

Handbook on the Ultrasonic Examination of Austenitic Welds

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Handbook On the Ultrasonic Examination of Austenitic Welds

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The Handbook represents the agreed view of the working group experts but has not necessarily been endorsed by the individual organizations represented.

For a definition of many of the terms used and further background information on the subject of this handbook, readers are referred to the existing IIW-publications listed below:

- (1) *List of Terms Used in Ultrasonic Testing* of the International Institute of Welding, 1967.
- (2) *Handbook on the Ultrasonic Examination of Welds* of the International Institute of Welding, 1977.
- (3) "Considerations on Ultrasonic Testing of Austenitic Weld Joints" *Welding in the World*, Vol 20 (1982), No 5/6, pp. 99-108.
- (4) "Geometrical defects in arc welded joints in steel materials — Classes of requirements" *Welding in the World*, Vol 22 (1984), No 1/2, pp. 34-52.

This Handbook has been produced by the Working Group Ultrasonic Testing of Austenitic Welds of the IIW-Commission VC Ultrasonics.

It is based on the *Handbook on the Ultrasonic Examination of Welds* (for carbon steel welds). Publications, practical experience, and available codes on ultrasonic examination of austenitic welds have been taken into account during preparation. The Handbook is intended to serve as a guideline for the preparation of procedures for specific applications but is not intended to provide a detailed inspection procedure for any particular weld.

Advice is given on how to devise procedures to take proper account of access available to the weld and of surface preparation. Methods are defined to ensure reproducible sensitivity setting for the ultrasonic examination and to provide a means of judging the test result. Specific problems such as the effects of grain structure and spurious indications, and the application of special probes are mentioned.

In spite of the limitations still existing, the Working Group believes that publication of the Handbook should not be delayed until all the outstanding problems have been solved.

This will help to spread present knowledge to the benefit of the many industries and institutions involved in constructions using austenitic welds.

The Handbook is intended to encourage a more uniform approach which should lead to better conditions for balanced evaluation and comparison of results.

The latter is of prime importance in guiding further work aimed at improving ultrasonic techniques as well as making progress in welding technology with regard to the metallurgical aspects involved.

1. GENERAL

Until recent years, austenitic steel welds were widely regarded as uninspectable by ultrasonics. Research and development have made it possible for a useful level of examination to be carried out in many situations. In general, though, the methods are more complicated and the capabilities more limited than for the examination of welds in ferritic steel. The main practical implications of this are

(1) Welding procedure and preparation geometry have a strong influence upon the capabilities of ultrasonic examination, so that careful consideration of these factors at the design stage can be very beneficial to the examination.

(2) Many technical aspects of the examinations are strongly influenced by the particular weld

structure so that only skilled, specially trained operators with a full appreciation of the physical basis of the examination should be employed.

(3) The capabilities for defect detection, positioning and size assessment are more limited than for ferritic weld examination. So, monitoring the occurrence of small defects can rarely be used for the quality control of welds, as is usual with ferritic welds. Rather, it may be necessary to use fracture mechanics to set less rigorous defect acceptance standards for the particular component. These acceptance standards should be compatible with the limitations of the ultrasonic techniques.

(4) The limited capabilities imply that it is prudent to supplement ultrasonic examination with radiography and surface examination techniques to a greater extent than is necessary with ferritic welds.

2. INTRODUCTION

2.1 Scope and Application

This Handbook gives recommendations for the ultrasonic examination of austenitic welds by manual scanning techniques which use the pulse-echo method and A-Scan presentation. The same recommendations can be extended to mechanical scanning techniques if special procedures are prepared for the data recording system.

The Handbook advises on how to devise procedures for the detection, location, and evaluation of ultrasonic indications of weld defects. Techniques involving the use of advanced instrumentation for signal processing might give better detection and identification of flaws but are not covered in this document.

The applications covered are limited to butt welds with weld metal of similar composition to the parent material. For dissimilar weld metals or for non butt weld geometries, procedures may be based on the general advice of this Handbook, provided attention is paid to the requirements of the specific geometry and material.

The recommendations given are primarily aimed at post fabrication rather than in-service inspection. Many sections of the Handbook will be relevant to both situations, but consideration of the specific problems of in-service inspection is outside the scope of this document.

This Handbook does not contain defect indication acceptance criteria.

2.2 Particular Problems Involved in the Examination of Austenitic Welds

The term *austenitic* covers a variety of materials and material combinations, including austenitic stainless steels and nickel chromium alloys such as "Inconel", "Incoloy", etc. The capabilities of ultrasonics for the examination of welds in austenitic materials are restricted compared to the ferritic case because of the presence of large elongated anisotropic grains (dendrites), often forming an ordered columnar structure, which are characteristic of the austenitic weld metal. This type of grain structure can lead to anisotropic ultrasonic behavior contrasting with the isotropic behavior of homogenous welds made in carbon or low alloy steels.

The size, the arrangement, and the elastic anisotropy of the different grains result in high scattering associated with mode conversion effects, beam distortion, and a variation of ultrasound velocity with direction and position in the weld. The scattering of energy is observed as a relatively high noise level (grass) and high attenuation.

The problems which occur in ultrasonic testing of austenitic welds differ according to the parent material production method (rolled, drawn, forged, or cast), the weld processes, and the heat treat-

ment as well as the composition of the parent and weld metals.

The guidelines given in this Handbook take account of the above factors to indicate how optimum test procedures can be prepared.

2.3 Principle of the Method

The ultrasonic methods applied to austenitic welds follow basically the same principles as those described in the *Handbook on the Ultrasonic Examination of Welds*. Some important differences do exist, however, which influence the ultrasonic method to be used and have implications for the capability of ultrasonics to detect, locate, characterize, and to estimate the size of weld defects. The most important of these differences are the following:

(1) Scattered energy from natural metallurgical discontinuities generates noise indications at higher amplitude than would be expected for the case of ferritic welds. The choice of wave mode (longitudinal, shear) and probe characteristics (sound field, frequency, bandwidth, etc.) should be optimized to allow a reliable separation of weld

defect indications from noise indications (see section 4.2).

(2) The ultrasonic beam has to cross different regions in the parent metal and in the weld itself. The velocity of sound may vary along this path (see section 4.2) and this may change the direction of the sound beam. Consequently, this may result in inaccuracy in determining reflector positions.

(3) Attenuation in the weld metal is generally more severe than for ferritic welds and can be more or less pronounced depending on the angle of the beam with respect to the preferred orientation direction of the grain structure. Therefore, the ultrasonic technique should seek to minimize beam path length in the weld metal and, where possible, aim to take advantage of any directions of reduced attenuation in the weld.

(4) Beam divergence can also be directionally dependent. The beam profile is usually different from that measured in parent plate (whether ferritic or austenitic) so that size estimation methods which depend on a knowledge of the beam profile, such as the so-called dB drop methods, are not always suitable on austenitic welds.

(5) Conventional instruments are used for examinations, but in most cases, special probes need to be applied (see section 5.3).

3. CONDITIONS TO BE ESTABLISHED PRIOR TO THE EXAMINATION

Since austenitic weldments present greater difficulties for ultrasonic testing than ferritic ones, the preparation of ultrasonic procedures requires more attention. In general, it is considered of great importance that operators should be informed about relevant details of weld fabrication, as given in section 3.3.2. Particular written procedures which specify the examination conditions and detailed ultrasonic techniques must be prepared in conjunction with metallurgists and NDT operators and need to take account of information that can be considered as fabrication know-how.

3.1 Personnel

The personnel applying this type of examination should be chosen from the best teams of

ultrasonic operators and be qualified at least to level two or equivalent. Their organization should submit them regularly to requalification tests particularly oriented to austenitic materials. As well as having good qualifications and sufficient experience in ultrasonic techniques, the personnel concerned should be trained on representative samples of austenitic welds to acquire specific experience in distinguishing defects from noise and spurious indications. For this they need the following:

- to be familiar with refraction/reflection rules and mode conversions
- to have experience in the use of specialized probes (e.g. angled longitudinal wave probes) and flaw detectors (e.g. selectable bandwidth)
- to have received appropriate instruction in the metallurgy of this type of material in order to be capable of determining the best approach for the examination, including how to relate defects and indications in the weld and in the parent metal
- to know the capacity of other NDT methods

which complement ultrasonics and the particular difficulties of these methods for austenitic materials ("wetting" behavior for dye penetrant examination — mottling and dark lines for radiography)

Supervisory personnel are strongly advised to keep themselves informed of new trends in methods of inspection, the evolution of equipment, and the development of new welding techniques.

3.2 Required Information About the Welds

As described in section 4, the effect of the material structure on ultrasound propagation is significant in this type of weld and, in addition, depends strongly on the geometry of the weld.

To obtain an effective ultrasonic technique with optimum flaw detection capabilities (e.g. choice of optimum probe parameters), it is necessary to collect maximum information on the weld characteristics.

(1) *Weld Geometry*. Selection of probe parameters depends on weld preparation and on the degree of penetration. On the drawing of the preparation, the operator will add the expected modifications of the fusion line introduced by the weld penetration. This depends on the nature of the filler material.

Particular attention should be paid to possible beam deviations resulting from the angle of the weld fusion faces. The extent of such difficulties can only be determined by experiment. Therefore, it is recommended that a weld sample be obtained wherever possible. Particular examples of problems associated with fusion face geometry are discussed in section 4.2. Furthermore, special problems can occur due to counterbore or weld root geometry in pipework. Details of root design should be obtained prior to ultrasonic examination.

(2) *Welding Process*. Knowledge of the weld process and procedure will contribute to an estimate of the likely grain structure (as discussed in section 4.1).

(3) *Heat Treatment*. Information on the heat treatment cycle is useful to provide an estimate of the parent material grain size. Using this information, the likely transparency can be assessed. Generally, fast quenching produces small grains, whereas maintaining high temperatures for a long time results in a large grain size.

The information required may be derived from representative weld samples as explained in section 7.3.

3.2.1 Welding Samples Available

The best way to obtain a sample is to take a section from the weld used as the welding procedure qualification block, or from a production weld. These samples should be as representative as possible of the weld to be examined in terms of weld preparation and process, procedure, geometry, heat treatment, heat input, etc. (See also section 7.3). The sample should be cut to produce macrographic sections perpendicular to the weld axis to show the structure and the weld fusion faces. Sections parallel to this axis may also be of value.

To obtain a good contrast, allowing the observation of columnar grains, fine polishing of the surface is necessary before etching.

3.2.2 Absence of Weld Samples

When it is not possible to obtain a sample of the weld to be examined, the above mentioned information should be obtained from the manufacturer or alternative sources.

3.3 Surface Preparation and Marking

Full volumetric inspection requires dressing of the weld crown. Only in this way can full access for scanning and adequate coupling be obtained.

Detailed requirements on surface preparation are specified in section 3.7.

When the weld is fully ground, the operator will not be able to visually identify the region to be examined (or a repaired zone) unless these areas are clearly marked.

It is considered good practice to mark the surface by punch marks. These marks may be made after completion of the weld to indicate the real fused zone of the weld. Alternatively, reference marks can be made at the stage of machining the weld preparation or counterbores, so that the position of the marks is known relative to a fixed datum such as the root face. If this is done, the center line of the reference marks should be clearly documented. When reference marks are absent, ultrasonic scattering methods or the use of a ferrite content meter can reveal the approximate weld position. Magnetic particle examination or careful chemical etching may be used to obtain more precise information on the weld limits.

The acceptability of any materials applied to the surface should be checked prior to use and residues subsequently removed.

3.4 Condition of the Parent Metal

To allow adequate penetration of ultrasonic waves into the weld, the parent metal should be

transparent to ultrasound and free from large flaws. Generally, rolled plate and forged pieces (medium thickness) are transparent, but this needs to be verified. Austenitic castings are generally hard to inspect because of the extremely coarse grain structure. As a guide, difficulties in penetrating parent material can become severe for grain sizes larger than ASTM 3 (average grain size 0.125 mm.)

To check the transparency of parent metal, an ultrasonic examination should be done using the same frequency and wave mode as for the examination of the weld. The velocity of ultrasound in the parent material should be measured with a normal beam probe to enable defects to be correctly positioned. The possibility of direction dependence of the acoustic properties of the parent material needs to be considered. After adequate transparency is demonstrated, all zones through which the beams pass should be checked for defects that could obscure examination of the weld region.

Specifications to examine base materials are generally less stringent than for weld metal. However, in this case, the material adjacent to the weld should be examined at a sensitivity based on a reflector size equal to that used for the weld examination. This should have been taken into consideration prior to cutting the base metal.

If localized variable attenuation is observed along the examined zone, the value must be taken into account to correct the sensitivity of the weld examination.

3.5 Agreements before the Start of the Examination

To avoid misunderstanding and arguments about the examination to be carried out, a number of conditions or directives need to be established prior to the examination.

3.5.1 Extent of the Examination

Generally, the extent of the examination will be determined in the first place by the degree of certainty to be achieved with regard to the absence of unacceptable defects.

The procedure to be established and the equipment to be used should take account of the criteria which the customer and inspecting authority require. For difficult examinations, this is likely to involve detailed discussion on flaw acceptance criteria and ultrasonic acceptance criteria.

The extent of the examination also refers to the total length to be examined, the degree of volumetric examination, the necessity to examine par-

ticular zones more carefully, etc., and also to special requirements such as checks by other operators, or alternative techniques or different equipment. Much depends on the type of weld, the situation in which it has to be examined, its ultimate service, and the possibilities of statistical control.

Ultrasonic examination of austenitic welds can cost more than that of similar ferritic welds because of the necessary preparatory work described later on. The greater the extent of the examination, the required sensitivity, or the details to be reported, the longer will be the examination time.

To avoid unnecessary expense, the aim should be to restrict these requirements to an acceptable minimum. It is, therefore, advisable to adopt different classes of examination in such situations, whereby structures may be examined according to the importance of individual welds in the component (see also section 4).

3.5.2 Sensitivity Required

The sensitivity is mainly determined by the smallest allowable defect and its position in the weld. However, not only are thickness, size, and length of defects important, but also their nature and orientation.

The sensitivity setting does not alone determine the ability to detect certain defects. Also involved are material characteristics and the whole technique applied, i.e., the frequency and wave mode used, the probe angle, the scanning technique (with one or two probes), etc. The ideal way to determine the required or practicable sensitivity is to use reference welds (see section 7.3), of the same configuration and material, welded by the same procedure and containing real defects of the maximum acceptable size.

However, this is often impracticable, and therefore levels of sensitivity which can be established with good reproducibility are mostly accepted as the appropriate solution. These levels are based on the reflections obtained from reference targets such as side drilled holes or flat-bottom holes of specified size. The levels to be set should bear a realistic relationship to the importance of the weld to be examined and should be agreed upon prior to the examination. Systems in use for sensitivity setting are described in section 7.6.

3.5.3 Special Conditions

Before commencing the examination, agreement should also be reached on the following points:

- Surface dressing (3.7)
- Coupling media to be used (3.8)
- System of marking welds (3.3)
- System of indicating defects found
- Examination of welds or parts of welds to which access is difficult or which are, for other reasons, difficult to examine
- Use of other NDT methods

3.5.4 Regular Check of Equipment

Regular checking of the performance of ultrasonic defect detection equipment is very important and should be agreed before the start of the examination. Various national and international standards or recommendations exist which might be used as a basis.

The recommendations in section 6 may be used to supplement these in order to meet the specialized requirements of austenitic weld inspection.

3.5.5 Reporting

The extent of the details to be recorded during the examination greatly influences the time required for a manual examination. After agreeing on the sensitivity for a particular class of work, only those defects producing echoes exceeding an agreed registration level should be reported in detail. It is therefore not advisable to call for reports containing detailed information on all possible indications with the aim of subsequently analyzing them and identifying acceptable defects.

Recommendations on the contents of a typical report are given in section 9. The object of this paragraph is to make it clear that this matter should be agreed upon prior to the examination.

3.6 Visual Inspection

The visual appearance of the welded joint should be recorded with particular reference to visible defects and the shape of the weld, e.g. surface curvature, degree of root penetration, backing ring, different parent metal thicknesses, extent

of the reinforcement, presence of undercut, weld finish, and alignment of parts.

3.7 Surface Preparation

The material surfaces to be used for the scanning procedures chosen must allow free movement of the probe(s) and provide satisfactory conditions for the transmission of the ultrasonic waves. Therefore, the surface roughness should generally not exceed 20 μm and the waviness should not exceed ± 0.5 mm over any area of 50 mm $\times$ 50 mm. This is necessary to avoid disturbance of the ultrasonic beam which could reduce the sensitivity and result in errors in defect location. Where there is access to only one surface of the weld, any weld reinforcement must be ground off if the whole weld volume is to be examined and if shear waves cannot be applied. This is because mode conversion losses on reflection reduce the effectiveness of examination in the second traverse with angled compression waves.

Furthermore, on each side of the weld for a minimum of 5/4 skip distances, the surface should be free from weld spatter, loose scale, machining and grinding particles, dirt, paint, or other foreign matter. It may be necessary to clean and smooth the surface with a flexible wheel sander.

3.8 Couplants

A couplant, usually a liquid or semi-liquid, is required between the face of the probe and the surface being examined to permit transmission of the acoustic energy from the transducer to the material under test. Typical couplants include water, oil, grease, and glycerine. The couplant used should form a film between the probe and the test surface. It should not be injurious to the material to be tested – or disturb subsequent surface treatment.

This is of particular importance in examining austenitic materials where coupling residues may cause problems such as stress corrosion cracking in service. Couplants containing halogens are to be avoided.

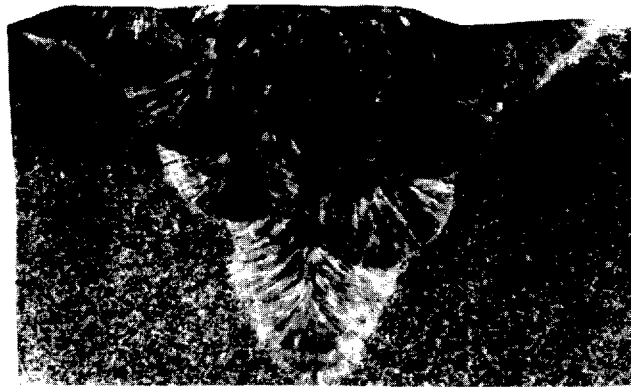
4. ULTRASONIC PROPAGATION BEHAVIOR

4.1 The Structure of Austenitic Welds

Austenitic weld metal is generally a coarse-grained material which often displays ordered

columnar grains when examined metallographically. Sometimes, extended grain growth occurs whereby columnar grains traverse several weld beads.

