:

In the use of I.I.W.- R.B. whilst determining the sensitivity with different angle probes, it is seen that for corresponding reflections from drilled hole, the ultrasonic beam has to travel different distances and so the indications cannot be compared since the sensitivity is affected by distance, unless compensating devices are provided with the instrument; the Japanese Institute of Non-destructive Testing has taken this into consideration and proposed[24] a reference block (Fig.13) for some fixed angle probes equalising the distance from probe to test hole. An improved reference block (Fig.13) has been designed for any angle-probes.

The I.I.W.-R.B. suffers from the further limitation that its sensitivity is limited to 1.5 mm dia hole. For greater sensitivity other blocks[24] are used in Japan.

The geometrical and material characteristics of the object under examination restrict the use of Standard Reference Blocks

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For instance, for shear wave probes changes in the angle of refraction for an R.B. made of material other than the test object cause inaccuracies in measurements. Effect of such behaviour is being studied in France[25] by means of R.B. made of Aluminium, mild steel, 13% Cr. steel and austenitic steel. In the case of cylindrical objects[14,19] since the contact area of transducer with the scanned surface is affected by the curvature of the latter, the height of reflected peak corresponding to artificially drilled hole will be affected and the correct size of hole can be judged from the peak height only if the reference block (Fig. 14a, b) is made (a) from same material, (b) subjected to the same metallurgical treatment and (c) having same geometry viz., the same radius of curvature of scanned surface and surface finish as the actual object.

Further due to sensitivity variations with distance, blocks with Standard holes have limited application and for thicker sections compensating devices are needed.

Inspite of all these limitations and the fact that for special test conditions special reference blocks, techniques and correction methods are to be devised, it is established that for general standardization work of the instrument and probe characteristics, simplified multipurpose reference blocks such as I.I.W. type R.B. are of great value.

<u>Reproducibility of R.B.:</u>

In any case, reproducibility during manufacture of these ultrasonic reference blocks have to be guaranteed. In this respect, metallurgical condition of the material and its acoustic soundness are important features to be considered. The state of the material, (whether in the cast or wrought state) its mechanical properties and heat treatment affect the attenuation

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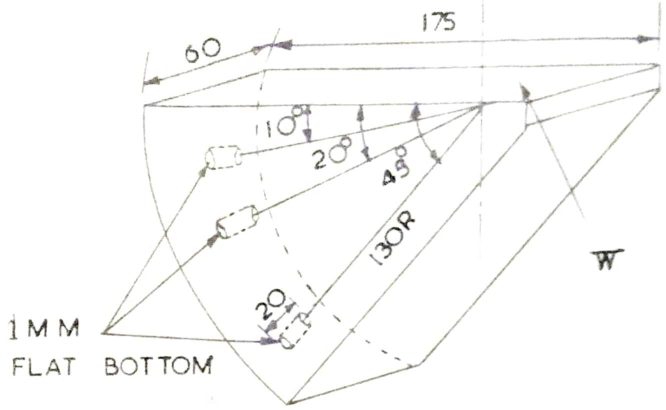
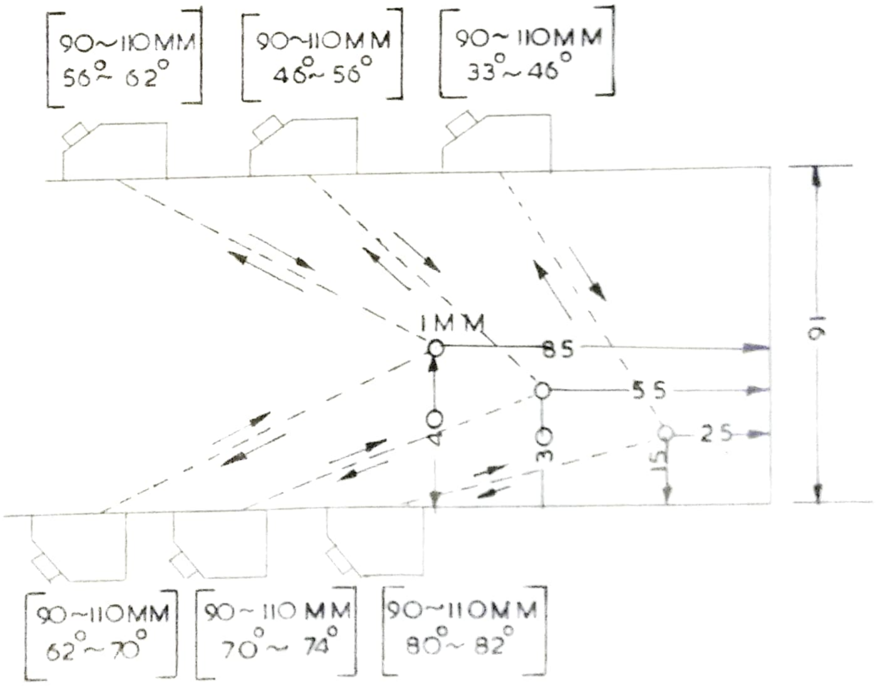


(FOR FIXED ANGLE PROBES)



(FOR ANY ANGLE PROBE)

FIG. 13 JAPANESE R. B. FOR SENSITIVITY WITH DISTANCE CORRECTION

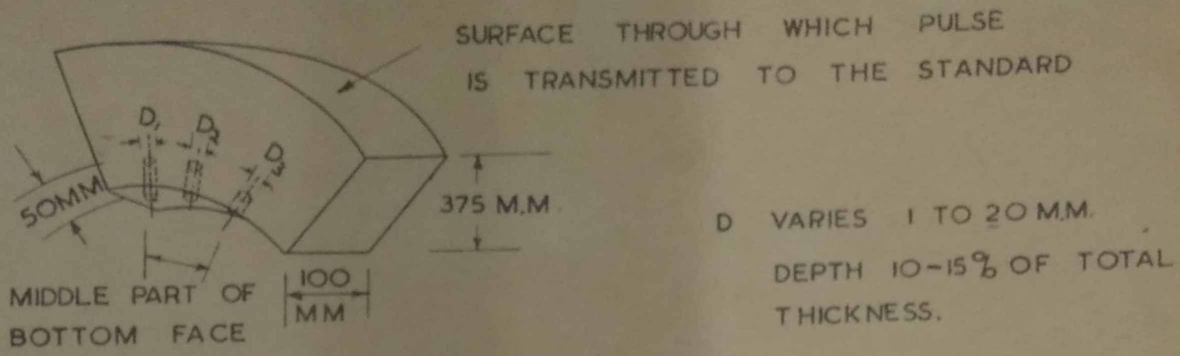


FIG. 14 a STANDARD BLOCK FOR DETERMINATION OF THE DIMENSION OF DEFECT IN CYLINDRICAL SPECIMENS.

Fig. 14b. Standard Test-blocks for objects with curved surfaces.