BRITISH STANDARD

BS 3923-1:
1986

Ultrasonic examination of welds —

Part 1: Methods for manual examination of fusion welds in ferritic steels

UDC 620.179.16:621.791.053:669.15-194.57

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Welding Standards Committee (WEE/-) to Technical Committee WEE/34 upon which the following bodies were represented:

Associated Offices Technical Committee
British Coal
British Constructional Steelwork Association Ltd
British Institute of Non-destructive Testing
British Railways Board
British Shipbuilders
Electricity Supply Industry in England and Wales
Energy Industries Council
Engineering Equipment and Materials Users' Association
GAMBICA (BEAMA Ltd.)
Health and Safety Executive
Institute of Physics
Institution of Production Engineers
Lloyds Register of Shipping
Ministry of Defence
National Radiological and Protection Board
Power Generation Association (BEAMA Ltd.)
Process Plant Association
Society of British Aerospace Companies Limited
Society of Motor Manufacturers and Traders Limited
United Kingdom Atomic Energy Authority
Water-tube Boilermakers' Association
Welding Institute

This British Standard, having been prepared under the direction of the Welding Standards Committee, was published under the authority of the Board of BSI and comes into effect on 28 November 1986

First published November 1965
First revision October 1968
Second revision December 1978
Third revision November 1986

The following BSI references relate to the work on this standard:
Committee reference WEE/34
Draft for comment 85/75382 DC

ISBN 0 580 15496 3

Amendments issued since publication

Amd. No.	Date of issue	Comments

Contents

Foreword

This Part of BS 3923 has been prepared under the direction of the Welding Standards Committee and supersedes BS 3923-1:1978 and BS 3923-3:1972, which are withdrawn.

This Part of BS 3923 forms part of a series dealing with methods for the non-destructive testing of welds. It does not state when this particular type of testing should be employed nor does it give standards of acceptance, as both of these aspects should either be covered in the appropriate application standard or be agreed between the contracting parties.

This Part of BS 3923 is not associated with any particular type of fabrication but has been prepared to cover a wide range of products and as such lays down the broad principles of ultrasonic examination. It may be used to develop test specifications and techniques but does not in itself constitute a test specification.

This Part of BS 3923 differs from the previous edition of BS 3923-1 in the inclusion of additional, more detailed requirements for the examination of the most common types of welded joint. These requirements are sub-divided into three Examination Levels, applicable to welds of different required levels of integrity, with specific details covering test sensitivity, test coverage and surface finish. A fourth Examination Level is listed, the details of which should be in accordance with the general requirements of this Part of BS 3923 and agreed by the contracting parties. In addition, methods for evaluating and sizing imperfections are presented in a more detailed and formalized manner than before. In order to apply ultrasonic inspection more efficiently, an appendix giving recommendations on the parameters to be defined when setting an acceptance standard for quality control purposes has been also added.

It is emphasized that a satisfactory technique can only be determined after taking into account all the relevant factors regarding the equipment to be used and the characteristics of the weld to be examined.

The use of any method should always be considered in relation to inspection and testing as a whole. The full benefits of this or any other method can only be obtained by considering the results in conjunction with those likely to be obtained from any other method.

Purchasers of ultrasonic examination services to this standard are advised to specify in their purchasing contract that the supplier operates a quality system in compliance with BS 5750 to assure themselves that examinations claimed to comply with BS 3923-1 consistently achieve the required level of performance.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 86, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

blank

1 Scope

This Part of BS 3923 deals with methods of manual ultrasonic examination of fusion welded joints in all forms of ferritic steels having a thickness range of 6 mm to 150 mm and, when in circular form, a minimum outside diameter of 100 mm.

NOTE 1 Some methods of ultrasonic examination which are not necessarily specific to welds have been included in appendices for completeness.

NOTE 2 The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 3923 the following definitions apply. Other definitions are given in BS 499-1 and BS 3683-4.

2.1
set-through connection

a form of welded joint between two connecting cylinders in which the smaller diameter cylinder penetrates the full wall thickness of the larger

2.2
set-on connection

a form of welded joint between two connecting cylinders in which the smaller diameter cylinder sits on the surface of the larger without penetrating its thickness

2.3
node joint

a form of welded joint between two non-connecting cylinders set either obliquely or at right angles, in which the smaller diameter cylinder sits on the surface of the larger without penetrating its thickness

2.4
branch weld

a form of welded joint between two connecting cylinders in which the diameter of the smaller cylinder is equal to or greater than half the diameter of the larger

2.5
nozzle weld

a form of welded joint between two connecting cylinders in which the diameter of the smaller cylinder is less than half the diameter of the larger

2.6
stub weld

a form of nozzle weld in which the thickness of the smaller cylinder is 12.5 mm or less, and the inside diameter is 120 mm or less

2.7
sides of weld (or joint)

the two sides of a weld are the regions occupied by the two components which are joined by the weld

2.8
surface of weld (or joint)

the whole surface of the welded joint, e.g. in a pipe butt weld the surfaces are the outer surface of the pipe and the inner (bore) surface

2.9
in-line butt joint

a connection between the edges or ends of two parts that are substantially parallel to each other

2.10
non-linear joint

any form of connection between two parts that are not substantially parallel to each other

2.11
evaluation level

a signal height in relation to the distance/amplitude correction (DAC) level, below which any signal can be disregarded and above which it is further investigated

2.12
echodynamic pattern

the form of change in signal height and shape on traversing the ultrasonic beam in two mutually perpendicular directions across an imperfection

2.13
recording level

a signal height in relation to the DAC curve above which the signal is recorded

2.14
weld body (weld metal)

all metal melted during the making of a weld and retained in the weld

NOTE See term 10 018 and Figure 4 of BS 499-1:1983.

3 Items for agreement

3.1 General requirements

Unless otherwise agreed between the contracting parties, actions shall be either:

a) as given in the application standard; or

b) as listed in Table 1.

NOTE Where action is agreed between the contracting parties, items 1 to 4 in Table 1 should be agreed during the contract negotiations and items 5 to 7 in Table 1 prior to the commencement of testing.

3.2 Specific requirements for Examination Level 4

If testing is to be carried out to Examination Level 4, the following additional items to those listed in **3.1** shall be agreed by the contracting parties:

a) method of setting test sensitivity and evaluation/recording levels;

b) test sensitivity and evaluation/recording levels to be applied;

c) details of the scans to be applied and the probes to be used;

d) surface condition category of the weld (see **8.2**).

NOTE Where agreement has not been sought on any of the above items, the provisions of Examination Level 2 should be applied.

3.3 Specific requirements for all Examination Levels

In addition to the requirements of **3.1** and **3.2**, the following items, which are specified in the clauses referred to, to be agreed between the contracting parties, shall be documented. Both the definitive requirements specified throughout this Part of BS 3923 and the following documented items shall be satisfied before a claim of compliance with the standard can be made and verified:

a) where the certification of personnel is not in accordance with a nationally accredited certification scheme, the qualifications of personnel carrying out the examination (see clause **4**);

b) additional, omitted or modified scans of the weld (see clause **6** and **9.1**);

c) the weld surface profile category to be applied to the test procedure (see **8.2**);

d) the manufacturing stage at which testing is to be carried out (see **9.1**);

e) if the optional scans for transverse defects are to be carried out (see Table 6);

f) if sizing of imperfections is to be carried out at a range exceeding the half-skip position (see **17.5**).

4 Personnel

The successful application of manual ultrasonic testing depends on the knowledge and experience of the personnel responsible for producing the test procedures, and the technical competence and ability of the ultrasonic practitioner to carry out the procedural requirements and interpret results.

Unless otherwise agreed between the contracting parties [see **3.3** a)] the appropriate level and category of certification of personnel shall be in terms of those obtained from an agreed nationally accredited certification scheme (such as the Personnel Certification in Non-destructive Testing (PCN) scheme).

NOTE If the PCN scheme is selected then:

a) personnel responsible for producing procedures to Examination Level 4 (see clause **6**) or procedures differing from this Part of BS 3923 should be either:

1) PCN level III, or

2) in a responsible position with technical training and experience to be considered senior to PCN level II;

b) personnel conducting and interpreting the tests carried out in accordance with this Part of BS 3923 should be PCN level II assisted, if appropriate, by PCN level I personnel.

5 Equipment

5.1 Flaw detector and probes

5.1.1 *Presentation.* A-scan presentation shall be used. The trace shall be well defined and associated with permanent graticule scale markings covering both range and amplitude.

5.1.2 *Test frequency.* The equipment shall be capable of working at a test frequency within the range 1 MHz to 6 MHz.

5.1.3 *Time base linearity.* The linearity of the time base shall be within 2 % over the whole range, i.e. the echoes do not deviate by more than 2 % of the time base range from their true position.

5.1.4 ***Amplifier linearity***

5.1.4.1 *Linear.* The amplifier shall be linear to an accuracy of ± 1 dB at any point within the range 20 % to 80 % full screen height. The amplifier shall also have a dynamic range up to 80 % full screen height of not less than 24 dB.

5.1.4.2 *Logarithmic.* The amplifier shall give equally spaced decibel steps throughout the graticule height.

5.1.5 *Calibrated gain control.* The gain shall be adjustable via a calibrated gain control having steps of not more than 2 dB and an accuracy of not less than 1 dB over any 20 dB range.

5.1.6 *Probes.* Any internal "noise" from probes shall not interfere with the interpretation of results at the working sensitivity.

NOTE 1 When a probe is to be used with a flaw detector from another manufacturer, inductive matching may be required to optimize performance.

NOTE 2 Guidance on probe selection is given in Appendix C, and guidance on the determination of probe characteristics is given in BS 4331-3.