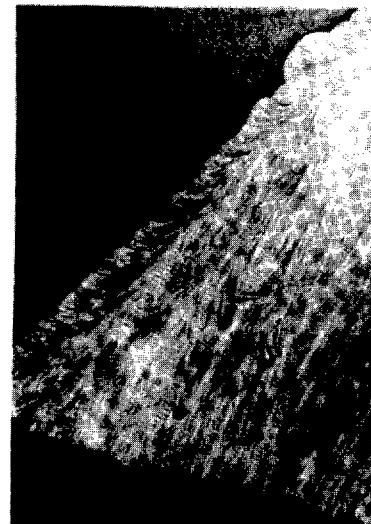
In principle, the coarse grain structures may be broken up by mechanical deformation or modified by heat treatment to above 1050°C, but such processes are not usually practicable. The grain



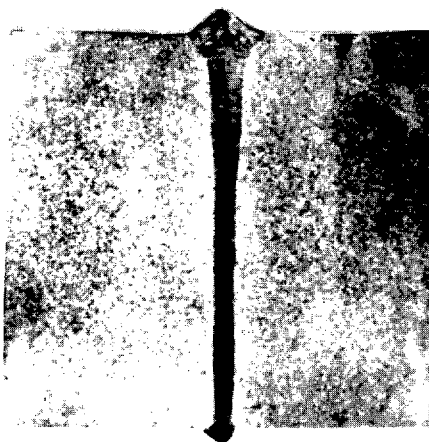
SUBMERGED ARC BUTT WELD



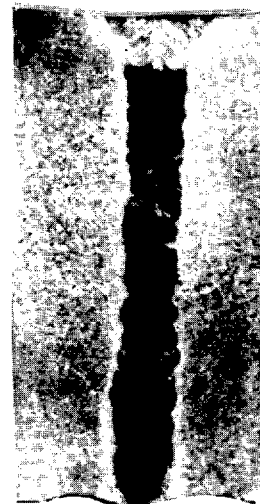
DOWNHAND SMA WELD



HORIZONTAL-VERTICAL
SMA WELD



ELECTRON BEAM WELD



GTA WELD

NARROW
GAP
WELDS

**Figure 4.1 — Macrographs of a selection of austenitic welds,
showing a variety of shapes for the fusion line**

structure orientation is not random and different types of welding procedures produce their own characteristic patterns. Generally, columnar grains will start to grow perpendicular to the surface of the weld preparation. However, they may gradually alter their direction in a manner depending on the welding process and the related heat flow during solidification.

(a) **SHIELDED METAL ARC WELDING (SMAW)** generally forms small weld beads compared to the other mentioned welding processes, with columnar grains extending from one bead to the next to give a highly aligned structure.

(b) **AUTOMATIC SUBMERGED ARC WELDING (SAW)** generally results in larger weld beads with the grains within each bead forming a fan shaped structure. Grain extension across the layers of the weld beads is less pronounced than for shielded metal arc welds. Depending on the weld current, some submerged arc welds can have a grain structure closely resembling that of the SMA type.

(c) **GAS SHIELDED ARC WELDING (GSAW)** weld runs, especially in the root region, can give a locally fine grain structure. Where the bulk of the weld metal is deposited by the TIG process, the likely structure will be that of a fan shaped arrangement of the grains within each weld bead with little grain extension between adjacent weld beads.

(d) **ELECTROSLAG WELDING (ESW)** results in a very different grain structure from the above process since there is a tendency for the grains to grow parallel to the weld preparation surfaces.

Figure 4.1 shows a selection of weld macrographs. Note that a major change of structure exists at the fusion face. This will influence the ultrasonic behavior as described in section 4.2.1.4.

Experiments have shown many similarities between ultrasound propagation in large single crystals and in a well ordered weld structure of elongated grains. It is difficult to produce two welds which are identical with regard to their structure.

For instance, Figure 4.2A represents diagrammatically the differences in grain structure produced by small changes in a manual welding procedure. This difference in grain orientations brought about by differences in the welding sequence as illustrated in Figure 4.2B, has an influence on sound propagation as indicated by the dotted lines in Figure 4.2A.

The so-called "skewing" of the beam is a result of multiple refraction at successful grain boundaries. The greatest care must therefore be taken when producing and using reference blocks to

simulate austenitic weld fabrications. See section 8.4.

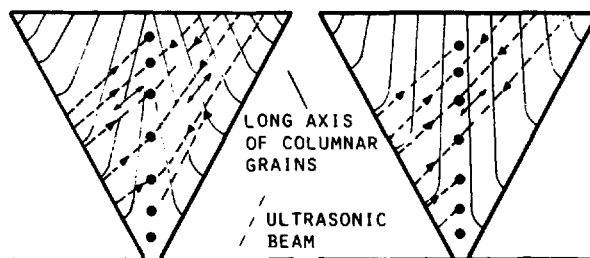


Figure 4.2A — Diagram of two downhand SMA welds showing differences in grain orientation and resulting sound path



Figure 4.2B — Example of differences in the sequence of bead placement bringing similar differences as illustrated in Figure 4.2A

4.2 Effects of Austenitic Structures on Ultrasound Propagation

The effect of austenitic structures on the behavior of ultrasound depends largely on grain size. Small grains, as found in rolled plate, have no adverse effect on sound propagation. On the other hand, coarse grain cast structures and those in the welds which have been described in the previous section have marked effects, leading to increased scatter and attenuation, variations in sound velocity, and often to beam-distortion.

The effects are primarily due to the anisotropic nature of the austenitic grains, as will be explained in the following sections.

4.2.1 Ultrasound Propagation in an Anisotropic Structure

In marked contrast to ferritic materials where a constant sound velocity is normally assumed,

many of the ultrasonic characteristics of austenitic welds derive ultimately from the anisotropic elastic properties of the columnar grains which form the weld. These grains have minimum dimensions which are usually comparable to the wavelength of the ultrasound, or somewhat smaller, while the width of the ultrasound beam usually covers several grains. The resulting mode conversion and scattering effects at grain boundaries are important sources of noise and of spurious indications.

Even for simple models of austenitic welds produced by the downhand SMAW process, the exact mathematical representation of their elastic properties and resultant ultrasonic behavior is very complex. The effect of the austenitic welds structure is that ultrasound propagation is sensitive to the angle of the wavefront with respect to the grain axes. The dependence on this angle changes dramatically as the wave mode under consideration is changed from the common vertically polarized shear waves (SV), to longitudinal waves (L) and to horizontally polarized shear waves (SH). An important factor is that when traveling through the coarse grained anisotropic material the wavefronts are not generally at right angles to the beam axes. This means that the effective direction of the beam (maximum energy flux) in anisotropic weld metal can differ from the nominal beam direction (see Figure 4.3).

Although these phenomena are evident from simple pulse echo observations, their nature is complex and can usually only be readily demonstrated using special test pieces. Figure 4.4 illustrates components for a demonstration which has been found useful for this purpose. The specimens are machined from weld metal laid down to produce a block with highly oriented grains.

A cube with several edges and corners machined off at 45° to the various faces can also be used to illustrate the directional dependence of velocity and the attenuation of both compression and shear waves.

4.2.1.1 Variation of velocity

Elastic anisotropy leads to variations in the propagation velocity of ultrasound waves. In general, the propagation velocity depends on the angle between the wave front and the major axes of the columnar grains.

The machined cube specimen referred to above may be used to measure the velocity in a number of directions. It gives results at 45° intervals for the principal axes of the specimen. By rotating cylindrical specimens with the probes fixed, the apparatus shown in Figure 4.4 may be used to study the large variation of compression wave velocity in the planes normal to the specimen axes.

Figure 4.5 illustrates the angular variations calculated in more detailed studies of highly oriented material.

4.2.1.2 Beam direction

If a specimen made from rolled austenitic or ferritic plate is rotated in the apparatus shown in Figure 4.4 (using a conventional couplant), no systematic variations will be observed on the screen of a flaw detector connected in transmission mode to the two probes. Also, the maximum signal amplitude will be received with the receiving transducer on the axis of the apparatus.

Very different results are obtained for two of the three specimens shown in Figure 4.4(A). In addition to the effect of the varying velocity referred to

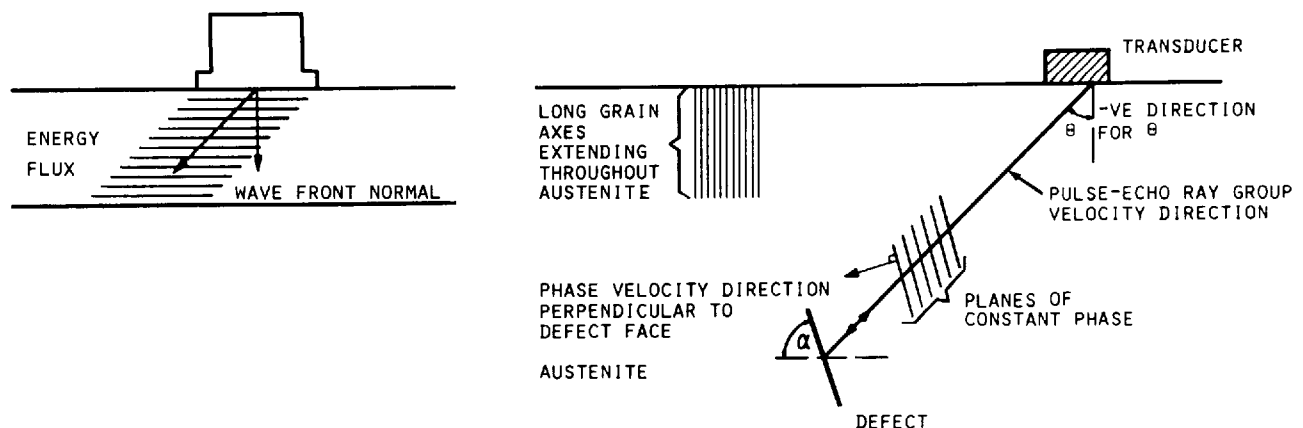


Figure 4.3 — Visualization of the wave front normal and the direction of energy flux, i.e. "propagation direction" (left: normal beam, right: angle beam)

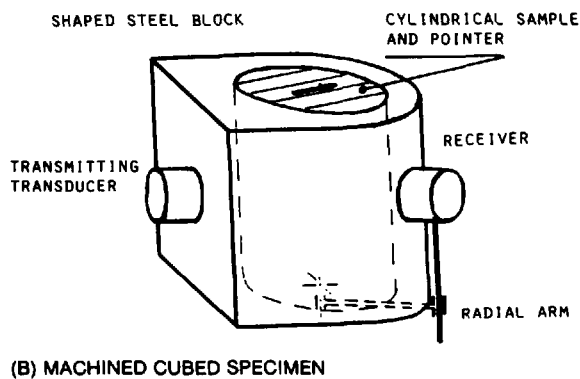
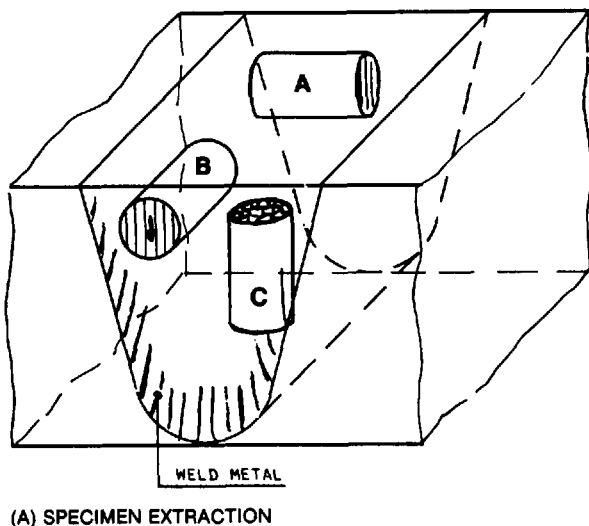


Figure 4.4 — Simple apparatus to demonstrate ultrasound propagation behavior

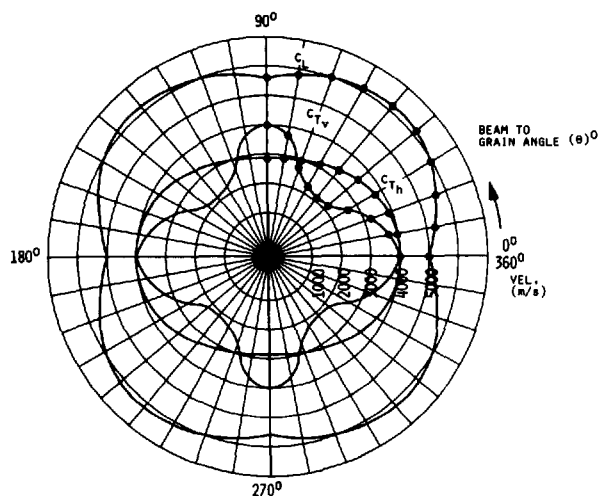


Figure 4.5 — Computed values of velocity variations for the three propagational wave modes in austenitic weld metal (C_L , C_{TH} , C_{TV})

in section 4.2.1.1, for the specimens with their axes machined parallel to the surface of the original weld sample the amplitude of the transmitted signal varies systematically. More surprisingly, it will be found that the position of the receiving transducer for the maximum received signal varies with specimen orientation.

No large systematic variations will be found for the third specimen with its axis normal to the surface of the original weld sample. Similar beam deviation, or skewing, phenomena occur for shear waves but are more difficult to demonstrate in a simple experiment due to couplant problems.

Figure 4.6 summarizes the basic effects which are calculated for beam skewing in one plane. The smaller skewing of angled longitudinal waves (L) compared with vertically polarized shear waves (SV) is evident.

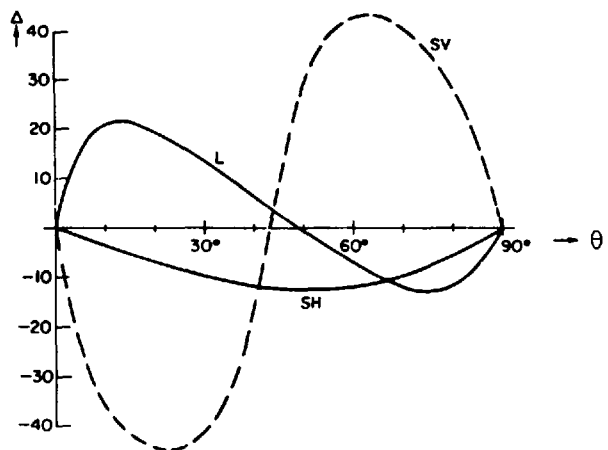


Figure 4.6 — Beam deviation plotted against beam-to-grain angle (calculation)

In a weld composed of imperfectly aligned large columnar grains, multiple refraction is to be expected as a sound beam passes through. On occasion when different parts of a beam undergo very different deviations, they can be split into two parts with comparable intensities during their passage through weld metal.

4.2.1.3 Beam deformation

The width of the ultrasound beam in columnar grained austenitic weld metal will vary depending on the angle of the incident beam to the long axes of the grains. This effect is a direct result of the beam skewing phenomenon described above.

Figure 4.7(A), which has been derived from Figure 4.6, shows as an example how the central

and limiting rays of a longitudinal wave beam of 5° divergence in an isotropic plate will be skewed as a function of the angle to the grains. The examples shown in Figure 4.7(B) illustrate the variability in beam width that can be expected at different angles; longitudinal wave L beams will be most divergent when directed at 0° (and 90°) to the grains and least divergent at an angle of about 48° . For angles in between these values (e.g. 24°), the beam itself will be skewed and the divergence will have an intermediate value.

Since this form of beam distortion is dependent on the degree of skewing, it is clear from Figure 4.6 that the effect will be greater for SV and less for SH waves, when compared to the longitudinal results.

In practice, for weld inspection it is not possible to predict the beam width except for simplified structures of the type shown in Figure 4.7(B). This means that defect size estimation by techniques which rely on knowledge of the beam shape (e.g. 20 dB drop method) will not be satisfactory in situations where the beam is distorted in its path through anisotropic weld metal.

Because of variations in beam shape, amplitude methods for defect evaluation are less reliable for austenitic than for ferritic welds.

4.2.1.4 Effect of the weld fusion faces

4.2.1.4.1 Reflection

At any interface, the reflection behavior is dependent on wave mode and angle of incidence. Reflection into the plate material can occur at the fusion faces between weld and plate: Figure 4.8 illustrates one example of the origin of a spurious indication.

For many welds, the combination of the weld fusion face and the bottom surface produces a pronounced "corner-effect". For SV waves, the resultant reflection can yield a larger signal than side drilled holes in the body of the weld metal. This effect is not so marked when using L waves, which are not so sensitive to the corner effect. A consequence of this observation is the need for care when examining for lack of fusion defects in such welds using SV waves.

4.2.1.4.2 Refraction

Refraction will occur at the fusion face, but the resultant beam deviation is not usually distinguishable from the beam deviations associated with the properties Figure 4.9.

4.2.1.4.3 Mode conversion

Mode conversion is to be expected at such an interface when the beam is incident obliquely.

(See Figure 4.10.) As with reflection effects, any indication should be considered carefully, and the possible change in velocities and directions due to mode conversion should be taken into account. Spurious indications from fusion faces can be associated with these conversion effects.

4.2.1.5 Interaction with defects

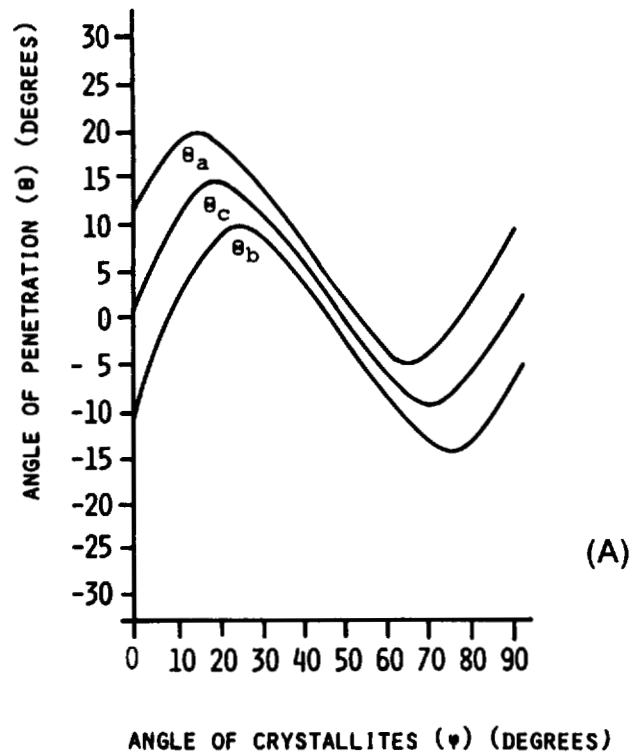
Theoretically, the interaction of a sound beam with a reflector is governed by the angle between the wave fronts and the reflector surface. Reflection back along the incident beam direction occurs when this angle is zero. This effect does not appear to have been intensively studied experimentally for ultrasound with skewed wave fronts, and thus results obtained using heavily skewed beams need to be interpreted with extra care. However, deviation from conventional behavior may sometimes be helpful, particularly when investigating awkwardly oriented defects in austenitic materials. Side drilled holes cannot be used for studies of these effects since there is always a favorably oriented reflecting surface if the beam direction is normal to the hole axis.

4.2.2 Attenuation in Weld Metal

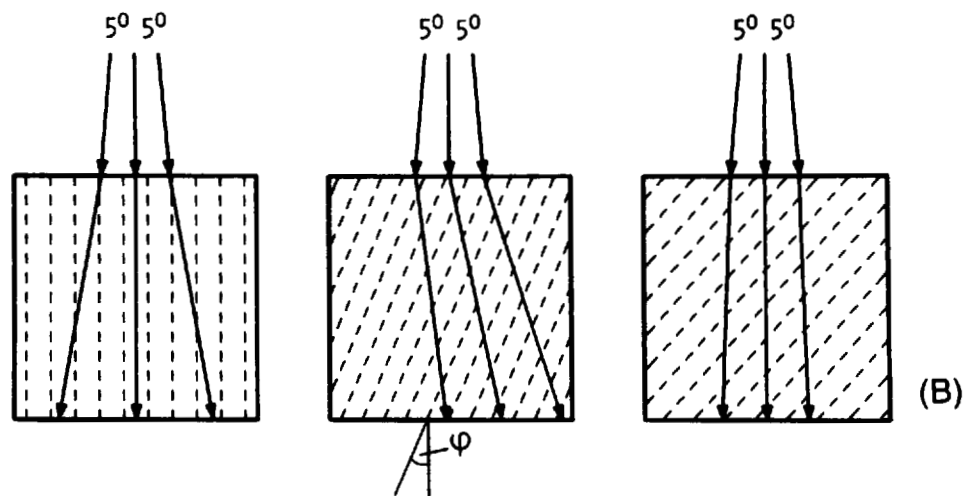
A major practical problem in the ultrasonic examination of austenitic welds is the occurrence of severe attenuation and of back scattered ultrasound (grain noise) which varies with the direction of the ultrasonic beam in the weld material. As discussed below, a number of mechanisms are involved. Combined with a high grain-noise level, the attenuation can cause considerable problems in obtaining an adequate signal-to-noise ratio when examining welds which are several centimeters thick.

Absorption is a genuine attenuation mechanism where the ultrasonic energy is converted into other kinds of energy like heat, but can be neglected here, being much less important than the scattering in the frequency-range of interest.

Ultrasonic scattering can be observed in polycrystalline material. It is caused by the elastic anisotropy of the single crystals and is also dependent on wave mode, being higher for the conventional shear mode than for the compressional mode. The scattering increases with grain size, frequency, and elastic anisotropy, and also depends on materials properties, density and sound-velocity. Superimposed on the scattering mechanisms are the effects of the beam deformations discussed in section 4.2.1.3. These can give a large and variable apparent attenuation which is direction dependent.



ANGLE OF CRYSTALLITES (ϕ) (DEGREES)
SKEWING OF CENTRAL AND LIMITING RAYS
OF A NOMINAL 5° BEAM



BEAM TO GRAIN ANGLE (ϕ)	0°	24°	48°
SKEW ANGLE	0°	12°	0°
BEAM DIVERGENCE	HIGH	INTERMEDIATE	LOW
PROPAGATION VELOCITY	SLOW	INTERMEDIATE	FAST

Figure 4.7 — Variations in beam width due to the beam skewing effect (longitudinal waves)

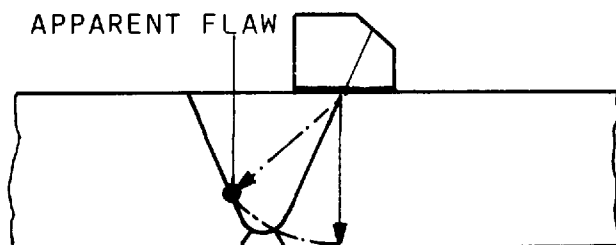


Figure 4.8 — Example of a spurious indication due to a fusion face reflection

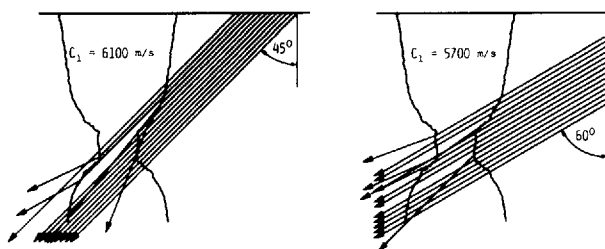


Figure 4.9 — Ultrasound refraction at the fusion face

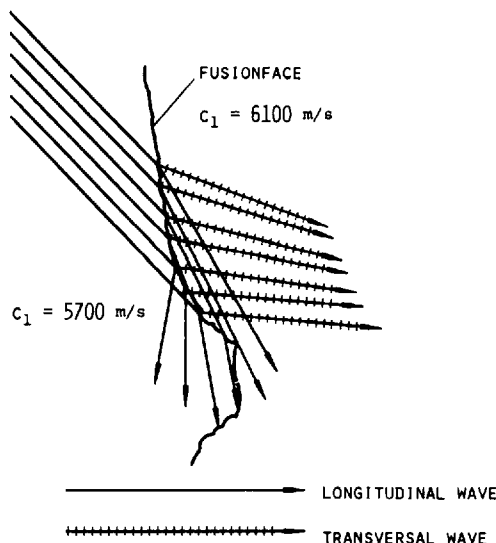


Figure 4.10 — Mode conversion at the fusion face

4.2.3 Influence of Weld Metal on Pulse Characteristics

The propagation of an ultrasonic pulse through a material is mainly influenced by the material properties. The pulse characteristics change during propagation.

4.2.3.1 Pulse spectrum

Figure 4.11(A) shows a typical ultrasonic pulse which is characterized by its maximum amplitude A , length Δt , and number of cycles N .

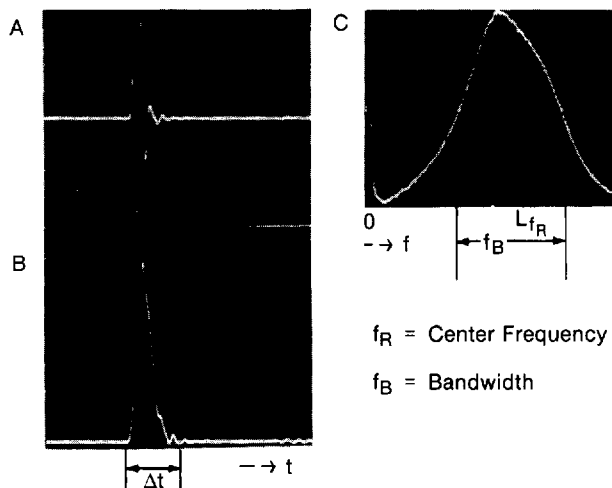


Figure 4.11 — (A) Typical ultrasonic pulse, (B) rectified signal, and (C) amplitude spectrum

To display this pulse on the flaw detector, it is rectified and smoothed [Figure 4.11(B)]. Figure 4.11(C) shows the amplitude spectrum of the pulse with f_R as the testing frequency and f_B as the bandwidth which characterizes the pulse. The bandwidth is inversely proportional to the pulse length. (See section 6.5.4). This spectrum is very useful for evaluating the phenomena which occur when an ultrasonic pulse passes through a material.

4.2.3.2 Influence of attenuation of the ultrasonic pulse

Attenuation is very much related to scattering and depends on frequency. Low frequencies will penetrate the material more easily. The total attenuation increases with sound path, so that the material's transfer characteristics are dependent on the sound path and the scattering coefficient. Figure 4.12 is an example of how the frequency content of the ultrasonic pulse varies with path length in coarse grained material.

It demonstrates the way in which the spectrum of an ultrasonic pulse can be distorted when traveling through the material. The material then acts as a filter (analogous to the hardening of the x-ray spectrum passing through material). This behavior has a large effect on the amplitude decay when

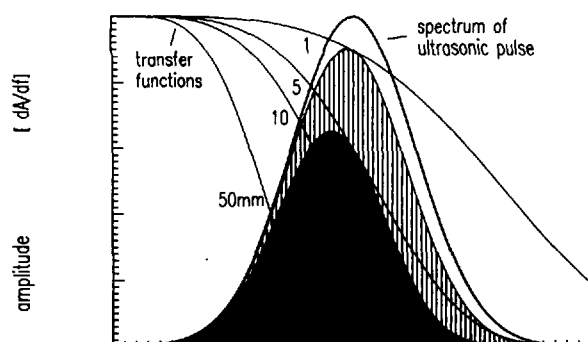


Figure 4.12 — Variation of spectrum with transfer function for different sound paths shown qualitatively

probes of different testing frequency and pulse length are used.

Figure 4.13 shows the spectra of a short and a long pulse of the same testing frequency and the two transfer functions of a fine grained and a coarse grained parent material. After penetrating through the fine grained material, there is only a very little amplitude loss and distortion of the pulse. Passing through the coarser grained material leads to limited amplitude loss and a large pulse distortion when a short pulse (broad band spectrum) is used, and to a severe amplitude loss

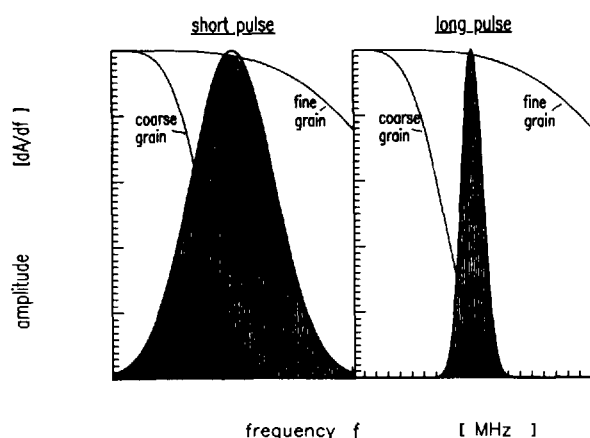


Figure 4.13 — Influence of coarse and fine grained material on frequency spectrum of long and short pulses shown qualitatively

and a small pulse distortion when a long pulse (narrow band spectrum) is used. Figure 4.14 shows as an example the back wall echoes obtained with a test piece examined by ultrasonic pulses of different testing frequencies and pulse-lengths. At lower frequencies, there is no difference in the

LOWER FREQUENCY HIGHER FREQUENCY

SHORT PULSE

LONG PULSE



Figure 4.14 — Influence of frequency and pulse length on back wall echo indications

amplitude decay between the short and long pulses. With increasing frequency (or increasing grain dimension), the long pulse is attenuated more severely.

4.2.3.3 Scattered ultrasound

Testing frequency and pulse length also have a strong influence on the amplitude of the grain noise. The amplitude of the ultrasonic backscattered signal increases with the testing frequency. The grain-noise amplitude also increases with pulse length; therefore, the application of low frequency probes with short pulses is advantageous.

One also has to take into account, however, the far field divergence of low frequency transducers. As shown in Figure 4.15, a wide sound beam will lead to a worse signal-to-noise ratio because of the greater volume of scattering grains. A reduction of the scattering volume is obtained by the use of focusing or twin crystal probes.

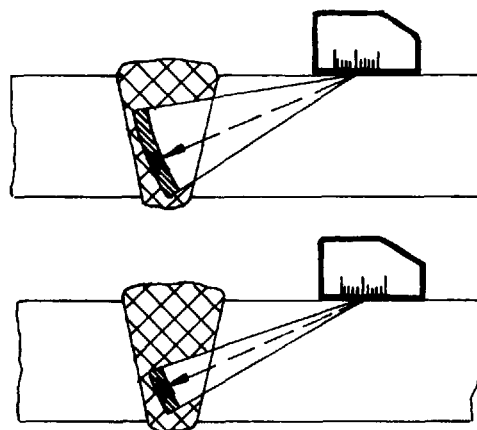


Figure 4.15 — Reduction in scattering volume associated with narrower beams

It is important to keep in mind that the signal-to-grain-noise ratio can be improved by the use of longitudinal wave probes. These may be preferred because the combined effects of mode conversion and scattering at grain boundaries result in the scattered energy being predominantly in the form of shear waves.

4.2.4 Practical Implications for Ultrasonic Testing on Austenitic Welds

4.2.4.1 Defect location

The most obvious effect of beam deviation can be a large difference between the beam angle in the weld metal and that measured using a conventional calibration block made up from similar plate material. The size of the discrepancy depends on the weld structure, fusion line configuration, wave mode, and nominal beam angle. This effect has obvious implications for defect location, particularly when velocity variations are not taken into account. These phenomena explain well known difficulties in correlating the results of ultrasonic and destructive examinations. Figure 4.2 indicates the effective beam directions for two welds with similar but not identical structures.

In practice, a triangulation technique can be useful to locate defects in butt welds which can be detected from two opposite directions (Figure 4.16).

4.2.4.2 Amplitude assessment

The beam deformation effects, particularly the variation in beam width, affect the use of a DAC curve to assess reflectivity. Thus, superimposed on the enhanced attenuation associated with weld metal is an apparently random variation in signal intensity from any given sized reflector. This makes the use of amplitude to assess indications even more difficult than for ferritic materials, and side drilled hole echoes have been found to differ in amplitude by 10 dB or more for similar ranges.

As referred to previously, the magnitude and significance of these effects depend largely on

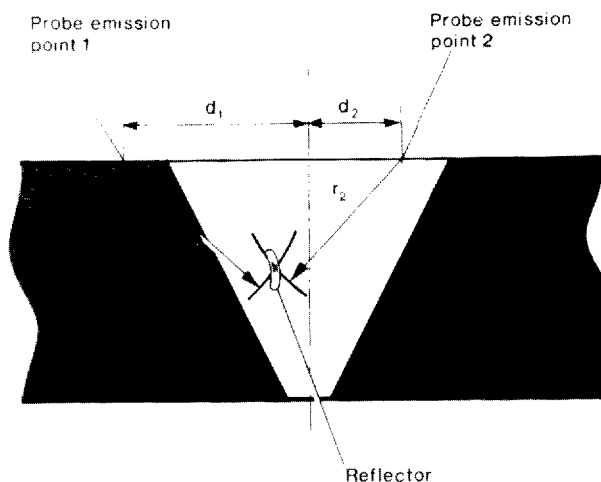


Figure 4.16 — Locating a reflector in austenitic welds using angled longitudinal waves

the weld structure. Relevant experimental data have only been published for a comparatively limited number of welds and are still insufficient to give general guidance. The availability of calibration and reference blocks is thus essential in estimating the magnitude and significance of structural influences. Calibration blocks are described in section 6.2. Guidance on the design of reference blocks is given in section 7.3. Much further work is required before detailed assessments can be provided for the problems associated with the full range of weld types which may be found in conventional practice, especially when positional welding is taken into account. In particular, most of the published detailed studies have involved welds with a well aligned grain structure rather than welds with a more random structure, such as that typical of GMA welds. Experiments show that minimization of the volume of weld metal is likely to minimize the effects of beam skewing, etc. Thus, from an inspection viewpoint, narrow gap welds appear preferable, but there are other weld geometries which could be advantageous. Narrow gap welding is not always practicable.

5. DESCRIPTION OF EQUIPMENT

5.1 Introduction

There is no general rule which can be used to select the best apparatus and probes for a specific

application. In many cases, the choice can be guided by previous experience. The paragraphs below describe the various types of equipment and probes commonly used for austenitic weld inspection.

It is important to point out that the probes may be different from those commonly used for ferritic welds.

5.2 Flaw Detector, Cables and Matching

Figure 5.1 illustrates the major factors which influence the shape of the indication seen on the flaw detector screen.

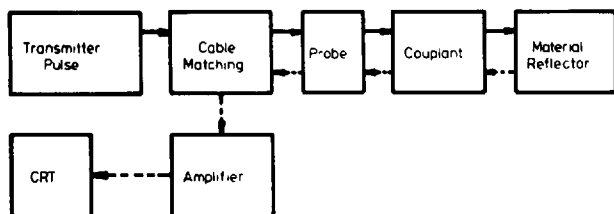


Figure 5.1 — Generation and path of the pulse

The minimum requirements for ultrasonic apparatus are defined in the *IIW Handbook on the Ultrasonic Examination of Welds*.

Those requirements are usually satisfied by conventional flaw detectors used for ferritic weld inspection. However, for austenitic welds, it is often necessary to pay special attention to additional requirements — transmitter pulse, amplifier, cable, and electrical impedance matching.

The transmitting pulse strength and the amplifier characteristics can influence the examination results. Both can change the length of the pulse and can therefore affect the signal-to-noise ratio (see section 4.2). Once the best setting for the equipment has been established, it is important to maintain this setting throughout the inspection and to avoid changing any part of the equipment. Special attention should be paid to the linearity and spectral response (e.g. bandwidth) of the amplifier. The amplifier response at low frequencies can be especially important.

Attention should also be paid to cable length and the equipment manufacturer's recommendation on matching should be followed. Cable length and matching devices should be specified in the procedure.

5.3 Angled Longitudinal Wave Probes

5.3.1 Introduction

Various possibilities exist for the selection of probe types for a particular austenitic weld examination. Where the examination is limited to welds in thin sections or where penetration through parent material only is required (as in examining for fusion face defects), then the use of shear wave probes can be considered. Requirements

and inspection procedures for shear wave probes are well known and are described in the *IIW Handbook on the Ultrasonic Examination of Welds*. In most circumstances, however, it is necessary to use angled longitudinal wave probes because of the high apparent attenuation and scattering associated with the use of shear waves. This rules out their effective use for weld metal examination. The general properties of angled compression wave probes differ in several respects from those of shear wave probes and this is discussed in section 5.3.2. Various categories of angled compression wave probes exist — the particular features of which are described in sections 5.3.3 to 5.3.6.

5.3.2 General Properties

As with shear wave probes, the beam angle is determined by Snell's Law. Figure 5.2 shows graphically the way in which refraction angle depends on incident angle.

An important point to note is that for any longitudinal wave angle, such probes also generate an associated shear wave beam at a smaller angle. The presence of this additional beam, which can

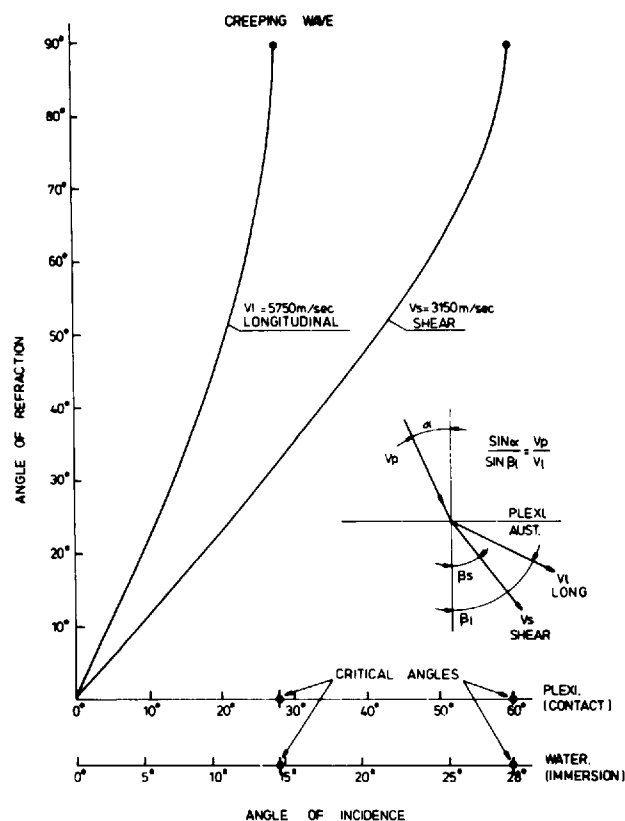


Figure 5.2 — Snell's Law for longitudinal and shear wave probes

have an intensity comparable to that of the compression wave beam, should always be considered because it can cause spurious echoes and consequently give rise to misinterpretation of the results (see Figure 5.3).

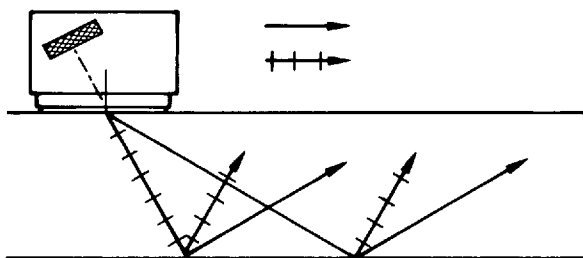


Figure 5.3 — 60° longitudinal angle beam probe with shear wave part and mode conversion

Although the additional shear wave beam can cause confusion during the examination (because any indication could be located on either beam), careful consideration of range, angle, and probe position relative to the weld often helps to decide which alternative is most likely.

A further important point to realize is that angled longitudinal beams lose substantial energy upon reflection at the inside surface of the component. This means that angled longitudinal wave testing is generally limited to half skip. (See, however, section 7.4.2.). An implication of this is that full volumetric examination of the weld requires the weld cap to be ground flat and flush.

It is generally accepted that large bandwidth probes and probes generating narrow beams increase inspectability. Various designs of angled compression wave probes are commercially available.

5.3.3 Single Crystal Probe

The basic construction of single crystal longitudinal wave probes is almost identical to the well known single crystal shear wave probes, but the wedge angle is such (see Figure 5.2) that compressional waves are generated.

Because of the relatively small angles of incidence, reverberations in the wedge will occur. Specific measures to decrease these reverberations are necessary, requiring long wedge delays and special wedge construction with damping material around the wedge.