Table 1 — Items for agreement or action

Item	Action
1 Acceptance standard (see note)	Agreement essential (unless an acceptance standard is included in the relevant application standard, when this shall be applied) When fracture mechanics or engineering critical assessment is to be applied, Examination Level 1 shall be used and the result reported
2 Examination Level (see clause **6**)	Unless an Examination Level is included in the relevant application standard apply Examination Level 2
3 Manufacturing stage at which examination is to be made	After final heat treatment wherever possible. If the design of the joint makes this not possible, a full ultrasonic examination shall be carried out as late as possible in the manufacturing sequence, and supplemented by whatever examination is possible after final heat treatment
4 Level of operator approval	Appropriate category of nationally accredited certification scheme NOTE Guidance is given in the note to clause **4**.
5 Positional reference data	In accordance with supplier's/manufacturer's normal practice
6 Use of special test blocks	In accordance with supplier's/manufacturer's normal practice
7 Detailed test procedures (see **7.2**)	To be prepared by supplier/manufacturer in accordance with the specific requirements and advisory sections of this Part of BS 3923
8 Reporting	Additional report content
NOTE Wherever possible the acceptance criteria should be written in a form that can be directly related to ultrasonically measurable parameters. Advice on the preparation of acceptance standards for quality control purposes is contained in Appendix A.	

5.1.7 *Resolution.* The resolution of the combined electronic apparatus and probe shall be measured on the A7 test block shown in BS 2704 by the method described in BS 4331-3.

This test block is suitable for measuring the resolution of compression wave probes and shear wave probes.

Compression wave probes in the range 4 MHz to 6 MHz shall clearly resolve the 3 mm step and the 4 mm step; lower frequency probes (2 MHz to 2.5 MHz) shall resolve the 5 mm step.

Shear wave probes in the range 4 MHz to 6 MHz shall clearly resolve the 2 mm step and the 3 mm step; lower frequency probes (2 MHz to 2.5 MHz) shall resolve the 4 mm step and the 5 mm step.

5.2 Reference and calibration blocks

Calibration blocks for routine calibration and the determination of specific probe characteristics shall be as specified in BS 2704 and BS 4331-3 respectively.

Reference standards to be used for setting sensitivity by means of the DAC method shall be as described in **K.1**.

5.3 Coupling

Coupling shall be obtained by either contact or gap scanning, using a liquid, gel or paste medium suitable for the application and compatible with the material under test.

The maximum surface temperature when using conventional probes and couplants shall not exceed 50 °C.

5.4 Calibration

The method of calibration of the flaw detector and probes shall be in accordance with BS 4331-1 and BS 4331-3.

The probes and test block(s) used during calibration shall be maintained at a temperature within ± 15 °C of that of the joint(s) to be examined.

NOTE With increasing temperature there is a marked increase in attenuation and decrease in ultrasonic velocity in the material from which the angle probe wedges are manufactured. This leads to a reduction in probe sensitivity and an increase in beam angle.

6 Examination Level

The purpose of these specific examination requirements is to enable a consistent level of examination, to a defined standard, to be achieved by different contractors on the main types of welded joint. Since the application for which the joints are to be employed will vary, three different levels of examination have been defined wherever applicable.

The requirements of Examination Levels 1, 2 and 3 for different categories of welds are contained in Table 3 to Table 28 which detail the surface condition category, the number and extent of the scans, the type of probe (i.e. normal or angle beam), and the surfaces from which scanning shall be carried out. These tables shall be used in conjunction with clauses **10** and **17** which give the required scanning sensitivity and recording/investigation levels, and the parameters to be measured for the principal types of imperfection.

The tables give the requirements for welds having unrestricted access for scanning (see Appendix D). Where the strict requirements of the tables cannot be met due to inherent features of the joint or associated components, the scanning requirements shall be modified to give at least an equal level of coverage. If this is not obtainable, the particular Examination Level cannot be met.

The Examination Levels have been written with the following applications in mind, although their use may be specified, as required.

a) **Examination Level 1:** High integrity examination where the highest practical level of inspection is required.

b) **Examination Level 2:** Medium integrity examination where a rigorous level of examination for quality control purposes is required whilst ensuring that, within the normal limits of ultrasonic examination, all unacceptable likely imperfections are detected and sized.

This level has been sub-divided into Examination Level 2A for fully dressed welds and Examination Level 2B for welds normally examined in the undressed condition.

c) **Examination Level 3:** An economical level of examination for quality and process control. This is not recommended for "fitness for purpose" applications.

NOTE It should be noted that where, in the interests of economy a more limited inspection to Examination Level 3 is chosen there may be reduced probability of detecting and correctly rejecting all structurally significant imperfections.

d) **Examination Level 4:** The requirements of this Examination Level are not defined, but shall be agreed by the contracting parties in order to cover those applications not covered by Examination Levels 1, 2 or 3.

The details contained in Table 3 to Table 28 represent the basic requirements for Examination Levels 1, 2 and 3.

In addition, except where specifically overruled by the requirements of the tables, the general requirements of clause **9** shall be met.

Specific beam angles and probe frequencies are not listed in the tables as these will depend on the weld profile, type of welding and weld thickness. In general, at least one beam angle shall be chosen to be as near normal to the weld fusion face(s) as practicable. Further details on the choice of probes are given in Appendix C.

NOTE Where considered necessary, additional scans may be specified by agreement between the contracting parties. Such an occasion may arise for example where there is a risk of chevron cracking. Similarly, certain scans may be omitted or substituted, if agreed between the contracting parties, where limited access or other features of the joint prevent one or more of the listed scans from being carried out [see **3.3** b)]. The access requirements for unrestricted examination of the welds are contained in Table 32.

In the event of a non-standard condition being encountered at the time of testing, details of any modification to the requirements listed in the tables shall be included in the operator's report.

Where Examination Level 4 is to be applied, the items to be agreed by the contracting parties are listed in clause **3**. In this case, as for Examination Levels 1, 2 and 3, the general requirements of this Part of BS 3923 shall be met.

7 Requirements to be met prior to scanning

7.1 Provision of datum points

In order to enable the position of possible imperfections to be permanently and accurately identified within the weld cross section and along its length, either datum points shall be marked on the component or details of an agreed method of referencing based on inherent features of the joint or associated components shall be provided for the operator.

Wherever considered applicable by the purchaser, extra reference datum points relative to the weld root shall be marked on the surface of the material prior to the commencement of welding. Where the nature of the material and its service conditions render scribing undesirable, other suitable means of marking shall be used (see also Appendix E).

The weld shall be clearly identified and cross-referenced to the engineering drawing.

7.2 Detailed test procedure

A test procedure shall be prepared for the particular weld or class of welds to be examined.

The following information and instructions shall either be included in the test procedure or be given to the operator through other relevant documentation:

a) Examination Level;

b) type(s) of ferritic parent material and form (i.e. cast, forged or rolled, etc.);

c) manufacturing stage at which examination is to be made, and post-weld heat treatment if any;

d) joint preparation and dimensions;

e) welding procedure;

f) surface condition category (see **8.2**);

g) couplant;

h) type of ultrasonic flaw detector;

i) details of scans and probes to be employed;

j) method of sensitivity setting (see clause **10**), and scanning and evaluation levels to be applied;

k) design and use of special test blocks, if any;

l) method to be used for referencing positions of imperfections, if found;

m) reporting requirements;

n) acceptance standard;

o) operator qualification.

7.3 Additional information

Immediately prior to examination, the operator shall be informed of any local deviations from joint preparation drawn in the welding procedure, and shall be given details of any repairs already made.

7.4 Preparation of cross-sectional drawings

In the event that it is not otherwise provided, the operator shall prepare a cross-sectional drawing of the joint showing the fusion faces as designed, the actual surface contour, and the weld and parent metal thicknesses after checking ultrasonically.

A pin profile gauge shall be used to record surface contour of welds where testing conditions are changing continuously due to changing geometry. Where the joint geometry is variable around the circumference of the joint, e.g. branch and nozzle joints, at least two cross-sectional drawings shall be made, namely longitudinal and transverse with respect to the axis of the larger diameter component.

NOTE Cross-sectional drawings at intermediate positions may also be necessary for accurate location of imperfections.

8 Surface condition, counterboring and access for scanning

8.1 Surface finish

The level of testing that can be achieved is dependent on the surface condition of the weld and adjacent parent material.

All scanning surfaces shall be free from loose scale and weld spatter and shall be of sufficiently uniform contour and smoothness that satisfactory acoustic coupling can be maintained. The surface finish (i.e. fine-scale roughness) of all surfaces from which scanning is carried out shall be not rougher than 6.3 µm R_a. (See BS 1134.)

NOTE An appropriate surface comparator should be used for estimating the surface finish.

8.2 Weld surface category

The requirements for the weld surface finish categories SP1 to SP6 specified in Table 3 to Table 28, shall be as given in Appendix B, which also includes details of the test coverage and standard of testing that can be achieved with each category.

NOTE The weld surface category necessary to meet the requirements of Examination Levels 1, 2 and 3 is given in clauses **11** to **16** which deal with specific examination requirements.

Where unspecified, the weld surface category shall be agreed between the contracting parties and included in any detailed testing procedure [see **3.3** c)].

8.3 Counterboring and access for scanning

Advice on the limitations imposed by counterboring, and the requirements with regard to both counterboring and access for scanning necessary for unrestricted examination of the weld are contained in Appendix D.

9 Test coverage: general requirements

9.1 General

A complete weld examination shall be sub-divided into the following inspection operations:

a) examination of the parent materials (see **9.2**);

b) location of the weld root where necessary by any one of the methods given in Appendix E;

c) examination of the weld root (where applicable) (see **9.3**);

d) weld scan with normal probes (where specified) (see **9.4**);

e) weld scan for longitudinal imperfections (see **9.5**);

f) weld scan for transverse imperfections (where specified) (see **9.6**);

g) other special scans, e.g. for chevron cracking (to be agreed by the contracting parties) (see **3.3** b) and **9.7**).

NOTE Where the existence of lamellar tearing is suspected, additional scans using an appropriate angle beam probe having the best angle of incidence, taking into account the orientation of the imperfections, may need to be carried out.

This clause details the methods that shall be used for operations a) to f), whether the examination is being carried out in accordance with Examination Level 1, 2 or 3, or to a procedure agreed by the contracting parties under the provisions of Examination Level 4.

The manufacturing stage at which testing is carried out shall be by agreement between the contracting parties [see **3.3** d)].

NOTE 1 Materials that are subject to reheat cracking (e.g. creep resisting steels of the CrMoV or 2¼ Cr type), irrespective of any intermediate testing, should be finally examined after stress relief heat treatment. Electroslag welds may have to be normalized prior to conducting a critical ultrasonic examination.

The examination of the weld shall be carried out by manual scanning using an A-scan presentation. The equipment, test blocks and calibration procedures shall meet the requirements of clause **5**.