The result is that the probes are often relatively large in size. Nevertheless, the reverberations may cause a dead zone which often requires an additional probe to cover the dead zone area. Selection of a good probe design is very important.

An advantage of the single crystal probe is its rather regularly decreasing distance amplitude response. (See Figure 5.4.). This makes less necessary the application of a number of probes, as explained in section 5.3.4.

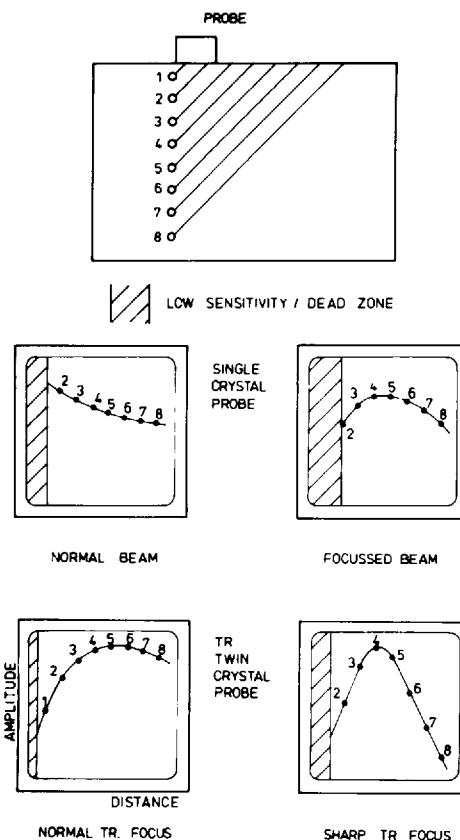


Figure 5.4 — Distance-Amplitude-Correction (DAC) curves for characterization of various probes

5.3.4 Twin Crystal Probes

These probes are constructed with two crystals, either arranged one behind the other or, more commonly, side by side.

The commonly used construction is shown in Figure 5.5. The abbreviation TRL indicates twin crystals radiating longitudinal beams.

Both crystals of the probe have been placed at such an inclination (squint angle), that their beam axes intersect, to give a quasi focus-effect leading to a higher S/N ratio by reducing the effective beam area. The construction of the probe almost eliminates the effect of reverberations from within the probe.

The effect of the TR probe construction on the distance amplitude characteristic is shown in Figure 5.6.

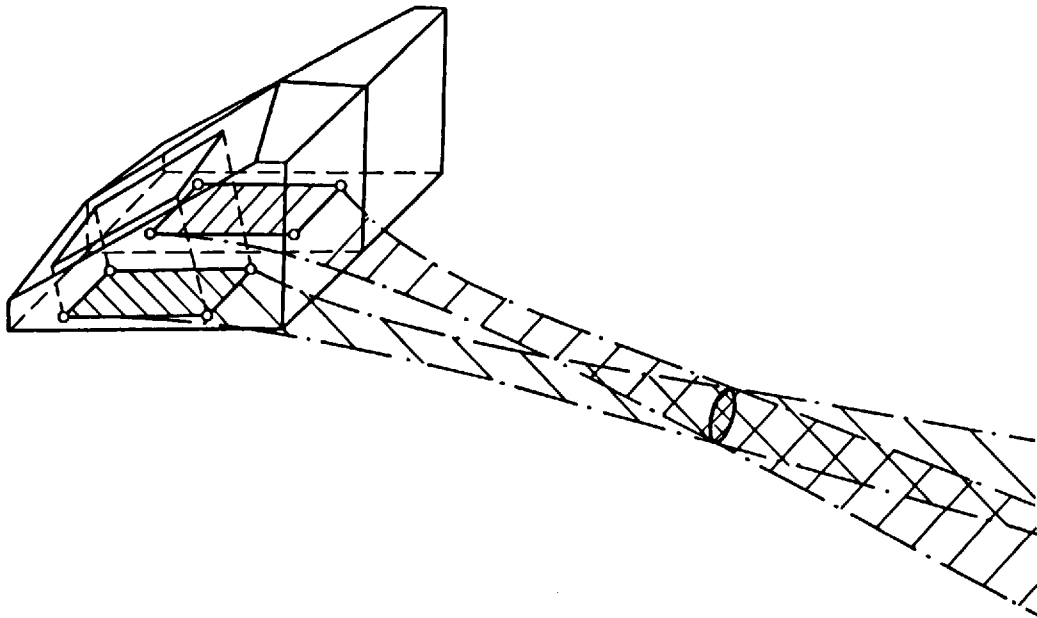


Figure 5.5 — Transmitter-receiver probe

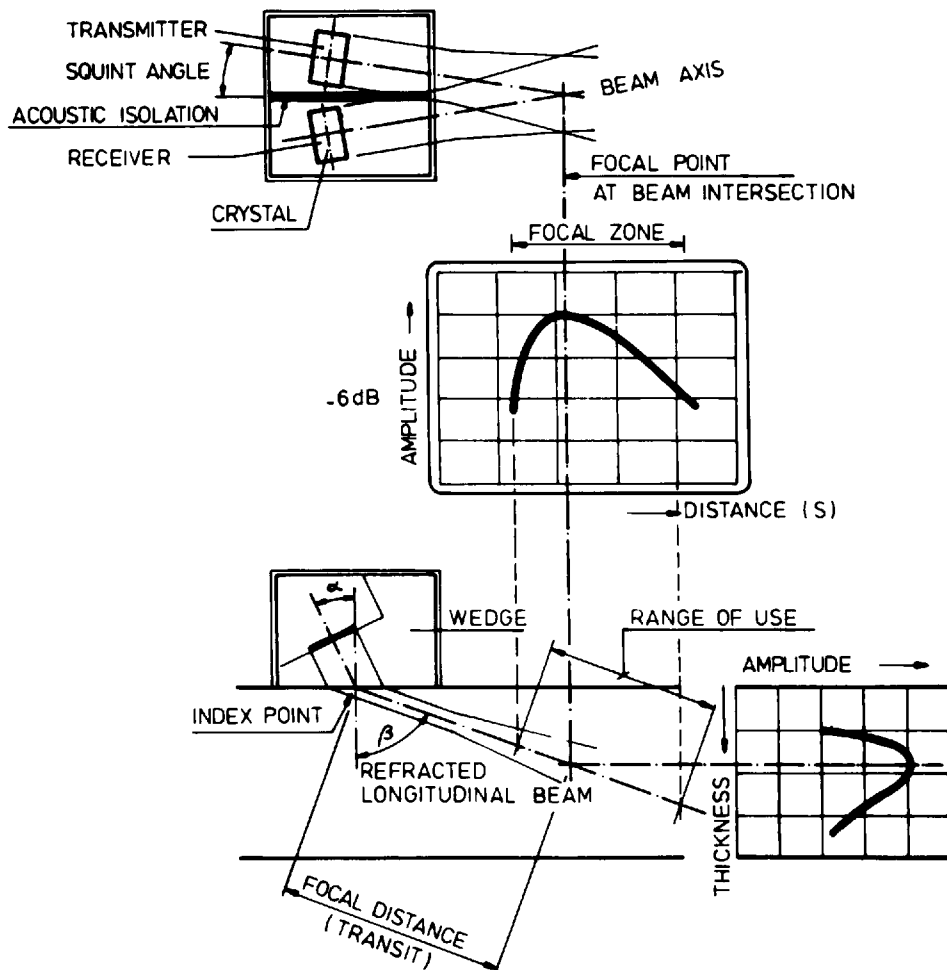


Figure 5.6 — Sensitivity diagrams of TRL probes for longitudinal waves

To cover the full weld thickness, several probes may be required as shown in Figure 5.7.

For relatively thin welds, a single probe is sufficient, preferably a creeping wave probe (see 5.3.5 below) or a 70° probe with a strong surface wave component.

In the case of thick welds, more probes are necessary. The advantage in more probes is that the probe angle can be an optimized selection for flaw detectability in each depth zone.

All compression wave TR probes have a very low sensitivity in the first part of the range behind the acoustic zero point. This causes a very small dead zone. The surface wave probe fully eliminates this effect as shown in Figure 5.7.

It should be born in mind, however, that probe characteristics determined theoretically or established experimentally on the probe characteriza-

tion block (6.4) may change dramatically in the highly attenuative anisotropic austenitic weld structure. In the absence of other information, initial probe selection criteria can be based on characteristics obtained on isotropic (low attenuative) materials.

5.3.5 Surface Wave Probes

A derivative of the angled longitudinal wave probe is the "surface wave" probe. The surface wave is generated at the first critical angle of incidence, as shown in Figure 5.8, and propagates along the surface as a compression wave. It is also referred to by other names, e.g. head wave, lateral wave, fast surface wave at the first critical angle. Unlike Rayleigh waves, the surface wave is not damped by couplants on the component surface, nor does the beam follow undulations in the surface.

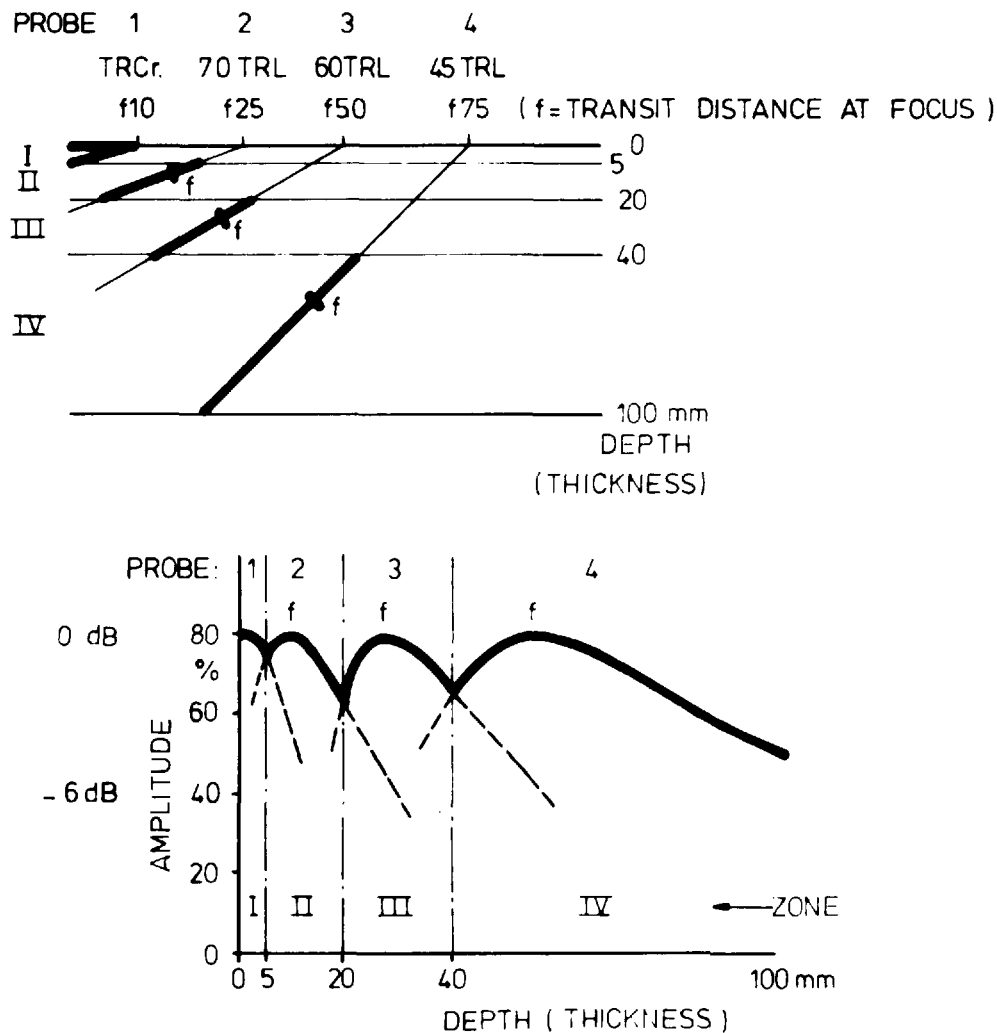


Figure 5.7 — Multi TRL probe concept (Probe 1 is surface wave probe)

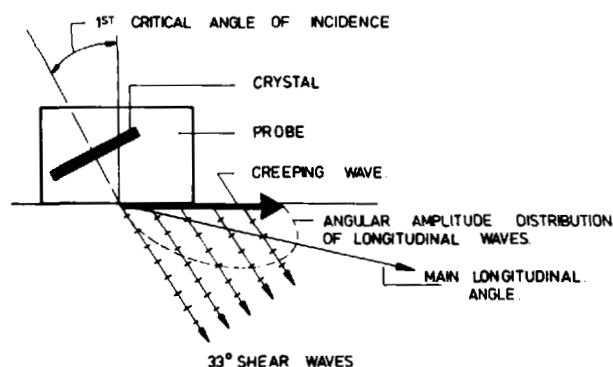


Figure 5.8 — Principle of the surface wave probe

By nature, a surface wave probe generates

- compression waves at large angles between 70° and 90°
- shear waves according to Snell's Law

The surface wave sound velocity is identical to that of compression waves.

Although it generates a beam with "complicated" characteristics, it is a very useful probe for detecting surface defects.

A surface wave probe can also be considered for inspection of the weld root. The 33° shear wave component of the surface wave probe converts to a secondary surface wave at the backwall of the component, as shown in Figure 5.9. In this case, the weld penetration echoes can largely be eliminated.

5.3.6 Focussing Probes

Focussing in general, enhances the signal-to-noise ratio. The effect of a narrow beam is described in section 4.2.3.3. It reduces the scatter from the area to be inspected while the echo from the defect remains constant (or even increases), resulting in a better S/N-ratio.

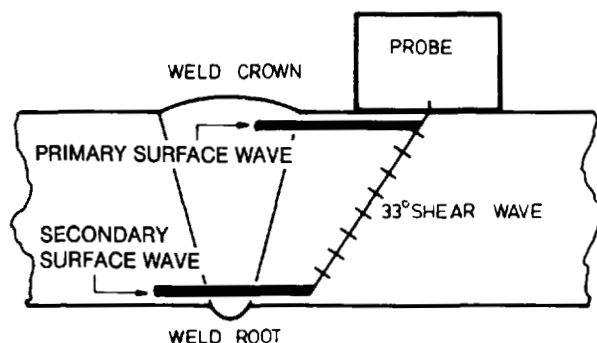


Figure 5.9 — Application of surface waves

Focussing for contact or immersion testing can be achieved by lenses or curved crystals, as shown in Figure 5.10. Zone plates, phased arrays, and other methods can also be used.

Immersion testing produces narrower beams than are achieved by the contact technique since larger probe sizes are practicable. On the other hand, the beam of a contact probe is determined by the probe construction. It is not so strongly influenced by the distance from the test surface or the incidence angle as is that from an immersion probe.

Sometimes, the improved S/N ratio observed for TR probes is due to the quasi focus effect, described in section 5.3.4. This quasi focus effect of TR probes can be increased by the use of lenses or curved crystals to further improve the S/N ratio.

It should be realized that small variations in probe characteristics or component geometries might reduce the S/N ratio, particularly if the immersion technique is applied to obtain a narrow beam. The beam profile is sensitive to small errors because of the high refractive index at the liquid-to-steel interface compared to that for the probe-to-steel interface in the contact technique. In the case of focussed beams, a careful selection of the probe settings appropriate to the configuration of the component to be tested is important. Such probes can be expected to have general characteristics similar to those of TR probes and also require the use of a multi-zone approach (see Figure 5.7).

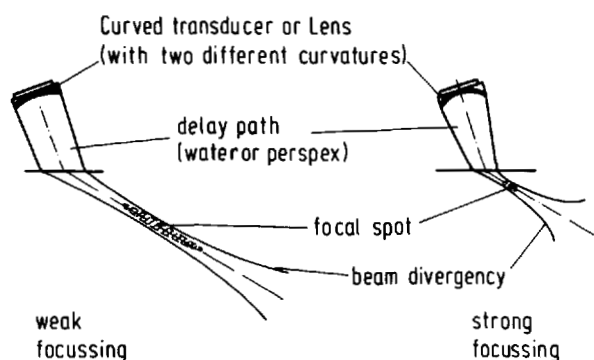


Figure 5.10 — Focussed sound field created by lens or curved crystal
left: medium focussing
right: sharp focussing

6. CALIBRATION AND CHARACTERIZATION

6.1 Introduction

If an austenitic weld can be examined by shear waves, then an examination procedure using angled shear wave probes can be used. This can be based on the guidance in the IIW, *Handbook on the Ultrasonic Examination of Welds*.

Nevertheless, in this case, it is necessary to procure a reference block, as detailed in section 7.3, to verify the feasibility of the examination by shear waves. In addition, a stainless steel calibration block, as described in section 6.2, is required for accurate time base setting and probe index determination. This applies even if examination of the weld metal volume is not required and coverage is limited to the detection of lack of sidewall fusion (which can generally be done with shear wave probes).

In those cases where it is established by experiment that a volumetric examination of the weld requires the use of angled compression wave probes, a number of blocks are necessary for the following:

- timebase and probe index calibration section 6.3
- probe characterization section 6.5
- sensitivity setting and compilation of an inspection procedure (reference block) section 7

6.2 Calibration Blocks

The existing IIW calibration blocks, numbers 1 and 2, are not well suited for use in austenitic weld inspection with angled compression wave probes for several reasons:

- The 100 mm radius of block 1 is often too large in relation to the short ranges at which the probes are used.
- Block 2 with radii of 25 and 50 mm is too narrow compared to the width of the probes used.
- The sound velocity of the low alloy steel IIW calibration blocks differs considerably (see section 4.2.1.1) from that of the average velocity in stainless steels.

For proper calibration, two radii are necessary so that a geometry can be chosen similar to the

IIW block 2. The calibration blocks are manufactured from a stainless steel material with a velocity of 5740 ± 20 m/s, which is the average for the types of stainless steel commonly used in high quality component construction. Figure 6.1 shows a drawing of the two calibration blocks. One block has radii of 25 and 50 mm, the other has radii of 50 and 100 mm.

A block width of 40 mm is chosen to provide an adequate contact surface to cope with the width of the angled longitudinal wave probes typically used for stainless steel weld testing. For outsized probes, special calibration blocks may be necessary.

Although the geometry of the IIW block 2 is used, the 5 mm hole is not incorporated for two main reasons:

- The hole causes spurious echoes during probe index determination, and the spurious echoes can easily cause false time base calibration.
- A single hole is not adequate for sensitivity setting and probe angle evaluation. The block recommended for these purposes is described in 6.4 below.

6.3 Steps in Timebase Setting

Angled shear wave probes. To calibrate the flaw detector screen for a range of 100 mm, the position of the shear wave probe is as shown in Figure 6.2.

Angled longitudinal wave probes. Due to mode conversion effects, the procedure used for shear wave probes is unsuitable for calibrating angled longitudinal wave probes and must not be used.

Instead, the following steps are recommended:

(1) Calibrate the flaw detector screen for longitudinal wave velocity using a 0° probe directed across the 40 mm width of the block, as shown in Figure 6.3. Two examples are shown — (A) where calibration from 0 to 50 mm is required and (B) where calibration from 0 to 100 mm is required.

(2) Maximize the echo of the angle beam probe from one of the radii at a suitable range and adjust the flaw detector delay control to bring this echo to the correct range on the screen. (For some probes, a second echo may also be obtained from the radius due to the shear wave component of the beam. In this case, the compression echo is the shortest range echo obtained).

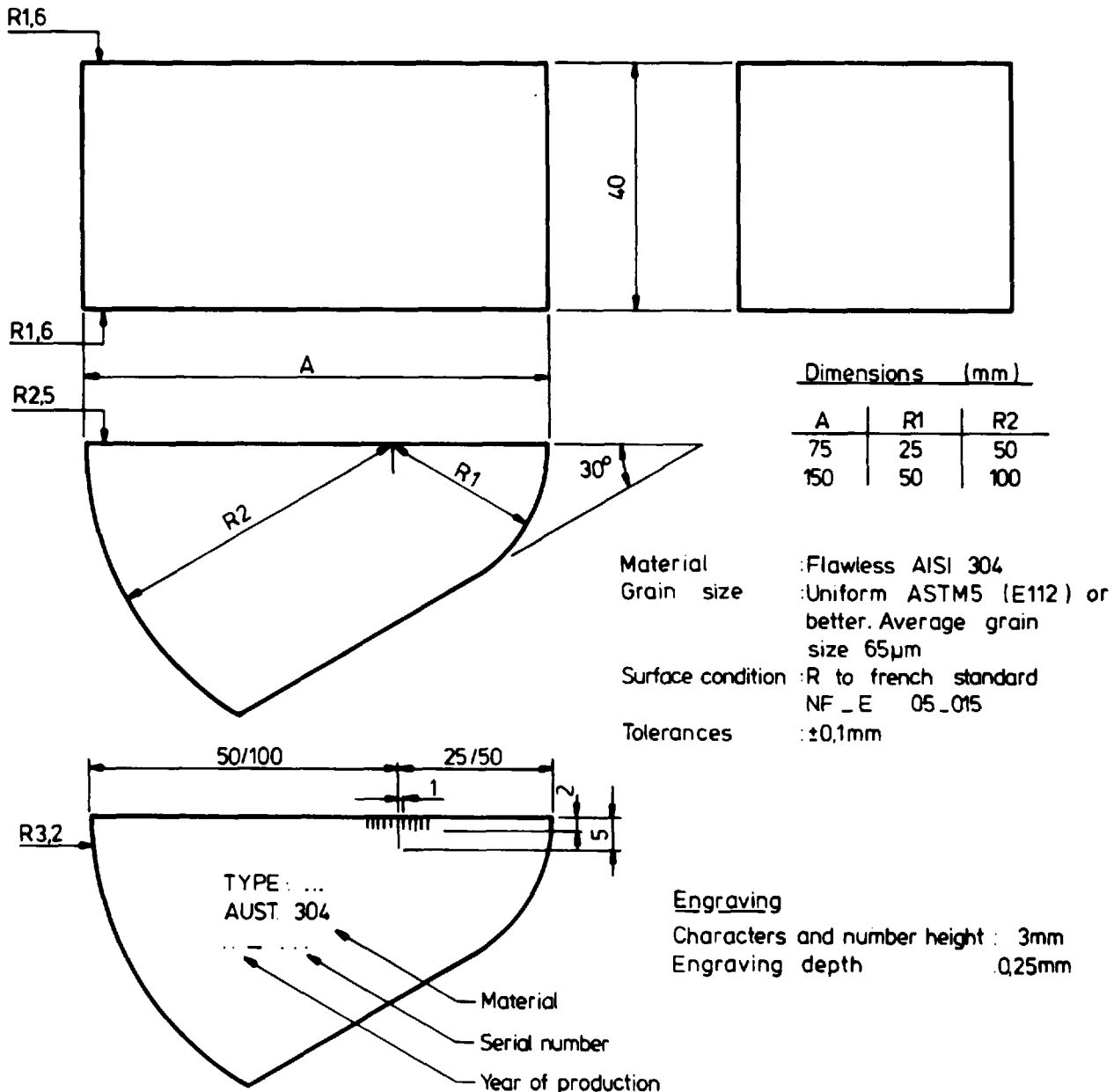


Figure 6.1 — Calibration blocks for the ultrasonic examination of stainless steel welds — IIW

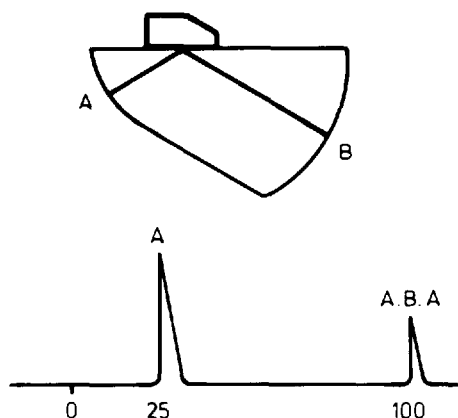
(3) Check the above calibration by maximizing the echo from a different radius and ensure that this is displayed at the correct range.

Note: The calibration blocks described in 6.2 are only suitable for calibrating full screen width for ranges of 50 mm and above. Where it is necessary to have the full screen width representing a range less than 50 mm, it is advisable to make special blocks for timebase calibration by scaling the dimensions of the calibration blocks shown in Figure 6.1. The larger radius should correspond to the maximum range to be displayed.

6.4 Probe Characterization Block

Although it is well known that acoustic behavior in welds is different from that in parent material, it is valuable to know the basic characteristics of the probe under ideal conditions. With the aid of the block described below, a number of characteristics can be established, such as

- distance amplitude curve (or focal curve)
- check of nominal focal distance marked on the probe



**Figure 6.2 — Shear wave calibration
(0 to 100 mm)**

- check of nominal probe angle marked on the probe
- beam spread
- zone height (for focussed probes)
- probe angle as function of distance
- bandwidth of the probe (see section 6.5.4)
- nominal signal to noise ratio

Figure 6.4 shows a universal block including side drilled holes, infinite reflectors at fixed angles, and notches.

Side drilled holes of 3 mm diameter are selected because they are suitable for frequencies as low as 2 MHz and are omni-directional.

The holes are situated in such a way that minimum interference is caused by the associated shear wave beam of a longitudinal probe reflecting from adjacent holes. Their distribution does not generally require the block to be turned over during characterization.

The block detailed in Figure 6.4 has a series of holes at different depths, which provide enough data points to draw a smooth amplitude distance diagram. The various holes are necessary because

- The pronounced distance amplitude characteristic, particularly for TR probes, requires a hole at the approximate working depth of the probe in order to set the sensitivity.
- The apparent probe angle of compression angle beam probes is dependent on transit distance. The nominal probe angle of TR probes can only be checked on a hole at approximately the nominal "focal" distance. At short distances, the apparent angle is greater than the nominal angle, while at longer distances the angle decreases.

6.5 Steps in Characterizing the Probes

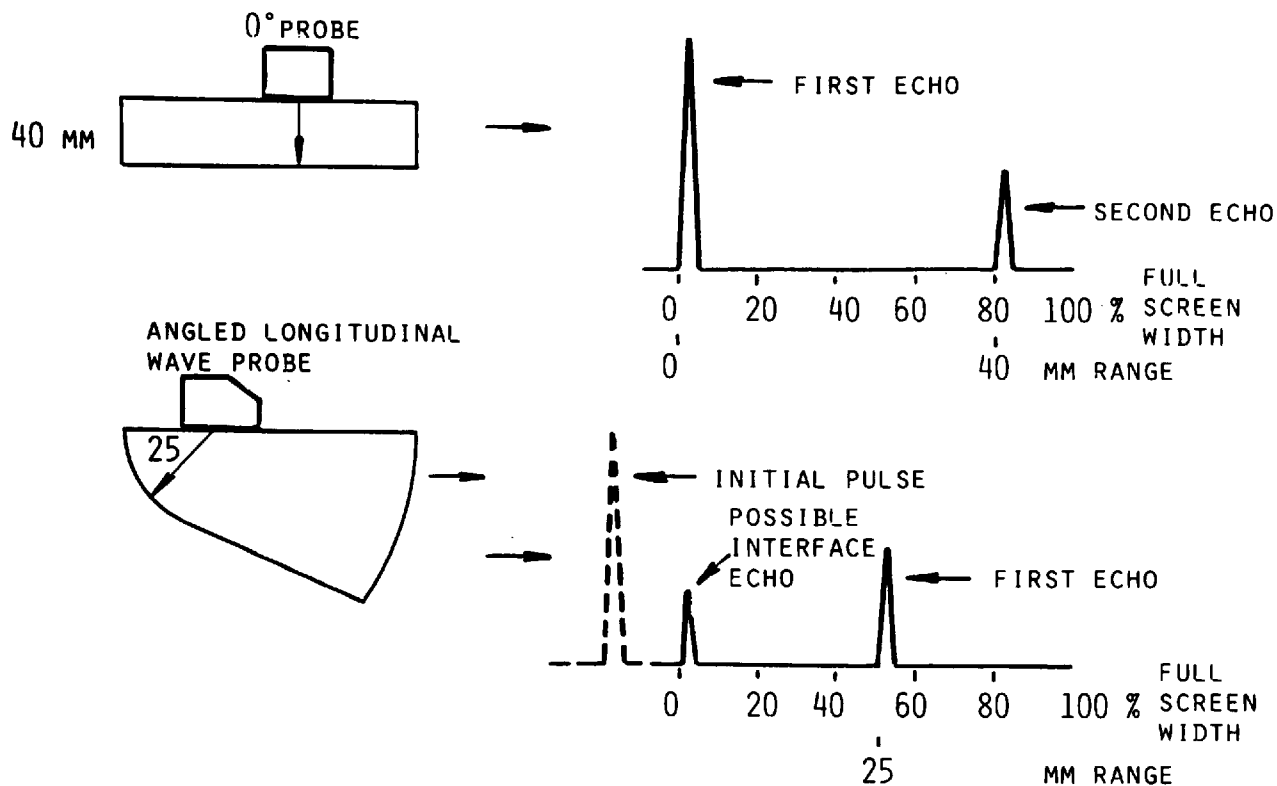
6.5.1 Introduction

The considerations involved in selecting probes for a particular weld examination are discussed later in section 7.4. When the appropriate type of probe has been selected, e.g. single crystal angled longitudinal, focused longitudinal, angled shear wave, etc., it is necessary to determine the probe characteristics in detail (even when nominally identical probes are used). For the specialized probes frequently needed for austenitic inspections, manufacturers may provide data sheets describing either the *nominal* specification or the *actual* performance claimed for a particular probe under standardized conditions.

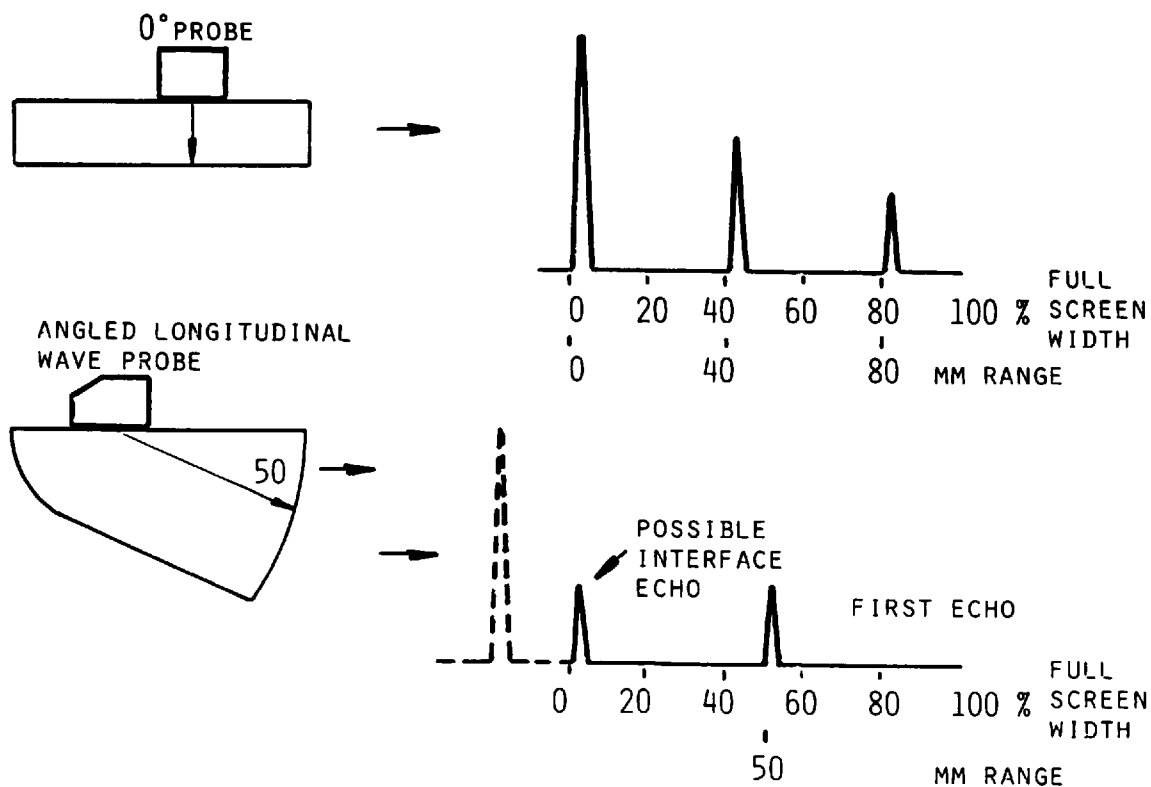
This paragraph provides guidance on methods which can be used to determine the characteristics of different kinds of probes. The properties determined are referred to as probe characteristics, but they are in fact also influenced by the characteristics of the electronic part of the test system. It is therefore essential that measurements are performed with a thoroughly checked flaw detector properly calibrated with regard to linearity, etc. Probe cables should be carefully selected. In spite of these precautions, one should be aware of the fact that the probe characteristics may change when the probe is used on coarse grain austenitic materials. For angled longitudinal wave probes, it is also essential to partially characterize the shear wave beam which accompanies the desired longitudinal wave beam. The blocks described in sections 6.2 and 6.4 and shown in Figures 6.1 and 6.4 are used for these tests. Extra measures are required to characterize contact probes for use on curved surfaces, since the standard blocks are only designed for probes with flat contact surfaces. Special blocks may also be needed for the accurate determination of some of the characteristics of focusing probes for critical applications.

For probes to be used with curved contact surfaces, it is often appropriate to make the measurements described in this chapter before machining the curve on the probe shoe. Subsequent checks can be made using the reference blocks described in section 7.3. The characteristics, especially the DAC-curve, may change significantly after shaping the probe shoe for the appropriate curvature.

Further information may also be found in the *Handbook on the Ultrasonic Examination of Welds*. This book gives basic information for normal compression wave and angled shear wave probes of the types generally used for ferritic weld examination.



(A) ANGLED LONGITUDINAL WAVE CALIBRATION (0 TO 50 MM)



(B) ANGLED LONGITUDINAL WAVE CALIBRATION (0 TO 100 MM)

Figure 6.3 — Steps in timebase calibration for angled compression wave probes

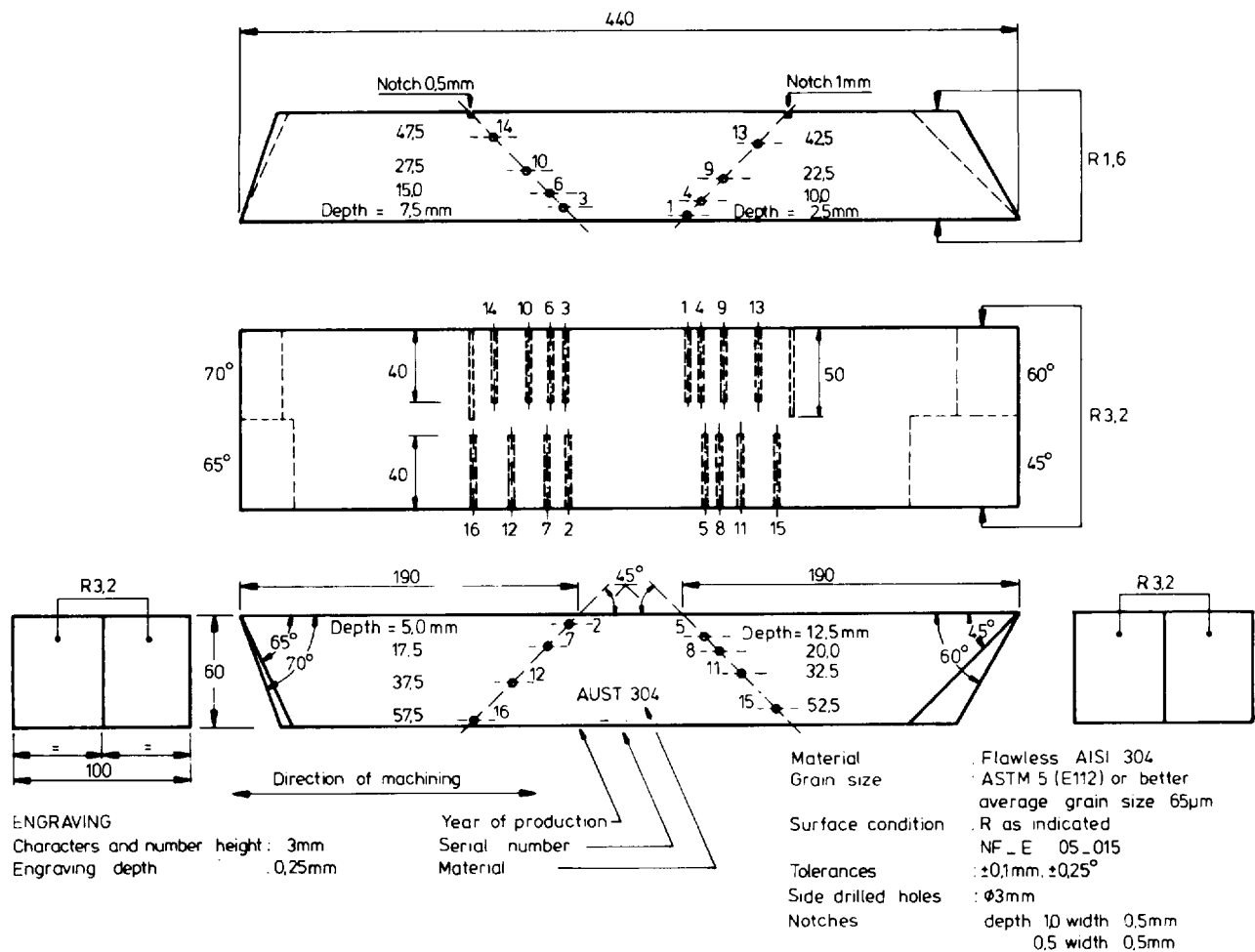


Figure 6.4 — Probe characterization block

6.5.2 Probe index of angled longitudinal wave probes

The probe index is the first probe feature which should be determined before any determination of beam angle or beam profile is made.

From the two blocks shown in Figure 6.1, it is preferable to choose the one which has radii most closely approaching the ranges of ultimate interest. The probe under test is then placed on the large plane face and moved parallel to the long edges, as shown in Figure 6.5, until the amplitude of the echo from the curved surface has reached its maximum value. The probe index then coincides with the center mark of the cylindrical surfaces. For single crystal probes, the probe index position should be the same for both curved surfaces and repeatable within 1 mm.

Because of the existence of a shear wave beam, only the first reflection should be used when calibrating longitudinal wave probes with these

blocks. It has been observed in practice that the shear wave beam can have a different index point from the longitudinal wave beam. The probe index point(s) should be permanently marked on the probe and must be checked from time to time during examination because of possible changes due to shoe wear.

Alternative calibration blocks with full quadrant radii are necessary for probes with beam angles less than 40° (see Figure 6.6).