NOTE 2 Additional guidance on the selection of probes for inspection operations c) to f) is contained in Appendix C. Methods for evaluating and sizing imperfections are detailed in Appendix M and Appendix N.

9.2 Parent metal examination

9.2.1 *General.* Whether or not the parent metal has been ultrasonically tested previously, an examination shall be made after welding:

a) to locate any imperfections, such as laminations or tears, in the material through which the ultrasonic beam will pass during examination of the weld;

b) to establish the material thickness in order to enable the actual beam path lengths to be determined.

Where imperfections are found, their influence on the degree of inspection possible in the vicinity of the weld shall be assessed and the technique for scanning during subsequent weld inspection adjusted to ensure the maximum possible local coverage of the full cross section of the weld.

During preliminary examination, the operator shall note variations in the attenuation of the material and the influence of surface condition on coupling in order to determine the practicability of performing an effective test.

9.2.2 *Method.* The material shall be examined manually by the pulse echo technique using a compressional single or twin crystal normal probe capable of good near surface resolution (see BS 5996 and **C.7**).

The nominal probe frequency shall be not less than 2 MHz.

NOTE In view of the requirement to note possible variations in attenuation in the material, probes in the range 4 MHz to 6 MHz are preferable. Where a single crystal probe does not give the necessary near surface resolution on material less than 25 mm thick, a twin crystal probe is preferable. Similarly, on thicker sections where the detection of small imperfections close to the test surface is important, a twin crystal probe should be used for this area in addition to a single crystal probe for the main body of the material.

The time base shall be calibrated using a suitable block by the method described in BS 4331-1 so that a minimum of two back wall echoes from the parent material are displayed on the screen.

During scanning it is essential that particular attention is paid to sudden apparent changes in material thickness as these may be caused by major imperfections lying close to the back wall.

The test sensitivity shall be set according to **10.2.1**, i.e. such that the second back wall echo is at full screen height on an imperfection-free area of the material. When the instrument sensitivity has to be locally increased to maintain this level, it shall be established whether the reduction in back wall echo is due to surface roughness or contour, increased material attenuation or parent metal imperfections, particularly those lying at an angle to the surface of the material.

9.2.3 *Test coverage.* The parent material shall be tested along the full length of the weld, for a distance back from the weld equal to the maximum scanning distance to be used for the subsequent angle probe examination.

In order to give complete coverage, the pitch between adjacent scan lines shall not exceed 0.8 times the diameter of the transducer. The speed of probe movement shall not exceed 150 mm/s.

9.3 Examination of weld root

9.3.1 *Single-sided welds.* On single-sided welds with an undressed root, wherever possible, a separate scan shall be carried out from both sides of the weld, in order to distinguish between echoes from normal features of the weld, such as the root bead, and echoes from root cracks or incomplete root penetration. In addition, where the weld cap is dressed sufficiently flat (SP2, SP3 or SP4), a normal probe shall be used to measure the depth of bead penetration or root concavity, or to confirm fusion on to the backing material, if used (see **9.4**).

9.3.2 *Double-sided welds.* The methods used to detect and measure the extent of the unfused root face will depend on the joint configuration and material thickness. Since imperfections of this type behave as specular reflectors, particularly as their size increases, it is very important to achieve the optimum angles for reflection.

9.3.3 *Method.* The method of examination of the weld root shall be one of those given in Appendix F.

9.4 Weld scan with normal probes

9.4.1 *General.* Where this technique is to be applied, the weld cap shall be dressed flush to surface condition categories SP3 or SP4 for in-line butt welds, or SP7 for non-linear welds (see Appendix B).

A normal probe shall be scanned over the surface of the weld in order to perform the following functions as appropriate to the type of weld under examination:

a) measure the depth of any excessive root penetration or root concavity;

b) determine the presence and extent of any lack of fusion into the backing material, where fitted (see Figure 1);

c) detect any lack of inter-run or root fusion, or other favourably oriented imperfections in the weld.

9.4.2 *Method.* The method of examination shall be that given in Appendix G.

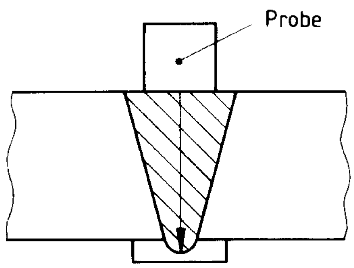


Figure 1 — Use of a normal probe to determine fusion of backing material

9.5 Weld scan for longitudinal imperfections

9.5.1 *General.* The methods covered by **9.5** are intended to detect all linear and non-linear imperfections which are predominately longitudinal with respect to the weld axis.

The most critical part of the examination is that for imperfections lying along the fusion faces, such as lack of side wall fusion or heat-affected zone (HAZ) cracking. Since these imperfections often behave as near-specular reflectors, the probe angle(s) shall be chosen such that the beam axis strikes the fusion face as near to the normal as possible.

NOTE Other imperfections in the body of the weld, such as cracks, slag inclusions, etc., tend to have a more random orientation and, in general for higher examination levels, require one or more additional probe angles to ensure reliable detection. In the case of non-linear welds, such as branch connections, T-joints and nodes, etc., a number of different probe angles and scanning surfaces may be required to give complete coverage, and the tables and figures in clauses **12** to **16** provide guidance. Particular attention should be paid, when selecting probe angles for branch and node welds, to the marked changes in weld geometry at different positions around the circumference.

Calibration of the probes and time base of the flaw detector shall be in accordance with clause **5**. If not otherwise agreed between the contracting parties the sensitivity shall be set in accordance with **10.2.2**.

Guidance on the choice of probes is given in Appendix C. The maximum test range shall not exceed 200 mm for 4 MHz to 5 MHz probes. For greater ranges, probes of 2 MHz to 3 MHz shall be used.

9.5.2 *Method.* The method of examination shall be one of those given in Appendix H.

9.6 Weld scan for transverse imperfections

9.6.1 *General.* Certain materials are prone to the development of transverse imperfections, which may be:

a) isolated and small, or

b) very frequent and across the whole weld, or

c) predominantly near the surface, or

d) of extensive depth almost to the root.

NOTE Imperfections near the test surface may sometimes mask the existence of others lying deeper in the material.

Generally, but not exclusively, transverse imperfections are orientated perpendicularly with respect to the weld surface and, as they are usually planar and therefore behave as near-specular reflectors, the choice of beam angle is particularly important.

On circumferential welds in cylindrical components, the angle of the beam with respect to the radial plane changes with depth in the material, and for each probe angle there is only one depth at which the beam strikes a radial imperfection normal to its surface (see Figure 2). This depth is also the limiting value for coverage of weld thickness.

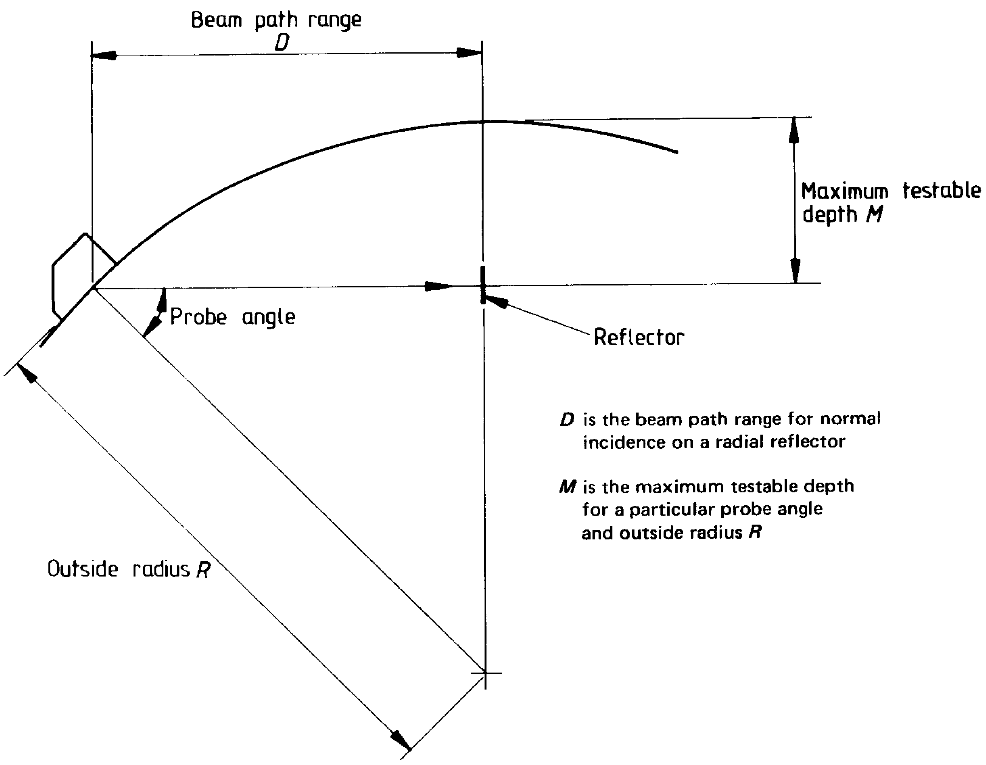
For a critical examination it is essential that the weld cap is dressed flat and flush with the parent material on either side to a minimum standard of SP3.

9.6.2 *Method.* The method of examination shall be one of those given in Appendix J.

NOTE The examination for transverse imperfections is generally confined to in-line butt welds as only a very limited degree of inspection is possible on non-linear welds due to their unfavourable geometry.

9.7 Other special scans

Scanning directions intermediate between transverse and longitudinal shall be carried out, as necessary, when imperfections of other orientations (e.g. chevron cracking) form part of the acceptance criteria.



Probe angle	Maximum testable depth, *M*	Beam path range, *D*
70°	0.06 *R*	0.34 *R*
60°	0.13 *R*	0.50 *R*
50°	0.24 *R*	0.64 *R*
45°	0.30 *R*	0.70 *R*
38°	0.38 *R*	0.79 *R*
NOTE The maximum testable depth, and beam path range to maximum testable depth, are given in terms of outside radius *R*, for different probe angles.		

Figure 2 — Effect of curvature on incident angle and maximum testable depth

10 Sensitivity

10.1 General

For Examination Levels 1, 2 and 3, sensitivity setting for the weld examination shall be referenced to a distance/amplitude correction (DAC) curve (see Appendix K) for a series of 3 mm diameter side-drilled holes in a suitable test block. The curve shall be corrected where necessary for differences between the attenuation and surface condition of the material under test and the test block.

The design of the test block, method of plotting the DAC curve, and the application of correction factors are described in Appendix K. If forms of test block are used where more convenient for "on-the-job" setting, the sensitivity shall always be relatable to the 3 mm DAC curve for the probe in use.

NOTE For Examination Level 4, other methods, including the distance/gain/size (DGS) system may be used by agreement between the contracting parties.

10.2 Scanning sensitivity

10.2.1 *General.* The initial scanning sensitivity shall be sufficiently high to give a reasonable assurance that all significant discontinuities are detected, irrespective of type or orientation. It shall be set as described in **10.2.2** and **10.2.3** and checked at intervals during inspection.

NOTE Alternative methods for setting sensitivity may be used provided they are referenced to the 3 mm side-drilled hole block.

10.2.2 *Parent metal examination (normal probes).* The scanning sensitivity shall be set on the parent material in an area free from imperfections such that the second back wall echo is displayed at full screen height.

In the absence of a back wall echo due to non-parallel surfaces, the scanning sensitivity shall be set as above using a separate parallel-sided plate with the same thickness and attentuation characteristics.

10.2.3 *Weld examination (normal and angle probes).* The minimum scanning sensitivity to be used for the weld examination will depend on the Examination Level to be applied, and the type of scan to be employed, i.e. whether using normal or angle probes and, if the latter, whether searching for longitudinal or transverse imperfections.

For Examination Level 1, the minimum scanning sensitivity shall be set to show evidence of "grass" up to the maximum testing range. This sensitivity shall be referenced to the DAC curve for 3 mm diameter side-drilled holes corrected for material attenuation or coupling losses, and shall be not less than the appropriate value shown in Table 2.

For Examination Levels 2 and 3, the minimum scanning sensitivity shall be set by adjustment of the instrument gain to the value at which the corrected DAC curve was plotted. The gain shall then be further increased by the appropriate decibel value shown in Table 2.

For Examination Level 4, the minimum scanning sensitivity shall be by agreement.

NOTE No maximum scanning sensitivity is specified. However, even when not a specific requirement, it is recommended that a low level of "grass", i.e. 2 mm to 3 mm above the baseline, should be visible up to the maximum testing range since this allows the operator visually to monitor the probe/workpiece coupling during scanning.

If an extended dead zone or excessive "grass" prevents the clear identification of possible imperfection echoes close to the probe at the minimum scanning sensitivity specified above, the full testing range shall be scanned in two parts, the sensitivity being set separately for each part.

11 Specific requirements for in-line butt welds in plate and pipe

Table 3 to Table 6 give the requirements for substantially in-line full penetration welds, welded from either one or two sides. They are sub-divided into four thickness ranges for Examination Levels 1 and 2, and into three thickness ranges for Examination Level 3. Examination Level 2 has been further sub-divided into Examination Level 2A for fully dressed welds, and Examination Level 2B for welds normally examined in the undressed condition.

Table 2 — Minimum scanning sensitivity levels

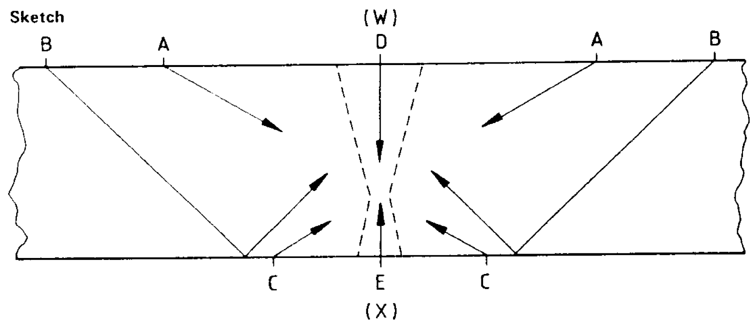
Examination Level	1	2	3	4
Normal beam scans	DAC + 14 dB	DAC + 8 dB	DAC + 8 dB	Method and level by agreement
Scans for longitudinal imperfections	DAC + 14 dB	DAC + 14 dB	DAC + 8 dB	
Scans for transverse imperfections	DAC + 20 dB	DAC + 14 dB	DAC + 8 dB[a]	

NOTE 1 Where excessive grass is experienced at the minimum sensitivity settings quoted, a lower frequency probe is recommended. Where excessive grass is still experienced with a lower frequency probe, it is recommended that testing should only continue by agreement between the contracting parties.

NOTE 2 + means more sensitive.

[a] When requested by the purchaser [see **3.3** e)].

Table 3 — Butt welds in plate and pipe: Examination Level 1



NOTE The letters in the table identify the scans shown here.

Access and surface condition

a) Double-sided welds, and single-sided welds meeting the following conditions:

Both surfaces dressed to SP4. Surfaces over which defect sizing has to be carried out shall be locally dressed to SP5 (see Appendix B)

b) Single-sided welds:

As for a) but upper surface only. Root bead to be dressed off where possible

Plate/pipe 6 mm to 15 mm thick	**Double/single-sided welds** (see access and surface condition a)		**Single-sided welds** (see access and surface condition b)
Scans from both sides of weld	**Upper surface**	**Lower surface**	**Upper surface**
Longitudinal defects	A to B 0–1 skip 1 angle	—	A to B 0–1 skip 1 angle
Transverse defects	(W) 0–1 skip 1 angle (W) Near surface 1 angle	—	(W) 0–1 skip 1 angle (W) Near surface 1 angle
Separate root scan (see note 1)	See note 1 a) or b) (if applicable)	—	A 1 angle (see note 2)
Normal beam scan	D Near surface and full section 1 probe	—	D Near surface and full section 1 probe
Plate/pipe 15 mm to 50 mm thick[a]			
Longitudinal defects	A 0–½ skip 2 angles A Near surface 1 angle	C 0–½ skip 2 angles C Near surface 1 angle	A to B 0–1 skip 2 angles A Near surface 1 angle
Transverse defects	(W) 0–½ skip 2 angles (W) Near surface 1 angle	(X) 0–½ skip 2 angles (X) Near surface 1 angle	(W) 0–1 skip 2 angles (W) Near surface 1 angle
Separate root scan (see note 1)	See note 1 a) or b) (if applicable)		A 1 angle (see note 2)
Normal beam scan	D Near surface and full section 1 probe	—	D Near surface and full section 1 probe
Plate/pipe 50 mm to 100 mm thick			
Longitudinal defects	A 0–½ skip 2 angles A Near surface 1 angle	C 0–½ skip 2 angles C Near surface 1 angle	A 0–½ skip 2 angles A Near surface 1 angle
Transverse defects	(W) 0–½ skip 2 angles (W) Near surface 1 angle	(X) 0–½ skip 2 angles (W) Near surface 1 angle	(W) 0–½ skip 2 angles (W) Near surface 1 angle
Separate root scan (see note 1)	See note 1 a) or b) (if applicable)	—	A 1 angle (see note 2)
Normal beam scan	D Near surface 1 probe D Full section 1 probe	E Near surface 1 probe	D Near surface 1 probe D Full section 1 probe
Plate/pipe 100 mm to 150 mm thick			
Longitudinal defects	A 0–½ skip 2 angles A Near surface 1 angle	C 0–½ skip 2 angles C Near surface 1 angle	Not applicable
Transverse defects	(W) 0–½ skip 2 angles (W) Near surface 1 angle	(X) 0–½ skip 2 angles (X) Near surface 1 angle	
Separate root scan (see note 1)	See note 1 b) (if applicable)	—	
Normal beam scan	D Near surface 1 probe D Full section	E Near surface 1 probe E Full section 1 probe	

NOTE 1 In the case of double-sided welds, where the depth of the weld root before welding does not exceed 3 mm, the root shall be scanned at not more than 20° from the perpendicular to the root plane, either as part of the general weld examination or, if necessary, as an additional scan.

If the weld root before welding exceeds 3 mm, there are two acceptable alternatives, as follows:

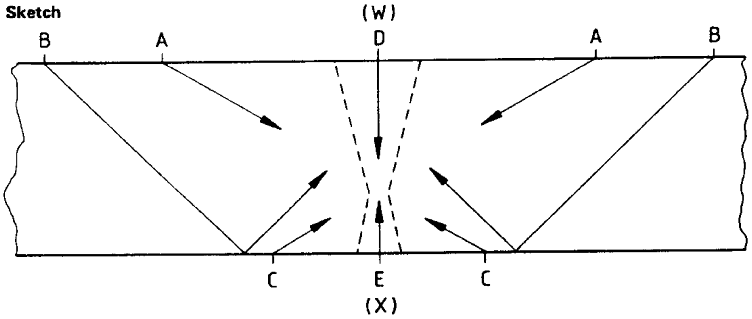
a) scan root at not more than 10° to the perpendicular, or

b) use a tandem technique with two 45° probes.

NOTE 2 In the case of single-sided welds, the root should be scanned with a 45° 4 MHz to 5 MHz probe where possible. A 70° probe may be used on welds below 20 mm thick, and a 2 MHz to 2½ MHz probe on welds over 100 mm thick, provided the probe has good range resolution.

[a] On thicknesses less than 35 mm scanning from the lower surface is not required.

Table 4 — Butt welds in plate and pipe: Examination Level 2A



NOTE The letters in the table identify the scans shown here.