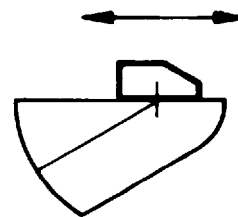


Figure 6.5 — Determination of probe index

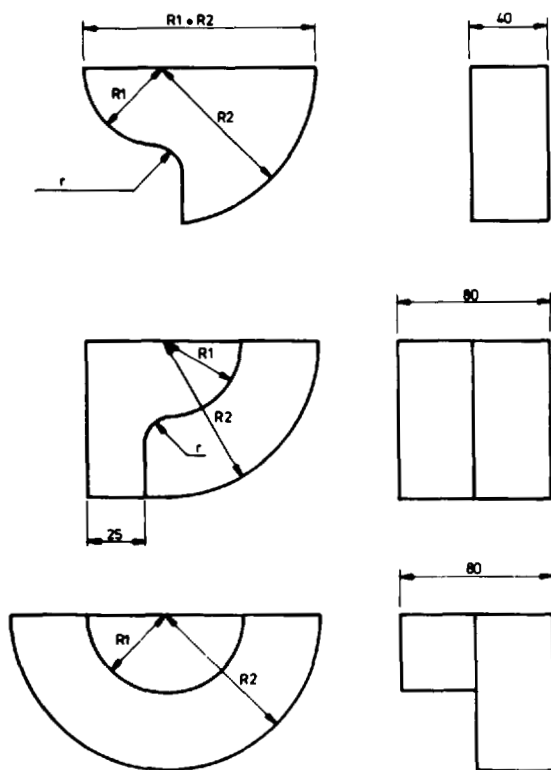


Figure 6.6 — Alternative calibration blocks

6.5.3 Distance Amplitude Curve, Beam Angle and Beam Width

The data obtained below will differ from those which would be obtained with a ferritic block such as the IIW block 1. It must also be emphasized that while the data determined by the following methods are essential for probe characterization, the effective beam angle and profile in coarse grained austenite are likely to be significantly different. The best estimate available for the behavior in the testpiece will be obtained using the reference block as described in section 7.3.

6.5.3.1 Distance amplitude curve

By using a series of holes at various ranges in the probe characterization block (Figure 6.4) and maximizing the echo amplitude for each, it is possible to determine enough data points to draw a best fitting distance amplitude curve. The various holes are necessary because the pronounced distance amplitude characteristic and focusing of TR probes require a hole close to the appropriate working depth of the probe to set the sensitivity.

A typical Distance Amplitude Correction Curve (DAC-curve) taken on such a block is shown in Figure 6.7 for a transmitter-receiver probe.

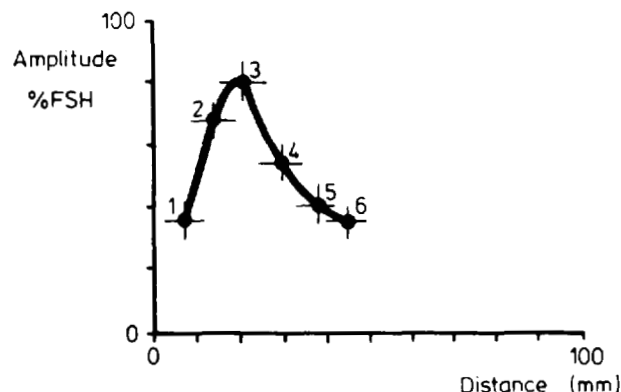


Figure 6.7 — Typical distance amplitude correction curve (for a 70° TRL probe) measured using holes 1 to 6 in the probe characterization block (shown in Figure 6.4)

6.5.3.2 Beam angle

For angled longitudinal wave probes, there are two beam angles to be measured, that for the longitudinal wave beam and that for the associated shear wave beam.

To determine the angle of the longitudinal wave beam, it is necessary to maximize the echo from a reflector at a depth that is sufficient to allow the angle to be measured directly (within 1°) with a protractor, or to be calculated from length measurements made using a ruler. The process is repeated for the shear wave component, which will have a smaller beam angle and produce an echo at a longer apparent distance.

Due to the occurrence of mode conversion into shear waves, notches produce a weak echo which make them difficult to use for the determination of the beam angle of longitudinal waves.

The apparent beam angle of transmitter receiver angle beam probes is dependent on transit distance. Nominal probe angle of these probes can only be checked at a hole at the nominal focal distance. At shorter distances, the angle is larger; at longer distances, the angle is smaller than the nominal angle. Therefore, for accurate probe characterization, an angle versus distance diagram of the type shown in Figure 6.8 should be determined.

6.5.3.3 Beam width

Using the series of reflectors at various ranges and determining also the probe movement for 6 dB reduction in amplitude from the maximum value (0 dB), the procedure may be extended to plot the vertical beam profile. It is recommended that the profile should be plotted at an appropriate level of

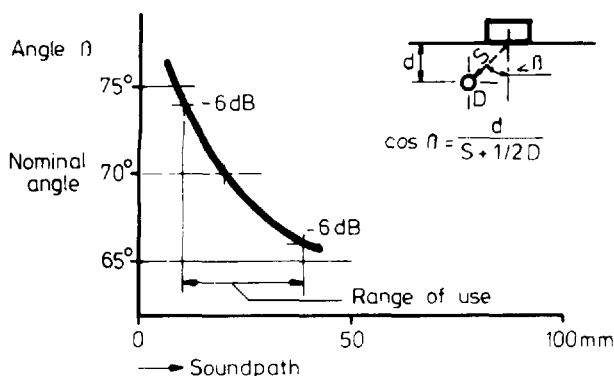


Figure 6.8 — Typical relation between apparent beam angle and soundpath

working sensitivity to allow the side lobes to be assessed.

From the beam profile, an estimate can be made of the focal distance for TRL and focussing probes. However, special blocks will normally be required for determination of the precise characteristics of probes for critical applications.

The occurrence of "squint" may be recognized by the need to twist the probe measurably in order to maximize a signal.

6.5.3.4 Amplitude behavior for different reflectors (for TRL or focussing probes)

One very important fact has to be mentioned: when making a reference curve of amplitude versus distance, e.g. for 45°, 60°, 65°, and 70° using the angled faces (infinite plane reflectors) of the probe characterization blocks, the maximum sensitivity might be reached at a distance which differs from that for curves established using side drilled holes, see Figure 6.9. Furthermore, the difference in sensitivity between the curves constructed using different reflectors (side drilled holes, flat bottom holes, infinite plane reflectors perpendicular to the beam) is most important. A large difference in amplitude between infinite plane reflectors and holes means a better amplitude discrimination between small and large reflectors.

6.5.4 Estimation of dominant frequency and bandwidth

Exact determination of the dominant frequency and bandwidth is only possible by special signal analysis. These properties are strongly influenced by material characteristics, sound path, and type of reflector. However, they can be estimated approximately by a straightforward method which

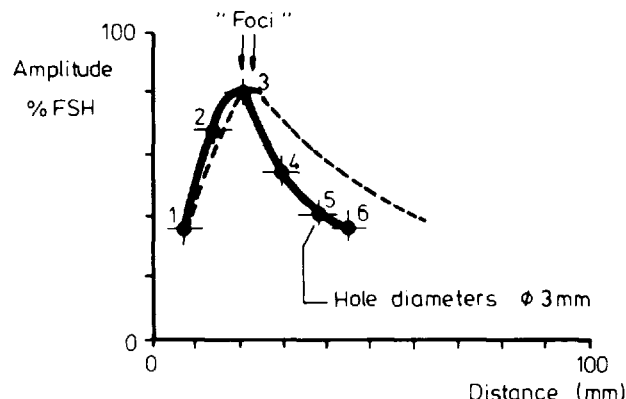


Figure 6.9 — Comparison between typical distance amplitude correction curves constructed using side drilled holes and an infinite plane reflector perpendicular to the beam (note that dotted line associated with the infinite plane reflector has been plotted with 12 dB lower sensitivity)

is good enough for most practical applications. To measure the dominant frequency f_R (see Figure 4.11), a flaw detector with an unrectified display may be used. The time base is first calibrated for a beam path length covering the range of interest. The echo of one of the calibration block radii (Figure 6.1) is then brought into the calibrated range of the time base, and the frequency f_R is estimated by counting the number of cycles N over a given sound path S in mm (see Figure 6.10). The velocity c for which the time base is calibrated has to be known in mm/s.

The bandwidth f_B should be established in relation to the dominant frequency f_R , which will give a percentage value by $f_B (\%) = (f_B/f_R) \cdot 100$. For example, a bandwidth of 20% means "narrow-band", 80% "broadband", and 120% "extremely broadband" (shock-wave probes). The bandwidth can be estimated by counting the number of cycles N of the complete echo (see Figure 6.10) of a block radius surface set at FSH (or other suitable height).

6.5.5 Dead Zone and Near Field

The probe characterization block can be used to check the dead zone of a probe by observing the echos from the near surface notch and from holes which are at intervals of 5 mm from 2.5 mm up to 57.5 mm and determining which is the nearest echo which can be distinguished.

These holes can also be used to explore the variation of sensitivity within the near field and

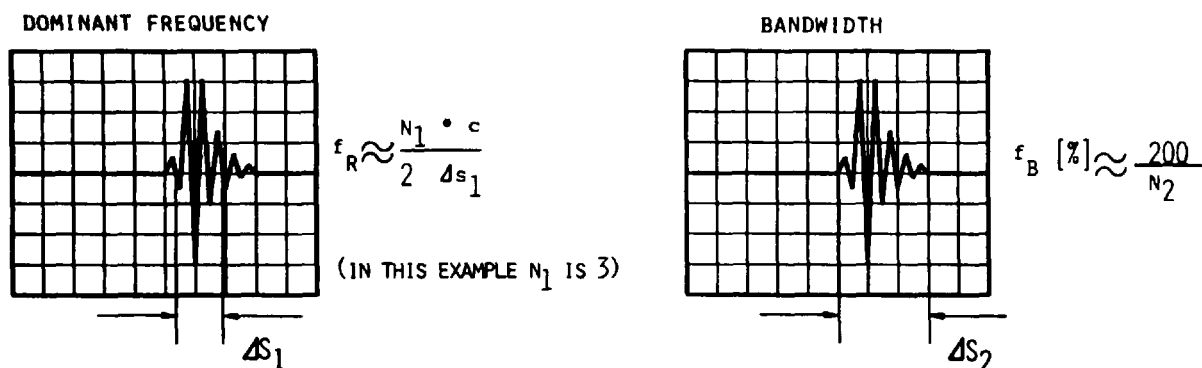


Figure 6.10 — Estimation of dominant frequency f_R and bandwidth f_B

ascertain whether a range of interest happens to coincide with a region of sufficient sensitivity.

6.5.6 Nominal Signal to Probe-Noise Ratio

A comparison of probes with regard to their noise level (i.e. amplitude of spurious probe indications) for ranges of interest may be made in the following way:

(1) Set the noise suppression on the flaw detector to zero.

(2) Place the probe on the characterization block and set the echo of the selected reflector to a predetermined height, for instance 20% FSH. Read attenuator.

(3) While keeping the probe on the block, adjust the attenuator until the maximum noise indication in the range of interest reaches the same height as the target echo level selected in (2) above. Read attenuator.

(4) The difference between the two attenuator readings gives the required value.

7. DEVELOPMENT OF AN EXAMINATION PROCEDURE

7.1 Outline of Activities

As pointed out previously, there is no general rule for developing procedures. The only efficient way is to select the best combination of probes, cable, and equipment by practical trials on representative test pieces containing artificial reflectors and natural defects, if this is possible.

Testing techniques can be developed using reference blocks. Reference blocks with reference reflectors are essential for longitudinal and transverse defects. The detail of the reflectors must be chosen with regard to the weld characteristics (see section 3.2) and to the requirements of the customer and/or inspection-authorities (see section 3.5). A possible choice is side drilled holes at the fusion line between the parent and weld metal or on the weld centerline. The suitability of the proposed examination procedure for that type of component must be demonstrated experimentally to obtain approval. As early as possible, a record-

ing level, a reporting level, and an evaluation level for indications and acceptance criteria should be agreed upon. There are many steps to be taken to establish an examination procedure. The flow chart on page 32 gives a typical example of the main steps required.

7.2 Preparation of Preliminary Procedure

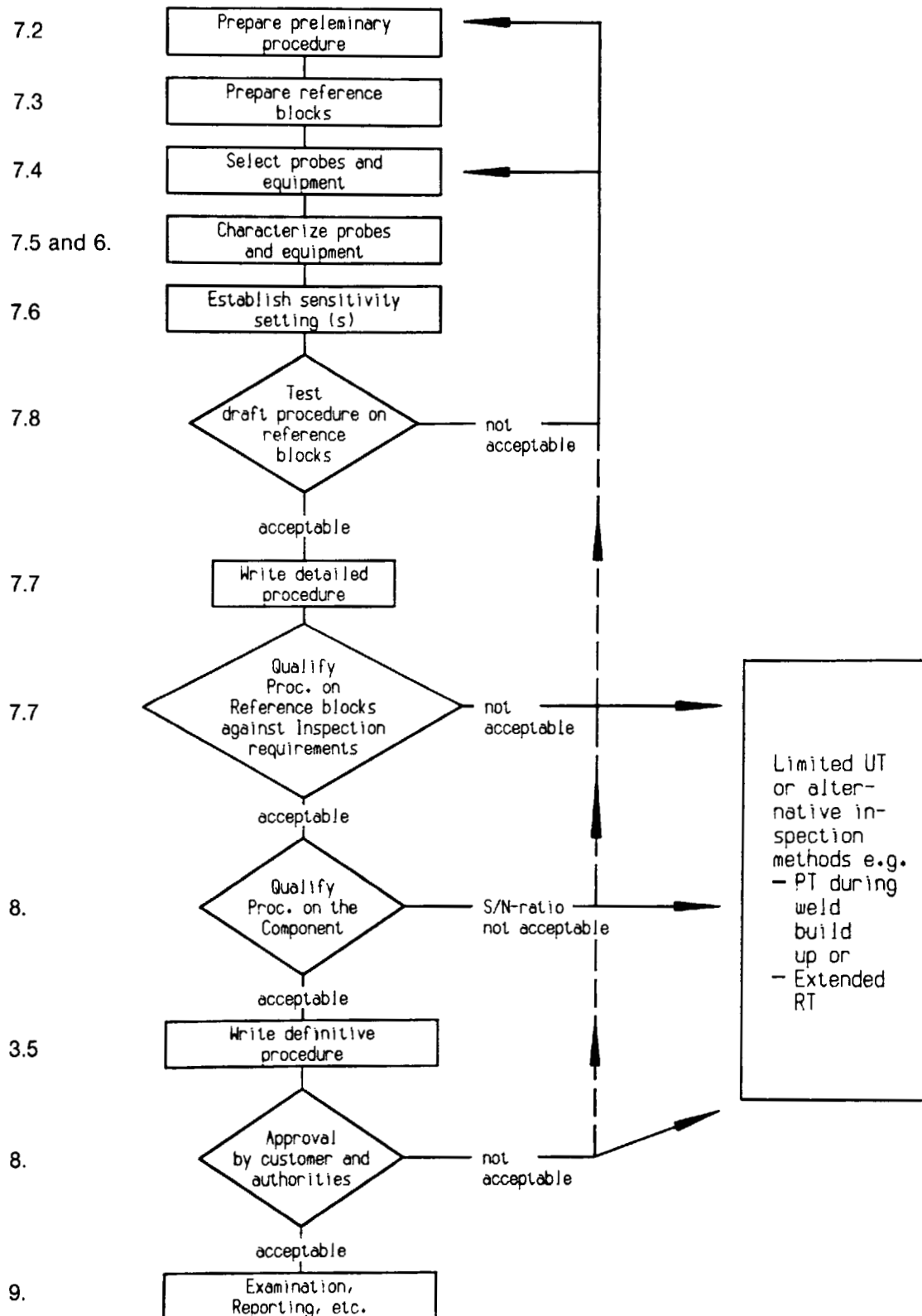
The procedure to be established can be strongly influenced by the requirements expressed by the customer and/or inspection authorities.

The first step is to consider the details of the weld to be examined. Using information on the weld geometry, welding process, heat treatment, and chemical composition as described in section 3.2, a preliminary choice can be made of the beam angles, wave modes and frequencies to be used to arrive at an effective examination.

In making this choice, consideration should also be given to the advice in section 3.5 and to the implications of the behavior described in section 4 on the technique, particularly on the use of shear and longitudinal waves (full skip/half skip)

Flow Chart Outline of Activities

Reference Chapter



and attenuation. Furthermore, one must also take into account the following:

- (a) The requirements for the examination
 - sizes and orientations of the defects of concern
 - coverage for longitudinal and for transverse defects

(In view of the relative difficulty of detection and the infrequent occurrence of transverse manufacturing defects in austenitic welds, the necessity for such an examination should only be considered in special cases. Supplementary reference blocks are then required.)

(b) Previous experience on similar welds if this is available.

(c) Experimental work on weld qualification specimens if these exist.

7.3 Preparation of Reference Block

7.3.1 General

Because of the special effects of austenitic weld metal on ultrasound, as described in section 4, it is necessary to produce a reference block in order to

- (a) develop an examination procedure
- (b) set a preliminary sensitivity level
- (c) assess the procedure
- (d) help to demonstrate the effectiveness of the preliminary examination procedure before a definitive procedure is written.

The material from which the block is fabricated should have the same composition as the material being examined, i.e. chemical analysis, product form, fabrication, procedure, heat treatment, cooling rate.

The weld in the reference block should be similar to the weld being examined and made using the same welding procedure. All variables should be respected, including those which may not be considered essential for the welding procedure qualification test pieces, weld preparation, weld position, heat input, cooling rate, etc.

The geometry and surface condition of the scanning and reverse side of the reference block should be considered, both for the base material and for the weld deposit. The reference block should generally contain known artificial reflectors, though in some cases, a weld containing real defects may be useful.

7.3.2 Artificial Reflectors

Before machining artificial reflectors as described below, the reference block should be examined by nondestructive methods such as pene-

trant testing, ultrasonic testing (straight beam), and radiographic testing to detect possible unwanted defects which would interfere with its use.

Side drilled holes (in combination with notches) are most commonly used as the artificial reflectors. Holes may be drilled at regular depth intervals, e.g. $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ t (where t is weld thickness) for single crystal probes. For twin crystal probes which are effective over a particular depth zone, the holes may be located at the zone center and the zone limits (6 dB). Alternatively, when a set of twin crystal probes is applied, a series of holes distributed over the thickness, say every 10 mm, may be used.

The holes may be drilled in the fusion zone of the weld to allow comparison of the sensitivities when the beam passes through the full width of the weld and through base material only. In some cases, this may not be practicable, and separate sets of holes at the weld center line and within the base material may be more suitable.

Flat bottom holes can also be used with the flat bottom perpendicular to either the examination surface or to the nominal beam direction. In the latter case, the holes represent flaw detection by reflection from facets and should be of small diameter.

Due to mode conversion (compression into shear) even in fine grain material, a smooth notch sometimes produces only a small reflection. Hence, when longitudinal waves are applied with 45° probes, the use of notches (corner effect) for sensitivity calibration is not advisable.

Also due to the mode-conversion effects, the response curve for a notch is a very irregular function of increasing depth as Figure 7.1 shows and generally gives a low amplitude signal for longitudinal waves.

Although weld defects similar in geometry to notches (e.g. incomplete penetration) can be expected to show the same effect, cracks in a weld may be detectable because of favorably oriented facets giving distinct echoes above the detection threshold.

In all cases, it is recommended that in addition to the artificial reflectors in the weld, a similar set of reflectors be machined in the adjacent plate or pipe material of the reference block, as shown in Figures 7.2, 7.3, and 7.4. This is important in order to quantify the effects of the weld structure and to give a reference reflector for the examination of the parent material near the heat-affected zone.