Access and surface condition

a) Double-sided welds, and single-sided welds meeting the following conditions:

Both surfaces dressed to SP3. (see Appendix B). Surfaces over which defect sizing has to be carried out shall be locally dressed to SP5

b) Single-sided welds:

As for a) but upper surface only

Plate/pipe 6 mm to 15 mm thick	**Double/single-sided welds** (see access and surface condition a)		**Single-sided welds** (see access and surface condition b)
Scans from both sides of weld	**Upper surface**	**Lower surface**	**Upper surface**
Longitudinal defects	A to B 0–1 skip 1 angle	—	A to B 0–1 skip 1 angle
Transverse defects	(W) 0–1 skip 1 angle	—	(W) 0–1 skip 1 angle
Separate root scan (see note 1)	See note 1 a) or b) (if applicable)	—	A 1 angle (see note 2)
Normal beam scan	D Near surface and full section 1 probe	—	D Near surface and full section 1 probe
Plate/pipe 15 mm to 50 mm thick			
Longitudinal defects	A to B 0–1 skip 2 angles		A to B 0–1 skip 2 angles
Transverse defects	(W) 0–1skip 2 angles		(W) 0–1 skip 2 angles
Separate root scan (see note 1)	See note 1 a) or b) (if applicable)	1	A 1 angle (see note 2)
Normal beam scan	D Near surface and full section 1 probe	—	D Near surface and full section 1 probe
Plate/pipe 50 mm to 100 mm thick			
Longitudinal defects	A 0–½ skip 2 angles A Near surface 1 angle	C 0–½ skip 2 angles	A 0–½ skip 2 angles A Near surface 1 angle
Transverse defects	(W) 0–½ skip 2 angles (W) Near surface 1 angle	C 0–½ skip 2 angles	(W) 0–½ skip 2 angles (W) Near surface 1 angle
Separate root scan (see note 1)	See note 1 a) or b) (if applicable)	—	(A) 1 angle (see note 2)
Normal beam scan	D Near surface 1 probe D Full section 1 probe	—	D Near surface 1 probe D Full section 1 probe
Plate/pipe 100 mm to 150 mm thick			
Longitudinal defects	A 0–½ skip 2 angles A Near surface 1 angle	C 0–½ skip 2 angles C Near surface 1 angle	Not applicable
Transverse defects	(W) 0–½ skip 2 angles (W) Near surface 1 angle	(X) 0–½ skip 2 angles (X) Near surface 1 angle	
Separate root scan (see note 1)	See note 1 b) (if applicable)	—	
Normal beam scan	D Near surface 1 probe D Full section 1 probe	E Near surface 1 probe	

NOTE 1 In the case of double-sided welds, where the depth of the weld root before welding does not exceed 3 mm, the root shall be scanned at not more than 20° from the perpendicular to the root plane, either as part of the general weld examination or, if necessary, as an additional scan.

If the weld root before welding exceeds 3 mm, there are two acceptable alternatives, as follows:

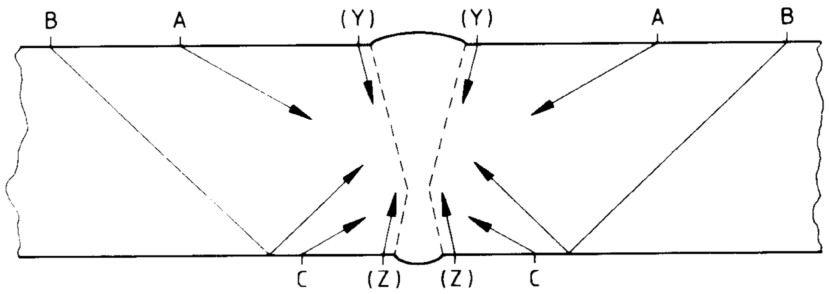
a) scan root at not more than 10° to the perpendicular, or

b) use a tandem technique with two 45° probes.

NOTE 2 In the case of single-sided welds, the root should be scanned with a 45° 4 MHz to 5 MHz probe where possible. A 70° probe may be used on welds below 20 mm thick, and a 2 MHz to 2½ MHz probe on welds over 100 mm thick, provided the probe has good range resolution.

Table 5 — Butt welds in plate and pipe: Examination Level 2B

Sketch



NOTE The letters in the table identify the scans shown here.

Surface condition
SP1. Weld dressing not required, except where necessary to remove the source of confusing echoes

Plate/pipe 6 mm to 15 mm thick	**Double-sided welds**		**Single-sided welds**
Scans from both sides of weld	**Upper surface**	**Lower surface**	**Upper surface**
Longitudinal defects	A to B 0–1 skip 1 angle	—	A to B 0–1 skip 1 angle
Transverse defects	(Y) 0–1 skip 1 angle for diameters greater than 250 mm	—	(Y) 0–1 skip 1 angle for diameters greater than 250 mm
Separate root scan (see note 1)	See note 1 a) (if applicable)	—	A 1 angle (see note 2)
Normal beam scan	—	—	—
Plate/pipe 15 mm to 50 mm thick[a]			
Longitudinal defects	A 0–½ skip 2 angles	0–½ skip 2 angles	A to B 0–1 skip 2 angles
Transverse defects	(Y) 0–½ skip 2 angles	0–½ skip 2 angles	(Y) 0–1 skip 2 angles
Separate root scan (see note 1)	See note 1 a) (if applicable)	—	A 1 angle (see note 2)
Normal beam scan	—	—	—
Plate/pipe 50 mm to 100 mm thick			
Longitudinal defects	A 0–½ skip 2 angles	C 0–½ skip 2 angles	A 0–½ skip 2 angles B ½–1 skip 1 angle
Transverse defects	(Y) 0–½ skip 2 angles	(Z) 0–½ skip 2 angles	(Y) 0–½ skip 2 angles (Y) ½–1 skip 1 angle
Separate root scan (see note 1)	See note 1 a) or b) (if applicable)	—	A 1 angle (see note 2)
Normal beam scan	—	—	—
Plate/pipe 100 mm to 150 mm thick			
Longitudinal defects	A 0–½ skip 2 angles	C 0–½ skip 2 angles	Not applicable
Transverse defects	(Y) 0–½ skip 2 angles	(Z) 0–½ skip 2 angles	
Separate root scan (see note 1)	See note 1 b) (if applicable)	—	
Normal beam scan	—	—	

NOTE 1 In the case of double-sided welds, where the depth of the weld root before welding does not exceed 3 mm, the root shall be scanned at not more than 20° from the perpendicular to the root plane, either as part of the general weld examination or, if necessary, as an additional scan.

If the weld root before welding exceeds 3 mm, there are two acceptable alternatives, as follows:

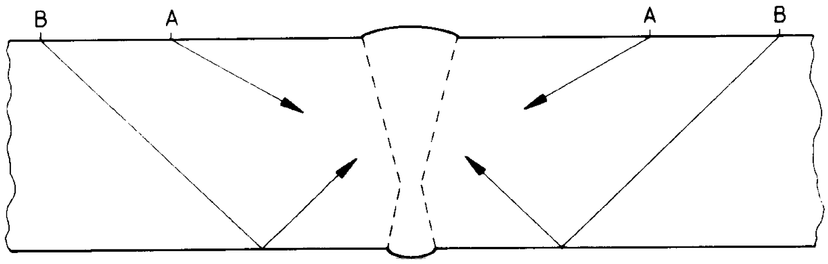
a) scan root at not more than 10° to the perpendicular, or

b) use a tandem technique with two 45° probes.

NOTE 2 In the case of single-sided welds, the root should be scanned with a 45° 4 MHz to 5 MHz probe where possible. A 70° probe may be used on welds below 20 mm thick, and a 2 MHz to 2½ MHz probe on welds over 100 mm thick, provided the probe has good range resolution.

[a] On thicknesses less than 35 mm scanning from the lower surface is not required.

Table 6 — Butt welds in plate and pipe: Examination Level 3

<table>
<tr><td colspan="3">Sketch


NOTE The letters in the table identify the scans shown here.</td><td>Surface condition
SP1. Weld dressing not required, except where necessary to remove the source of confusing echoes</td></tr>
<tr><th>Plate/pipe 10 mm to 50 mm thick</th><th colspan="2">Double-sided welds</th><th>Single-sided welds</th></tr>
<tr><th>Scans from both sides of weld</th><th>Upper surface</th><th>Lower surface</th><th>Upper surface</th></tr>
<tr><td>Longitudinal defects</td><td>A to B 0–½ skip 1 angle</td><td></td><td>0–1 skip 1 angle</td></tr>
<tr><td>Transverse defects</td><td>0–1 skip 2 angles[a]</td><td>—</td><td>0–1 skip 1 angles[a]</td></tr>
<tr><td>Separate root scan (see note 1)</td><td>See note 1 a) (if applicable)</td><td>—</td><td>A 1 angle (see note 2)</td></tr>
<tr><td>Normal beam scan</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td colspan="4">Plate/pipe 50 mm to 100 mm thick</td></tr>
<tr><td>Longitudinal defects</td><td>A 0–½ skip 1 angle
B ½–1 skip 1 angle</td><td>—</td><td>A 0–½ skip 1 angle
B ½–1 skip 1 angle</td></tr>
<tr><td>Transverse defects</td><td>0–½ skip 2 angles[a]
½–1 skip 1 angle[a]</td><td>—</td><td>0–½ skip 2 angles[a]
½–1 skip 1 angle[a]</td></tr>
<tr><td>Separate root scan (see note 1)</td><td>See note 1 a) or b)</td><td>—</td><td>A 1 angle (see note 2)</td></tr>
<tr><td>Normal beam scan</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td colspan="4">Plate/pipe 100 mm to 150 mm thick</td></tr>
<tr><td>Longitudinal defects</td><td>A 0–½ skip 2 angles
B ½–1 skip 1 angle</td><td>—</td><td rowspan="4">Not applicable</td></tr>
<tr><td>Transverse defects</td><td>0–½ skip 2 angles[a]</td><td>0–½ skip 2 angles[a]</td></tr>
<tr><td>Separate root scan (see note 1)</td><td>See note 1 a) or b)
(if applicable)</td><td>—</td></tr>
<tr><td>Normal beam scan</td><td>—</td><td>—</td></tr>
<tr><td colspan="4">NOTE 1 In the case of double-sided welds, where the depth of the weld root before welding does not exceed 3 mm, the root shall be scanned at not more than 20° from the perpendicular to the root plane, either as part of the general weld examination or, if necessary, as an additional scan.
If the weld root before welding exceeds 3 mm, there are two acceptable alternatives, as follows:
a) scan root at not more than 10° to the perpendicular, or
b) use a tandem technique with two 45° probes.
NOTE 2 In the case of single-sided welds, the root should be scanned with a 45° 4 MHz to 5 MHz probe where possible. A 70° probe may be used on welds below 20 mm thick, and a 2 MHz to 2½ MHz probe on welds over 100 mm thick, provided the probe has good range resolution.
[a] When requested by the purchaser [see 3.3 e)].</td></tr>
</table>

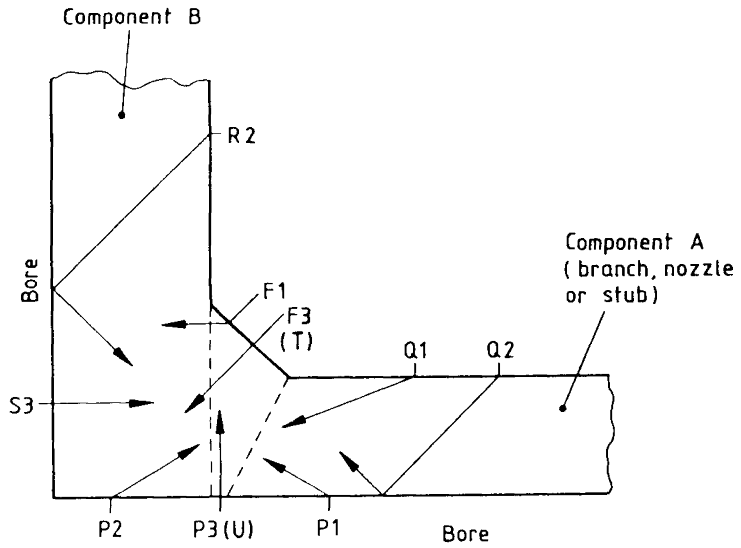
12 Specific requirements for set-on connections

Table 7 to Table 14 give the requirements for substantially radial full penetration welds. They are sub-divided into branch welds, nozzle welds and stub welds, as defined in clause **2**, according to the relative diameters of the two parent components, or in the case of stubs welds to their small diameter and thickness. Branch and nozzle welds have been sub-divided into two thickness ranges; stub welds fall into a single thickness range.

Examination Level 1 is not considered achievable on stub welds due to the inaccessibility for inspection from the bore.

Table 7 — Set-on connections. Branch welds: Examination Level 1

Sketch



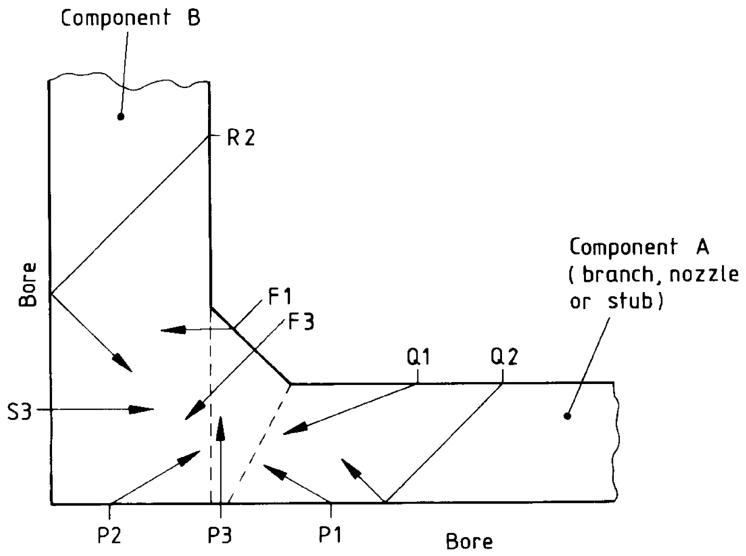
Surface condition:
SP7. Root bead removed

Branch 15 mm to 50 mm thick	Bores of A and B accessible	Bore of A only accessible	Neither bore accessible
Outer surfaces of branch	Scan Q1 to Q2 (0–1 skip) 2 angles	Scan Q1 to Q2 (0–1 skip) 2 angles	Examination Level 1 not achievable
Branch bore	Scan P1 (0–½ skip) 1 angle Scan P2 (0–½ skip) 1 angle	Scan P1 (0–½ skip) 1 angle Scan P2 (0–½ skip) 1 angle	
Inner/outer surfaces of component B	Scan S3 from bore 1 probe Scan R2 from outer surface 1 angle	Scan R2 from outer surface 1 angle	
Weld fillet	—	Scan F1, 1 angle[a] Scan F3, 1 probe[a]	
Separate root scan	—	—	
Scans for transverse defects	Scan T from weld fillet[a] 1 angle Scan U from bore 1 angle	Scan T from weld fillet[a] 1 angle Scan U from bore 1 angle	
Branch > 50 mm thick			
Outer surfaces of branch	Scan Q1 to Q2 (0–1) skip 1 angle Scan Q2 (½–1 skip) 1 angle	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle Scan Q1 (0–½ skip) 1 angle	
Branch bore	Scan P1 (0–½ skip) 1 angle Scan P2 (0–½ skip) 1 angle Scan P3, 1 probe	Scan P1 (0–½ skip) 2 angles Scan P2 (0–½ skip) 2 angles Scan P3, 1 probe	
Inner/outer surface of component B	Scan S3 from bore 1 probe Scan R2 from outer surface 1 angle	Scan R2 from outer surface 1 angle	
Weld fillet	Scan F1, 1 angle Scan F3, 1 probe	Scan F1, 1 angle Scan F3, 1 probe	—
Separate root scan	—	—	—
Scan for transverse defects	Scan T from fillet 1 angle Scan U from bore 1 angle	Scan T from fillet 1 angle Scan U from bore 1 angle	—

[a] Where weld fillet is sufficiently wide.

Table 8 — Set-on connections. Branch welds: Examination Level 2

Sketch



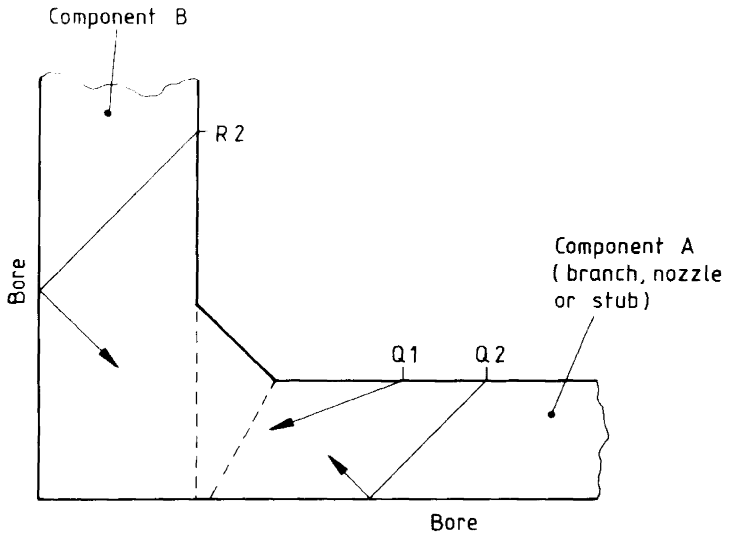
Surface condition:
a) Bore A accessible: SP6. Root bead removed
b) Neither bore accessible: SP7

Branch 15 mm to 50 mm thick	Bores of A and B accessible	Bore of A only accessible	Neither bore accessible
Outer surface of branch	Scan Q1 to Q2 (0–1 skip) 2 angles	Scan Q1 to Q2 (0–1 skip) 2 angles	Scan Q1 to Q2 (0–1 skip) 2 angles Scan Q1 (0–½ skip) 1 angle
Branch bore	Scan P2 (0–½ skip) 1 angle	Scan P2 (0–½ skip) 1 angle Scan P1 (0–½ skip) 1 angle	—
Inner/outer surface of component B	Scan S3 from bore 1 probe	Scan R2 from outer surface 1 angle	Scan R2 from outer surface 1 probe
Weld fillet	—	—	Scan F1, 2 angles[a] Scan F3, 1 probe[a]
Separate root scan	—	—	Scan Q1, 1 angle
Branch > 50 mm thick			
Outer surface of branch	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle	Scan Q1 to Q2 (0–1 skip) 2 angles Scan Q1 (0–½ skip) 1 angle
Branch bore	Scan P2 (0–½ skip) 1 angle Scan P1 (0–½ skip) 1 angle	Scan P2 (0–½ skip) 2 angles Scan P1 (0–½ skip) 1 angle	—
Inner/outer surface of component B	Scan S3 from bore 1 probe	Scan R2 from outer surface 1 angle	Scan R2 from outer surface 1 angle
Weld fillet	—	—	Scan F1, 2 angles Scan F3, 1 probe
Separate root scan	—	—	Scan Q1, 1 angle

[a] Where weld fillet is sufficiently wide.

Table 9 — Set-on connections. Branch welds: Examination Level 3

Sketch

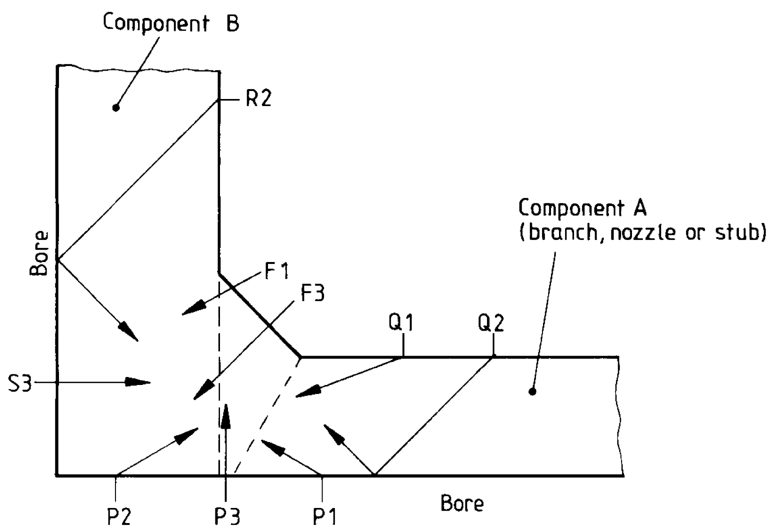


Surface condition:
SP6. If root bead is removed the separate root scan can be omitted

Branch > 15 mm thick	Bores of A and B accessible	Bore of A only accessible	Neither bore accessible
Outer surface of branch	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle
Branch bore	—	—	—
Inner/outer surface of component B	Scan R2 from outer surface 1 angle (for thicknesses above 50 mm only)	Scan R2 from outer surface 1 angle (for thicknesses above 50 mm only)	Scan R2 from outer surface 1 angle (for thicknesses above 50 mm only)
Weld fillet	—	—	—
Separate root scan (only if bead not removed)	Scan Q1, 1 angle	Scan Q1, 1 angle	Scan Q1, 1 angle