The reference block shown in Figure 7.2 is an example of one used for flat or large radius components where transverse defects in the weld

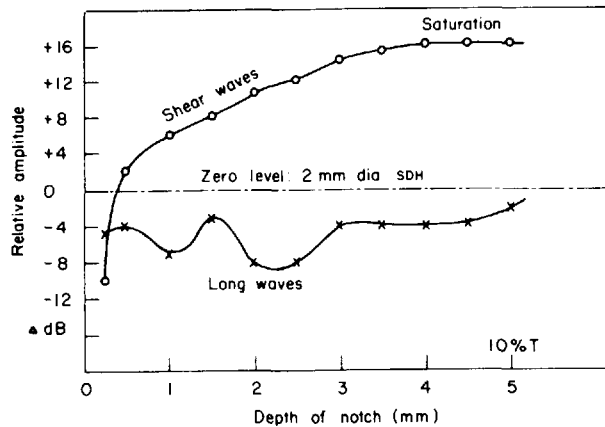
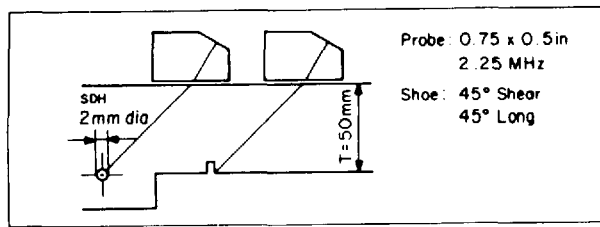


Figure 7.1 — Comparison of amplitudes of reflections from reference notches of different depths in a test block, for shear and longitudinal waves

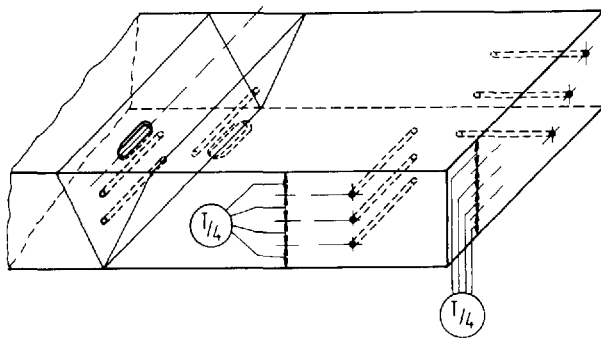


Figure 7.2 — Typical flat reference block with side drilled holes and notches at the weld center line plus additional side drilled holes in the base metal

need not be considered. The artificial defects are situated at the weld center line.

Figure 7.3 shows a detail of the above blocks adapted for a curvature and indicates suggestions for machining.

For thin components with a tight radius of curvature, Figure 7.4 suggests another arrangement of reference block and reflectors.

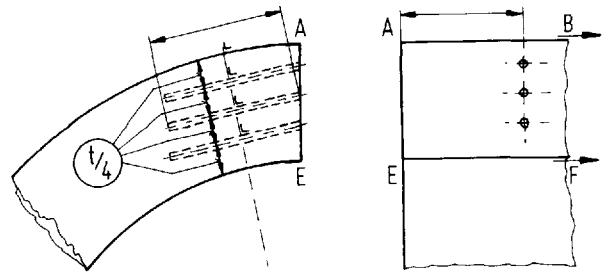


Figure 7.3 — Reference reflectors in curved reference block

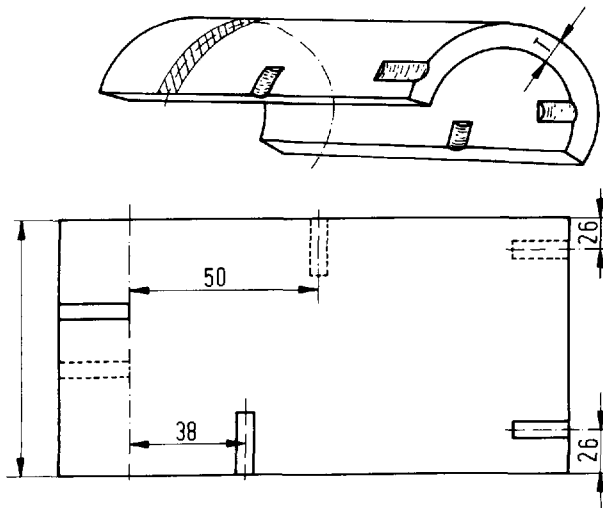


Figure 7.4 — Reference block for small thickness and strong curvature

Figure 7.5 shows a set of reference blocks including the reference reflector for both longitudinal and transverse defect examination.

7.4 Selection of Probes

The major variables to be considered when selecting a probe are

- (1) wave type
- (2) angle
- (3) frequency
- (4) type of probe
- (5) size and geometry of probe and component

7.4.1 Wave Type

The use of conventional shear wave probes should always be considered first. If the signal-to-noise ratio is insufficient for an effective inspection, special probes like refracted longitudinal angle beam probes, including the surface wave type, need to be used (see section 5.3.5).

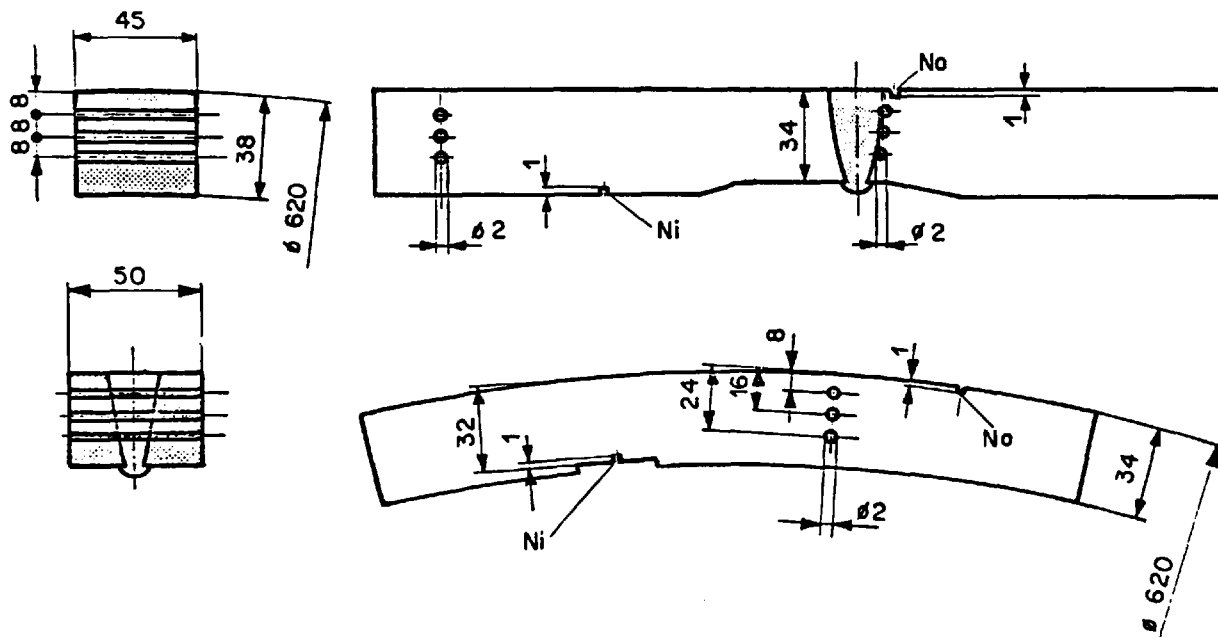


Figure 7.5 — Typical reference blocks for longitudinal and traverse defect examination of pipe welds

7.4.2 Probe Angle

In general, the probe angle should be selected to be suitable for the defect orientation expected. This means that if possible, the incident angle should be chosen to strike a defect perpendicularly for maximum echo amplitude.

For weld examination, it is therefore necessary to know the weld geometry prior to and after welding; particularly the details of the weld root if this is not machined or ground flush.

An example of how the entire volume of weld and fusion zone can be covered with at least two angles of incidence is shown in Figure 7.6.

However, this approach does not take into account the above consideration of preferred beam to flaw orientation. Nevertheless, in some cases it may only be necessary to examine inner and outer surfaces of the weld to demonstrate fitness-for-purpose from a fracture mechanics point of view. In this case, the use of an additional surface wave probe may be considered (see section 5.3.5). If optimized flaw detection over the whole thickness is required, then a range of probe angles between 60° and 70° should be included to detect lack of sidewall fusion.

In some cases, one would also consider using 45° angle probes to inspect the root area in relatively thick welds. However, if the weld penetration is not ground flush, geometrical or false echoes may be generated with a 45° probe, and for that reason, a probe with a larger angle (for

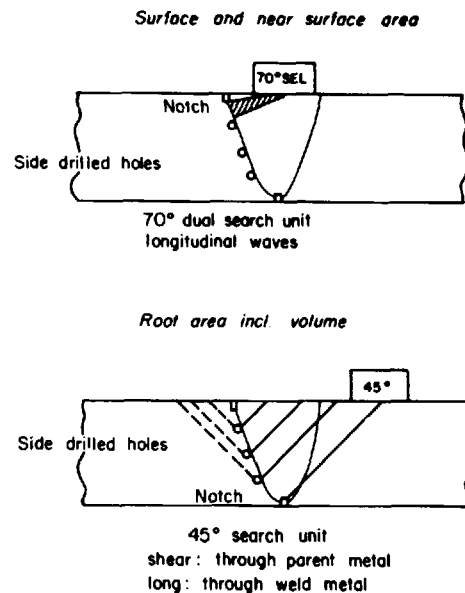


Figure 7.6 — Volumetric examination of austenitic welds

instance 60°) may be used to improve the identification of defect echoes. Therefore, the choice of probe angle largely depends on the weld preparation and weld surface condition. It should also be remembered that examination at more than half-skip distance is not very effective due to mode conversion effects at the backwall. To reach the lower part of the weld with large angle probes

requires a long sound path and this can also reduce the effectiveness of the examination.

This is influenced by the total attenuation and is highly material dependent.

If all these different effects are considered, it can generally be concluded that

- For thin welds and for the near surface area (at the scanning side) of thick welds, large angle probes provide the best results.
- For wide welds, the weld surface should be dressed smooth to enable the probe to be scanned across the weld.
- If the weld is narrow, then surface wave probes can still provide a good examination of the upper part of the weld even if the weld crown is not dressed.
- Surface wave probes are also well suited for detection of surface breaking defects and near surface defects in wide welds, provided the welds are dressed smooth since the effective range is restricted.

As the surface wave probes do not have a significant dead zone, their use can be considered under all circumstances where the required working depth does not extend beyond about 10 mm (see also section 5.3.5). For detection of deep lying defects in thick welds, steeper angles must be selected and a compromise found between optimum incidence on flaws and scanning distance. This may result in the selection of a range of angled probes.

Also, a tandem arrangement of longitudinal wave probes or a combination of a longitudinal and shear wave probe(s) should be considered as suggested in Figure 7.7.

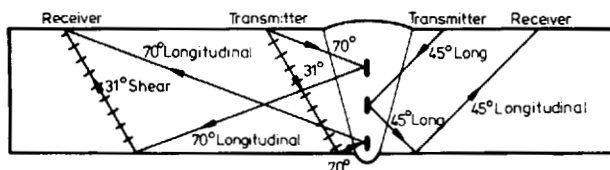


Figure 7.7 — Tandem inspection

As a result of the above approach, thick welds are often considered divided into thickness zones and examined with different probes whereby each zone is inspected by the most appropriate probe(s), as illustrated in Figure 5.7.

7.4.3 Frequency

The frequencies used are generally in the range of 1 to 5 MHz. The interaction between grain-size

and wave length dominates the selection of the best frequency to optimize signal-to-noise ratio (see section 5).

Ultimately, the frequency selected is a compromise between the resolution required and signal to noise ratio. This often leads to the use of probes with a large bandwidth. In special cases, a selectable bandwidth for the ultrasonic pulse might be appropriate.

Equipment bandwidth should be appropriate to probe type.

In practice, it is found that for welds over 25 mm thickness and cast material, frequencies of 2 and 1 MHz are predominantly used.

For welds below 25 mm thickness, the frequencies most commonly used are 4 and 2 MHz.

The side drilled holes in the probe characterization block provide a means for comparing different probes with respect to signal-to-noise ratios. The "signal" is the echo of a side-drilled hole, whereas the "noise" can be taken as the maximum level of material grain indications occurring at the same soundpath as the side-drilled hole.

Clearly the signal-to-noise ratio of a probe is not a constant, but dependent on soundpath. The signal-to-noise ratio found on the probe characterization block represents the "nominal" condition and can change considerably in the presence of a weld, and it should also be determined on the reference block.

7.4.4 Type

The main probes in use for austentic weld inspection are

- single crystal probes
- twin crystal probes with separate transmitter and receiver crystal (TR)

The selection is often arbitrary.

In order to decrease the number of probes and inspection zones, single crystal probes are favored because they do not show so pronounced a distance amplitude curve as for TR probes.

On the other hand, many single crystal probe designs show a long acoustic dead zone, which decreases the efficiency of surface and near surface examination.

Occasionally, single crystal point- or line-focusing probes are used, particularly where the more conventional probes described above fail. The use of such purpose built focussing probes is critical because they will behave only as calculated if all aspects of the examination such as surface roughness, geometry, acoustic material properties, etc., are kept within narrow tolerance limits.

The above remarks are valid for both immersion and contact techniques.

Immersion testing, in particular, requires a very stable and precise mechanical arrangement because the refractive index is roughly twice that for contact probes. As a result, small variations in angle of incidence cause considerable variations in the angle of refraction.

7.4.5 Size and Geometry of Probe and Component

Apart from the beam characteristics necessary for the examination, the probe should be of a size which allows manual examination with good acoustic coupling.

Thus, coupling involves an interaction between probe size, roughness, and the geometry of the component. If the probe dimension W fails to meet the requirement $R < W^2/4$, dimensions in mm, or the coupling gap exceeds 0.5 mm, the probe shoe should be adapted to the geometry of the component. R = radius of the curved surface under examination and W = probe dimension (length or width).

This can be done by machining or by applying grinding paper on the component and matching the probe shoe to the component curvature.

Care should be taken when operating from curved surfaces. The probe performance should be checked after modification of the probe shoe by trials on the appropriate reference blocks. The probe index point and/or nonimal angle may change if shoe adaption is not carried out properly (see 6.5.2).

7.5 Use of Reference Blocks to Establish DAC-Curves

In section 6.5.3.4, the determination of Distance Amplitude Correction (DAC) curves on the probe characterization block, Figure 6.4, is described. This DAC curve will differ from one made on a reference block due to the influence of the weld structure.

Figure 7.8 shows a typical example of a DAC-curve constructed with the help of side-drilled holes in the fusion line of the weld in a reference block. The indications from the various reflectors (taken with the probe on the left side) where the beam is passing through the weld, have been exposed successively on a photograph of the screen. The DAC-curve from the opposite direction, with the beam passing only through the fine-grained parent metal, is quite different.

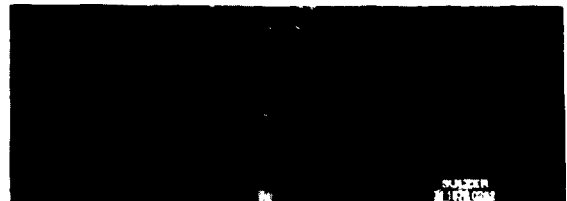
A comparison of the two DAC-curves gives the opportunity of assessing the apparent attenuation by the weld metal. Beam distortion can be investigated by comparing the expected and empirically

DAC - curve

DAC = Distance - Amplitude - Correction

Material :

X 20 CrMoV12 1 Inconel 10 CrMo 9 10



0 1 2 3



-x- -x- DAC through parent metal
-o- -o- DAC through weld metal

Probe : TRL 45° 4 MHz
f ~ 30 mm

Figure 7.8 — Typical DAC-curves of a transmitter receiver longitudinal (TRL) angle probe through anisotropic weld metal and isotropic parent material

established probe positions for maximum echo indications of the different holes. Other effects of the material on the ultrasound pulse from the probe under test can be investigated. The results will guide a decision that can be made as to whether the weld should be examined in different depth zones with different probes. An example of a DAC-curve for an examination for transverse defects is shown in Figure 7.9.

In this situation, different DAC-curves can again be obtained depending on the direction of incidence (whether from left or right). For actual examinations, the one with the lower response curve should be used for sensitivity setting.

It should be noted that with different reference blocks representing the same weld one will get slightly different DAC-curves. In practice, it is also permissible to connect the individual points with straight lines instead of constructing a best fitting curve as described in 6.5.3.1.

Probe RTD 45° TRL2 2(10x15)S, $n=16^\circ$, $f \sim 25$

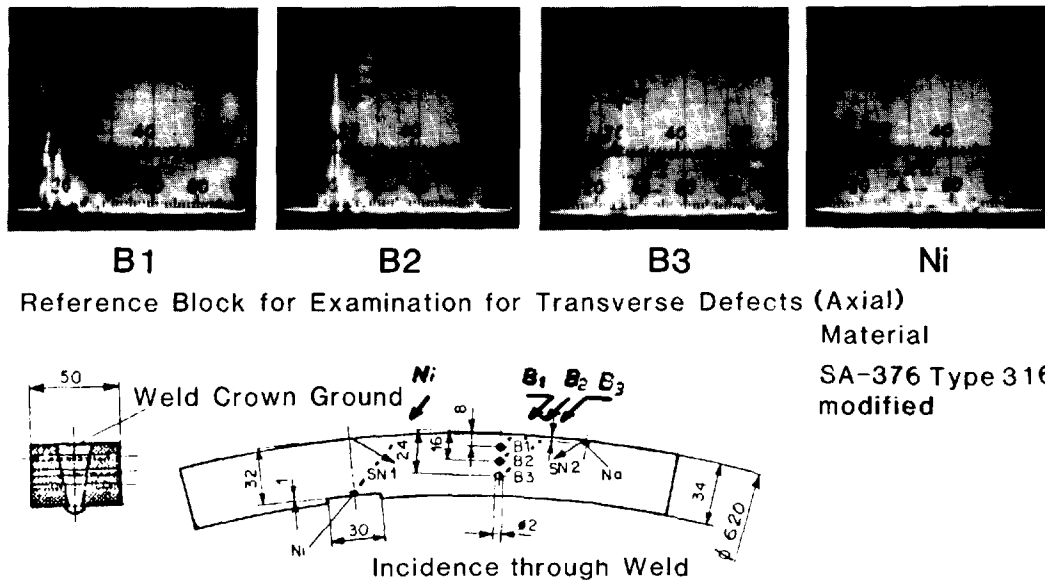


Figure 7.9 — Typical DAC-curve for transverse defect examination

7.6 Sensitivity Setting

7.6.1 Introduction

For sensitivity setting, the reference blocks and reference reflectors described in 7.3 are used.

There are several starting points to define this setting:

- (a) Previous experience
- (b) Experimental work on specimens with defects
- (c) Acceptance standards given in codes, standards or the specifications of clients or authorities

Obviously, the sensitivity settings should, where possible, be adequate to detect defects of sizes that might be of concern.

7.6.2 Setting Examination Sensitivity

After selecting the probes for a particular wall thickness and weld geometry (section 7.4) and determining their characteristics on the probe characterization block (section 6.5), the examination sensitivity should be set. This is done with the aid of the reference blocks shown in Figure 7.3 using side drilled holes at the fusion face or at the weld center line.

Where possible, welds should be examined from four sides to detect longitudinal defects (see also section 7.7.3), and in principle four different sensitivity scans will be required.

Where fusion face holes are used, two calibrations are to be performed per scanning surface:

(a) by establishing the echo height of the side drilled holes, with the beam passing through parent metal only

(b) by establishing their echo height with the beam passing through the weld metal

If center line holes are used, sensitivity setting from both sides is not required unless dissimilar metals are welded together (e.g. cast and rolled austenitic material).

Within the zone over which a particular probe will be used, the echoes from each of the available holes is maximized. The highest echo should then be set to approximately 80% screen height. Then, without altering the gain setting, the peaks of the echoes of the other holes are marked on the screen, and a DAC-curve is drawn to connect the points.