Table 10 — Set-on connections. Nozzle welds: Examination Level 1

Sketch

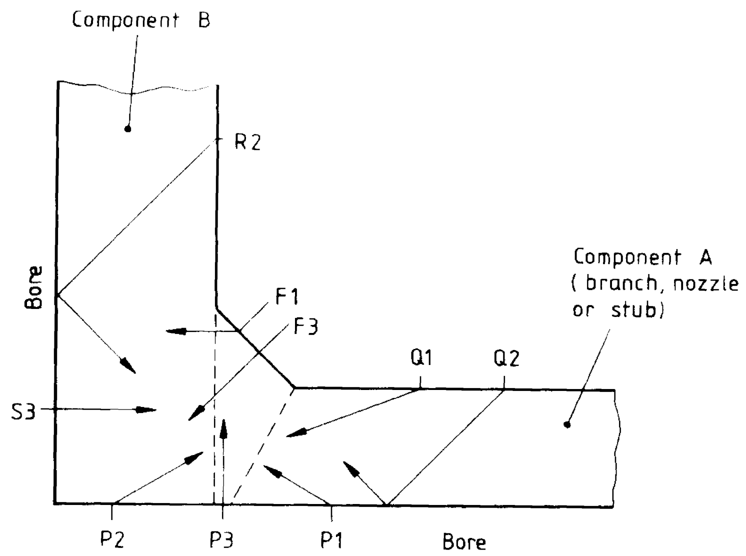


Surface condition:
Nozzle thickness 15 mm to 50 mm:
SP6. Root bead removed
Nozzle thickness over 50 mm:
SP7. Root bead removed

Nozzle 15 mm to 50 mm thick	Bores of A and B accessible	Bore of A only accessible	Neither bore accessible
Outer surface of nozzle	Scan Q1 to Q2 (0–1 skip) 2 angles	Scan Q1 to Q2 (0–1 skip) 2 angles	
Nozzle bore	Scan P1 (0–½ skip) 1 angle Scan P2 (0–½ skip) 1 angle	Scan P1 (0–½ skip) 1 angle Scan P2 (0–½ skip) 2 angles	
Inner/outer surfaces of component B	Scan S3 from bore 1 probe Scan R2 from outer surface 1 angle	Scan R2 from outer surface 1 angle	Examination Level 1 not achievable
Weld fillet	—	—	
Separate root scan	—	—	
Nozzle > 50 mm thick			
Outer surface of nozzle	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle Scan Q1 (0–½ skip) 1 angle	
Nozzle bore	Scan P1 (0–½ skip) 1 angle Scan P2 (0–½ skip) 1 angle Scan P3, 1 probe	Scan P1 (0–½ skip) 2 angles Scan P2 (0–½ skip) 2 angles Scan P3, 1 probe	Examination Level 1 not achievable
Inner/outer surfaces of component B	Scan S3 from bore 1 probe Scan R2 from outer surface 1 angle	Scan R2 from outer surface 1 angle	
Weld fillet	Scan F1, 1 angle Scan F3, 1 probe	Scan F1, 1 angle Scan F3, 1 probe	
Separate root scan	—	—	

Table 11 — Set-on connections. Nozzle welds: Examination Level 2

Sketch



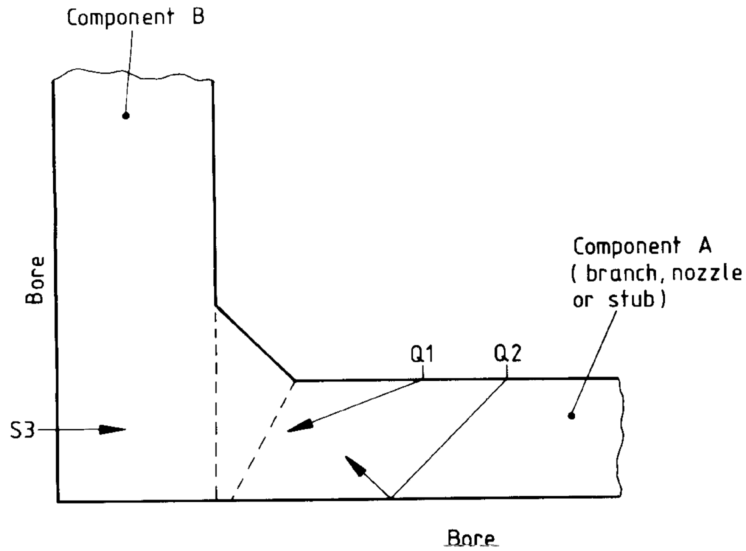
Surface condition:
Where bore of B is accessible: SP6.
Where bore of B is not accessible: SP7.
Root bead to be removed where
bore A is accessible

Nozzle 15 mm to 50 mm thick	Bores of A and B accessible	Bore of A only accessible	Neither bore accessible
Outer surface of nozzle	Scan Q1 to Q2 (0–1 skip) 2 angles	Scan Q1 to Q2 (0–1 skip) 2 angles	Scan Q1 to Q2 (0–1 skip) 2 angles Scan Q1 (0–½ skip) 1 angle
Nozzle bore	—	Scan P2 (0–½ skip) 1 angle	(See note)
Inner/outer surfaces of component B	Scan S3 from bore 1 probe	—	Scan R2 from outer surface 1 angle
Weld fillet	—	—	—
Separate root scan	—	—	Scan Q1, 1 angle
Nozzle > 50 mm thick			
Outer surface of nozzle	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle	Scan Q1 to Q2 (0–1 skip) 2 angles Scan Q1 (0–½ skip) 1 angle
Nozzle bore	Scan P1 (0–½ skip) 1 angle Scan P2 (0–½ skip) 1 angle	Scan P1 (0–½ skip) 1 angle Scan P2 (0–½ skip) 2 angles	(See note)
Inner/outer surface of component B	Scan S3 from bore 1 probe	—	Scan R2 from outer surface 1 angle
Weld fillet	—	Scan F1, 1 angle	Scan F1, 1 angle Scan F3, 1 angle
Separate root scan	—	—	Scan Q1, 1 angle

NOTE In the absence of access to either bore the level of examination will be reduced. In particular, for nozzle thicknesses above 50 mm the detectability of defects along the B-side wall will be significantly reduced.

Table 12 — Set-on connections. Nozzle welds: Examination Level 3

Sketch

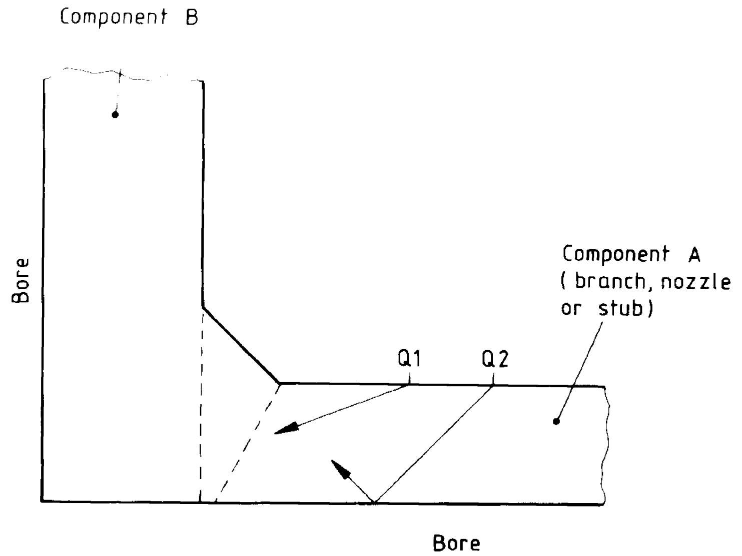


Surface condition:
SP6. If root bead is removed the separate root scan can be omitted

Nozzle > 15 mm thick	Bores of A and B accessible	Bore of A only accessible	Neither bore accessible
Outer surface of nozzle	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle	Scan Q1 to Q2 (0–1 skip) 1 angle Scan Q2 (½–1 skip) 1 angle
Nozzle bore	—	—	—
Inner/outer surface of component B	Scan S3 from bore 1 probe (for thicknesses above 50 mm only)	—	—
Weld fillet	—	—	—
Separate root scan (only if bead not removed)	Scan Q1, 1 angle	Scan Q1, 1 angle	Scan Q1, 1 angle

Table 13 — Set-on connections. Stub welds: Examination Level 2

Sketch

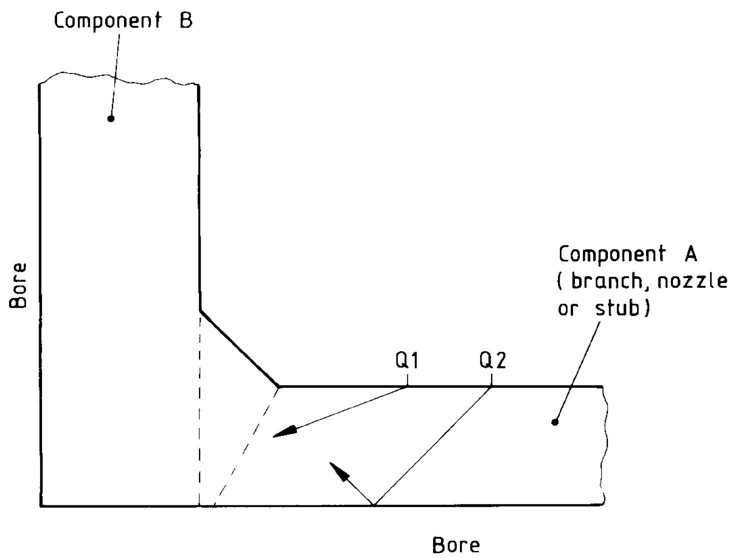


Surface condition:
SP6. If root bead is removed the separate root scan can be omitted

Stub 5 mm to 15 mm thick	Bores of A and B accessible	Bore of A only accessible	Neither bore accessible
Outer surface of stub	Scan Q1 to Q2 (0–1 skip) 2 angles	Scan Q1 to Q2 (0–1 skip) 2 angles	Scan Q1 to Q2 (0–1 skip) 2 angles
Separate root scan	Scan Q1, 1 angle	Scan Q1, 1 angle	Scan Q1, 1 angle

Table 14 — Set-on connections. Stub welds: Examination Level 3

Sketch



Surface condition:
SP6. If root bead is removed the separate root scan can be omitted

Stub 5 mm to 15 mm thick	Bores of A and B accessible	Bore of A only accessible	Neither bore accessible
Outer surface of stub	Scan Q1 to Q2 (0–1 skip) 1 angle	Scan Q1 to Q2 (0–1 skip) 1 angle	Scan Q1 to Q2 (0–1 skip) 1 angle
Separate root scan	Scan Q1, 1 angle	Scan Q1, 1 angle	Scan Q1, 1 angle

13 Specific requirements for node joints

Table 15 and Table 16 give the requirements for full penetration welds of node joints (see **2.3**) set at up to substantially non-radial angles in one thickness range. Examination Level 1 is not considered applicable to their class of construction for reasons of geometry.