In practice, the shape of such a curve can differ considerably from that obtained on the probe characterization block; especially when the beam passes through the weld metal.

It may sometimes be found that a different probe combination and/or zone distribution are required from that previously chosen on the basis of measurements on the probe characterization blocks.

For this revised probe selection, a new set of DAC curves should be established on the reference block.

7.6.3 Recording Level

A recording level is often specified in terms of a percentage of the reference reflector-response or the distance amplitude correction (DAC)-curve.

In the absence of any experience and of any prescribed criteria, 50% of the DAC for reference reflectors indicated through the weld might be a good first approach. In certain cases, it may be necessary to go down to 25%. However, the recording level in the appropriate depth zone should be at least 6 dB higher than the maximum noise level in that depth zone.

7.6.4 Acceptance Criteria

Acceptance criteria can be related to the recording level. In general, quality assurance criteria are defined in terms of signal amplitude (relative to recording level), indication length, number of indications, and their position.

It is not the intention of this document to define acceptance criteria. Nevertheless, some ideas are given in section 9.

7.7 Preparation of Detailed Procedure

7.7.1 Written Procedure Requirements

Ultrasonic examination shall be performed in accordance with a written procedure, including as a minimum, the following information:

- (a) weld types and configurations to be examined, including thickness dimensions, materials and product form (casting, forging, plate, etc.)
- (b) scanning surface(s) and surface condition requirements
- (c) equipment list including each of the following items:
 - (1) make and model of pulse-echo ultrasonic flaw detection instrument
 - (2) search unit(s), including for each type, angle, frequency and transducer size
 - (3) size(s) and configuration(s) of welds and shoes
 - (4) couplant
 - (5) search unit cable type, length, and number of connectors
- (d) examination technique, including angles and modes of wave propagation in the material and directions, maximum speed, and extent of scanning
- (e) techniques of calibration and of establishing scanning sensitivity levels, including instrument controls to be used and acceptance standards for the calibrated conditions

- (f) design of
 - calibration block
 - probe characterization block
 - reference block(s)
- (g) data to be recorded and method of recording
- (h) techniques for data interpretation, plotting
- (i) personnel qualification requirements
- (j) approval of the procedure

7.7.2 General Examination Requirements

7.7.2.1 Examination coverage

The required examination volume shall be scanned with beam overlap. While scanning, the search unit shall be oscillated approximately $\pm 20^\circ$. If oscillation is not possible, the search unit shall be overlapped at least 50%.

The weld should be examined from both sides, and wherever possible, from both surfaces of the weld (Figure 7.10).

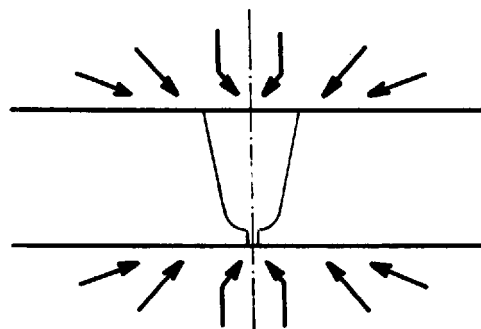


Figure 7.10 — Examination from both sides and surfaces of the weld

To detect all possible longitudinal defects, the weld should be scanned over its entire cross section and along the specified length, perpendicular to the weld (Figure 7.11).

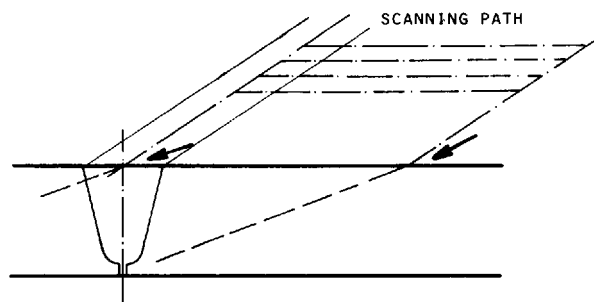


Figure 7.11 — Scanning path for examination in half skip for longitudinal defects

For the detection of transverse defects, the probe must be moved parallel to the weld and in both directions.

7.7.2.2 Rate of probe movement

The rate of probe movement shall not exceed 50 mm/sec, unless the examination capability has been verified at the higher scanning speed. (This reduced speed is because of the low signal-to-noise ratio compared to ferritic welds.)

7.7.2.3 Scanning sensitivity

Manual scanning shall be done at a minimum of twice (+ 6 dB) the primary reference level, if signal-to-noise allows.

7.8 Assessment of Procedure and Documentation

For the assessment of the procedure, the following characteristics and capabilities of specific probes in the reference block should be documented by trials on the test reflectors. The following variables are of interest:

- (a) DAC-curves
- (b) Signal-to-noise ratio of reference reflectors

(c) Amplitude difference between a reference reflector and an ideally oriented infinite reflector

For each probe, a DAC-curve through weld metal and through base metal should be documented with photographs of the screen, showing responses from appropriate reference reflectors. For judgement of signal-to-noise ratio, the most important case is that where the beam has passed through the weld metal. Examples of documentation are given in Figures 7.8 and 7.9.

In preparing the photographs described, a demonstration of flaw detector linearity should be included: e.g. an indication of 50% screen height should, after a reduction of 20 dB (calibrated attenuator), still be visible on the base line. If the indication is no longer visible, the apparatus should not be used for ultrasonic testing of austenitic welds.

Furthermore, it is worthwhile to document the results in relation to the recording level and the acceptance criteria if these are available.

The larger the difference that can be demonstrated between the recording threshold and the echo from an infinite reflector, the greater the confidence that can be placed on the results of the inspection.

8. INSPECTABILITY OF THE COMPONENT COMPARED TO THE REFERENCE BLOCK

8.1 Introduction

The aim of this section is to specify a series of checks to ensure that the components can be reliably examined, or examined to a standard at least as good as that for the reference block.

8.2 Surface Condition

Before the examination, requirements for surface finish will have been specified in terms of contact surface roughness and surface waviness.

8.3 Geometrical Conditions

Geometrical conditions will sometimes limit access compared to the reference block. In particular, mismatched slopes across the weld and other geometrical limitations must be noted. Furthermore, inner surface conditions (weld root) which are not in agreement with the reference block may limit the effectiveness of the examination. Wherever possible, counterbore and inner

surface conditions in pipes should not interfere with the examination.

8.4 Comparison of Attenuation Between Reference Block and Component

A comparison of ultrasound attenuation should be made between the reference block and the component using the adjacent base material on both sides of the weld. Care should be taken to avoid making measurements on the weld or above the counterbore run-out. Measurements should be made at regular intervals along the weld by straight beam probes of the same wave length and wave mode as applied during volumetric inspection of the weld.

Deviations must be compensated for. In the report on the reliability of the examination, large deviations should be reported. In some cases, it may be concluded that the component cannot be ultrasonically examined.

For the examination itself, the maximum deviation should be compensated for. Where shear wave inspection is required (e.g. for the weld fusion faces or for the root region) it will be valuable to make an attenuation comparison using two shear wave probes in a V-path arrangement.

8.5 Signal-to-Noise Ratio

For a reasonable ultrasonic examination, the noise level should be at least 6 dB below the recording level for the whole sound path.

8.6 Weld Repairs

After weld repairs, the condition of the weld might have changed, and this may require alternative procedures for examination of the repaired area.

9. REPORTING AND EVALUATION

9.1 Reporting

The results of an ultrasonic examination should be given in a report which includes all the necessary information required to

- make decisions on the acceptance of the defects revealed
- facilitate repairs of nonacceptable defects
- permit the examination to be repeated by the same or another operator

As a minimum, the following data shall be reported:

- (a) Date of examination.
- (b) Names and levels of examination personnel.
- (c) Examination procedure (including revision).
- (d) Applicable calibration sheet identification (including reference to the procedure qualification record).
- (e) Identification and location of the weld(s) examined (including, if necessary, marked up drawings or sketches). The report shall include observations of any geometrical feature which have limited the access compared to the reference block or in other ways reduced the effectiveness of the examination.
- (f) Surface from which examination is conducted, scanning direction, orientation of the probe(s). Nonconformity of surface condition with regard to specification should be included.
- (g) Identification of the apparatus, cables (including length) and probe(s) (brand name, type, serial number, fabrication or identification sheet of the probe).
- (h) If applicable, a record of reportable indication(s) including:
 - attenuation correction if required
 - peak amplitude (in dB or percent of DAC) range to reflector, search unit position, and sound beam path direction
 - defect length or locations of the reflector end points where the amplitude crosses the recording level or -6 dB points

- plot of reflector location on a cross section sketch showing OD profile and ID geometry (such as root and counterbore) in the case of pipe welds
- the location of any subsidiary peaks in the amplitude response as the probe is moved towards or away from the reflector (if they are pronounced)

Note: The beam angle shall be measured on an artificial reflector in the reference block at a range close to that distance. This angle shall be used to plot the position of the indication.

9.2 Evaluation

It is not the purpose of this handbook to define acceptance criteria for welds. (Acceptance criteria shall be established between authorities, purchaser, and the manufacturer.) Nevertheless, it is recommended that important facts such as signal-to-noise ratio, etc. be taken into account before defining acceptance criteria.

In general, the acceptance criteria should be specified in terms of signal amplitude (relative to recording level), indication length, number of indications, and position within the weld, which are the usual quality assurance criteria. False indications or geometrical indications may occur. It may help a final judgement of the acceptability of questionable indications to use a variety of probes of different angles together with accurate plotting of the defect location.

9.3 Additional Investigations

In general, defect sizing and characterization cannot be reliable for indications from within austenitic weld metal. However, the assessment routine detailed below is helpful since indications which plot out as having significant through wall extent are unlikely to be associated with insignificant defects. (It must be remembered that the reverse is not necessarily true. That is, it is possible for a large defect to be represented by a small indication.)

For each probe used, indications detected at the specified testing sensitivity shall be examined

by probe movement in two mutually perpendicular directions. Angle beam scans shall be made in directions towards and away from the reflector, and at right angles to these directions. The response of each defect shall be noted, and the defect shall be classified in terms of Patterns 1 to 3, as detailed below.

Pattern 1

A single sharp signal rising smoothly in height to a maximum then falling smoothly to zero (see Figure 9.1).

Pattern 2

A single sharp signal rising smoothly in height to a maximum which is held with or without minor

amplitude fluctuations with probe movement and falling smoothly to zero (see Figure 9.2).

Pattern 3

A signal, or group of signals, which may be fully or partially resolved, fluctuating in height as it/they rise to and fall from one or more principal maxima (see Figure 9.3).

For Pattern 1 behavior, it is not possible to estimate the defect size because the width of the beam in austenitic weld metal cannot be accurately known (see section 4.2.1.3). Such indications are often associated with volumetric defects, but it is recommended that indications of this type be assessed by other angles of probe to confirm a volumetric character.

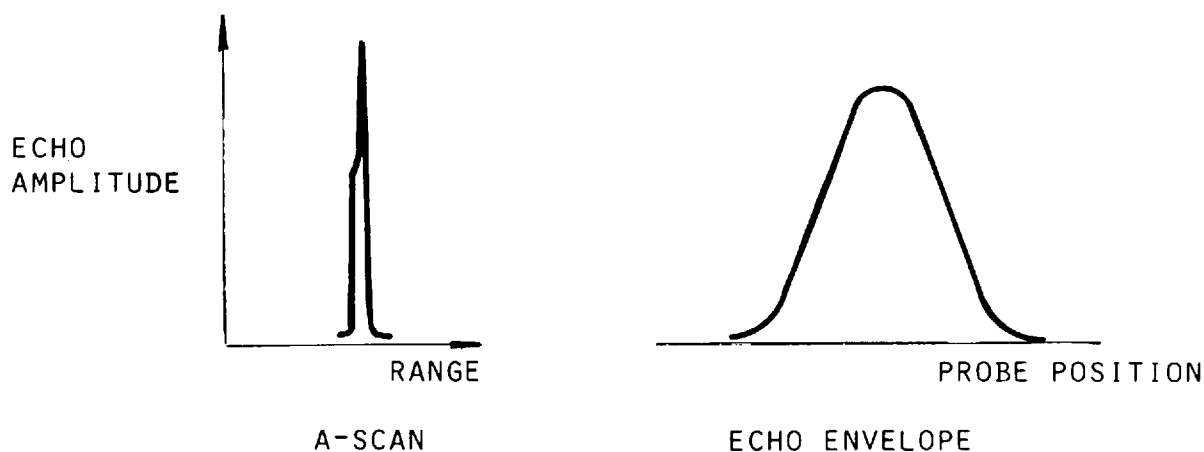


Figure 9.1 — Pattern 1 for echo envelope evaluation

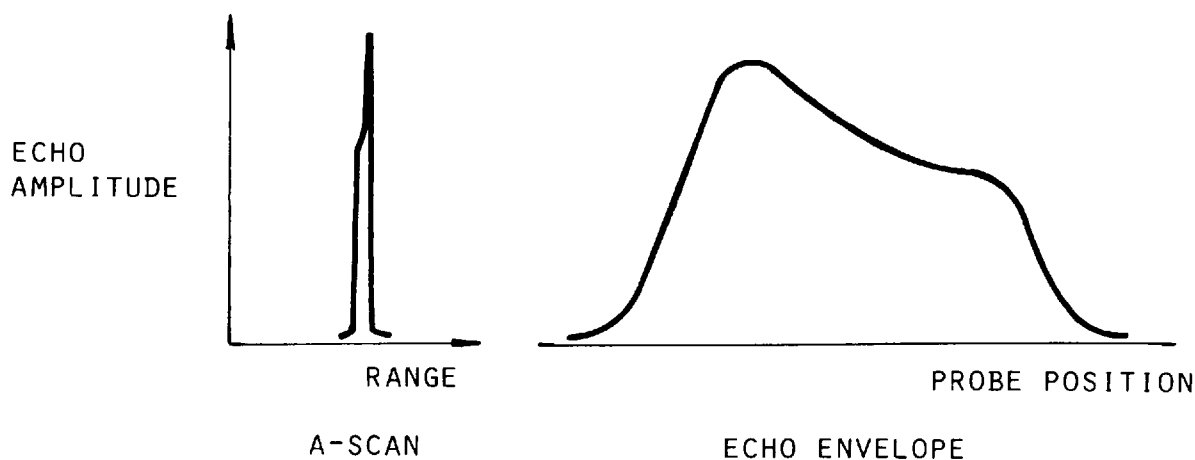


Figure 9.2 — Pattern 2 for echo envelope evaluation

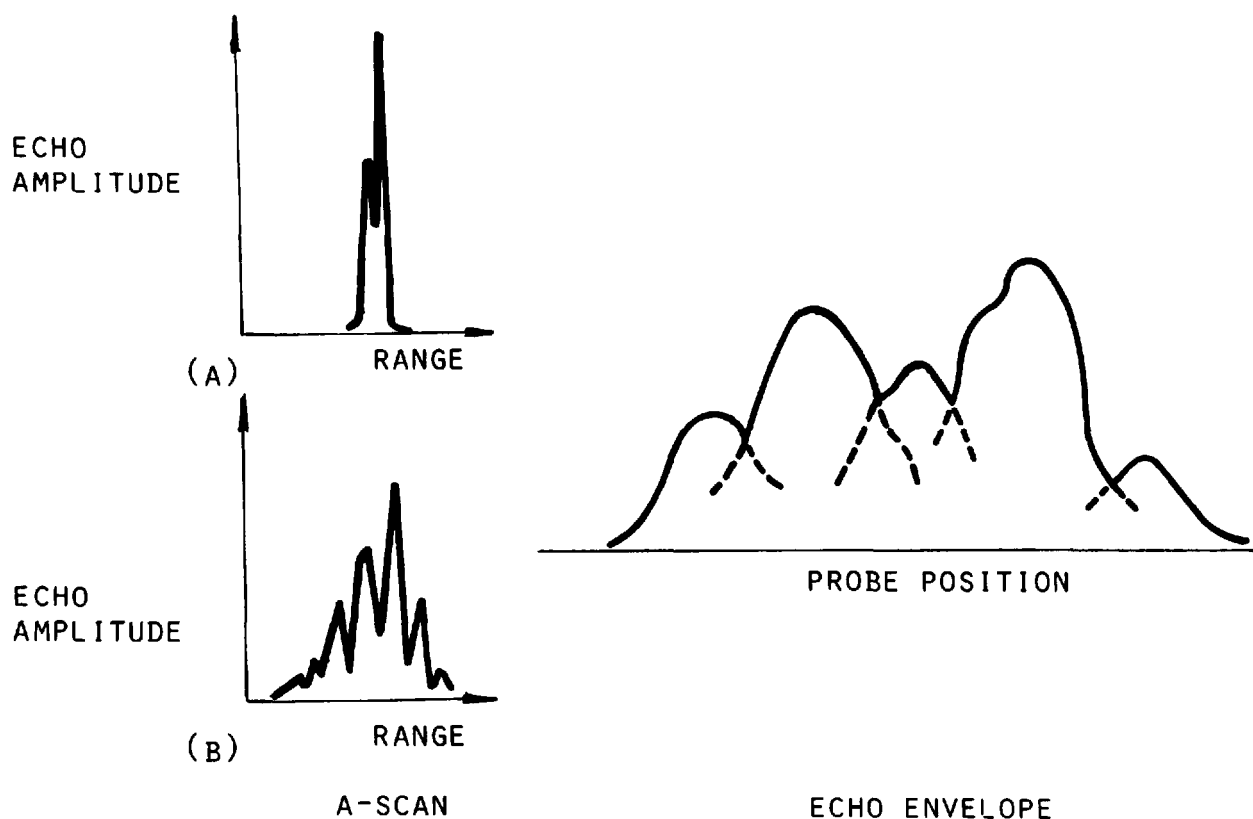


Figure 9.3 — Pattern 3 for echo envelope evaluation

Pattern 2 and Pattern 3 behavior are likely to indicate the presence of a planar defect. A rough estimate of defect height can be obtained by plotting the positions of the last maxima in the echo response (for Pattern 2 this involves plotting the positions corresponding to the extremes of the "plateau" in the echo response).

These techniques should only be applied when the operator has a clear understanding of the principles involved.

In some circumstances, specialized techniques may be of value, but these are outside the scope of this document.

10. GENERAL RECOMMENDATIONS AND COMMENTS

(1) Ultrasonic examination of austenitic and transition welds remains difficult, but inspections are possible in many cases. However, all parties must be aware that sensitivity is invariably inferior to that achievable on a ferritic weld of comparable thickness.

(2) In view of the reduced capabilities, fracture mechanics studies should be initiated at an early stage to provide estimates of tolerable defect

sizes and to identify regions for ultrasonic coverage. Then, ultrasonic procedures can be devised to take account of fitness for purpose criteria, rather than attempt to detect small defects which will be without structural significance. It should be remembered that even the detection of large defects may require high sensitivity, together with an adequate number of beam angles.

(3) Inspection capability varies significantly with weld process and procedure.

(4) Designers should be aware of the major factors, including weld process and geometry, that will influence inspectability.

(5) Operator qualifications and specific training on austenitic welds are especially important.

(6) Proper attention to combined equipment characteristics and probes can be of significant benefit in austenitic weld inspection.

(7) A knowledge of ultrasound propagation behavior is important, and the possibility of false indications should be considered.

(8) To develop ultrasonic procedures requires the manufacture of fully representative weld specimens which may need to reproduce the types of

defect of concern. Experimental work is necessary to qualify procedures. These activities make austenitic weld inspection more expensive than ferritic weld inspection, and early planning is required.

(9) Further development of the techniques is still required and is continuing. It is important to keep up to date with developments in this area.

(10) While the techniques described in this handbook are not perfect, they provide a valuable solution in many situations.