Table 15 — Node joints: Examination Level 2

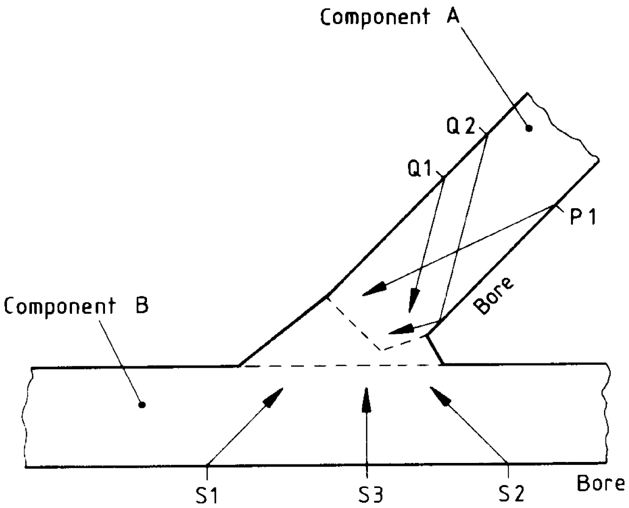
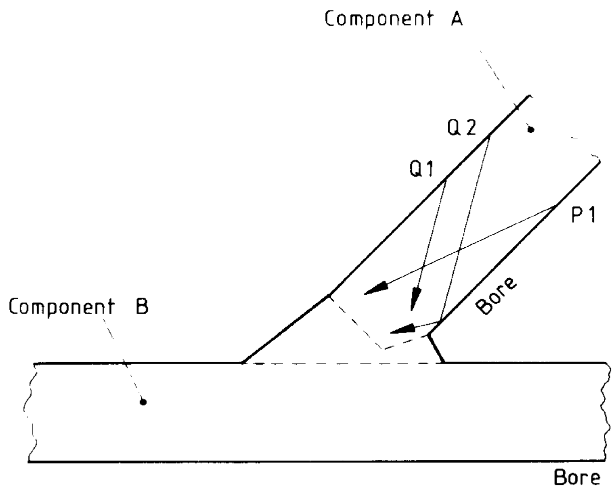
Sketch  	**Surface condition:** SP6
Material 15 mm to 100 mm thick	
Component A	Scan Q1 (0– skip) 3 angles Scan P1 (0–½ skip) 3 angles if bore of A is accessible; otherwise scan Q2 (½–1 skip) 2 angles
Component B	Scan S3, 1 probe Scan S1, 1 angle Scan S2, 1 angle
NOTE Examination Level 1 is not normally applicable to this type of construction unless there has been special preparation. If the bore of the component B is not accessible for scanning, Examination Level 2 cannot be achieved.	

Table 16 — Node joints: Examination Level 3

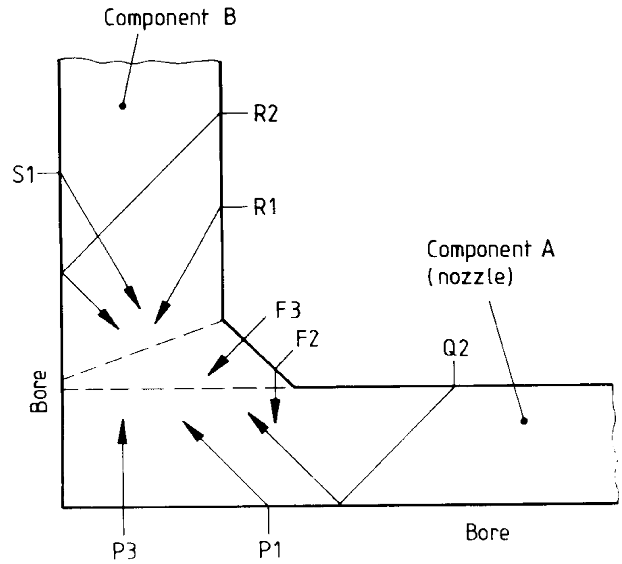
Sketch 	**Surface condition:** SP6
Material 15 mm to 100 mm thick	
Component A	Scan Q1 (0–½ skip) 3 angles Scan P1 (0–½ skip) 3 angles if bore of A is accessible; otherwise scan Q2 (½ – 1 skip) 2 angles
Component B	—

14 Specific requirements for set-through nozzle joints

Table 17 to Table 22 give the requirements for substantially radial full or partial penetration welds in one thickness range. They are sub-divided into single- or double-sided welds.

Table 17 — Set-through nozzle welds. Single-sided: Examination Level 1

Sketch

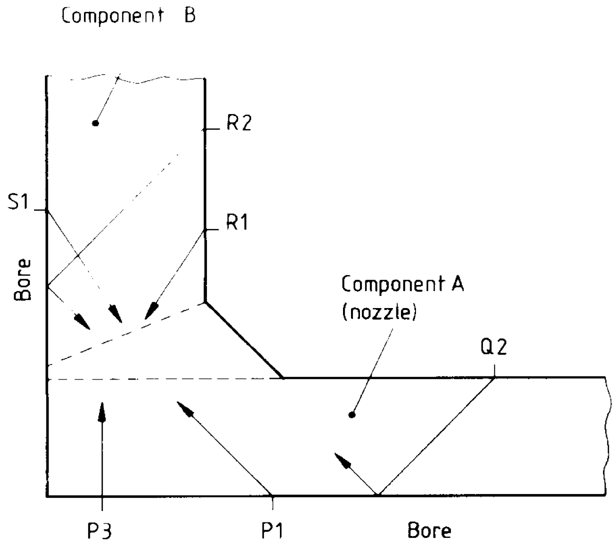


Surface condition:
a) Thicknesses up to 50 mm or with access to bore A: SP6. Root bead removed
b) Thicknesses over 50 mm and without access to bore A: SP7. Root bead removed

Nozzle 15 mm to 100 mm thick	Bore A accessible	Bore A not accessible
Nozzle surface	Scan Q2, 1 angle (or scan P1, 1 angle)	Scan Q2, 1 angle
Nozzle bore	Scan P1, 1 angle (or scan Q2, 1 angle) Scan P3, 1 probe	—
Inner/outer surface of component B	Scan S1 (0–½ skip) 2 angles, or scan R1 to R2 (0–1 skip) 2 angles if thickness of B is less than 50 mm	Scan R1 (0–½ skip) 1 angle Scan S1 (0–½ skip) 2 angles (or R2 (½–1 skip) 2 angles if thickness of B is less than 50 mm)
Weld fillet surface (where thickness > 50 mm)	—	Scan F2, 1 angle Scan F3, 1 probe

Table 18 — Set-through nozzle welds. Single-sided: Examination Level 2

Sketch



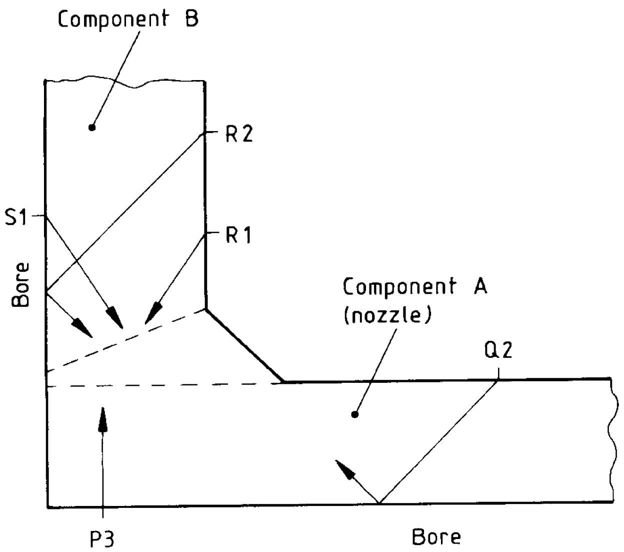
Surface condition:

SP6. Root bead removed

Nozzle 15 mm to 100 mm thick	Bore A accessible	Bore A not accessible
Nozzle surface	Scan Q2, 1 angle (or scan P1, 1 angle)	Scan Q2, 1 angle
Nozzle bore	Scan P1, 1 angle (or scan Q2, 1 angle) Scan P3, 1 probe	—
Inner/outer surfaces of component B	Scan S1 (0–½ skip) 1 angle, or scan R1 to R2 (0–1 skip) 1 angle	Scan S1 (0–½ skip) 2 angles, or scan R1 to R2 (0–1 skip) 2 angles

Table 19 — Set-through nozzle welds. Single-sided: Examination Level 3

Sketch



Surface condition:

SP6. If root bead is removed separate root scan can be omitted

Nozzle 15 mm to 100 mm thick	Bore A accessible	Bore A not accessible
Nozzle surface	—	—
Nozzle bore	Scan P3, 1 probe	—
Inner/outer surfaces of component B	Scan S1 (0–½ skip) 1 angle, or scan R1 to R2 (0–1 skip) 1 angle	Scan S1 (0–½ skip) 2 angles, or scan R1 to R2 (0–1 skip) 1 angle and scan R1 (0–½ skip) 1 angle
Separate root scan	Scan R1, 1 angle	Scan R1, 1 angle

Table 20 — Set-through nozzle welds. Double-sided: Examination Level 1

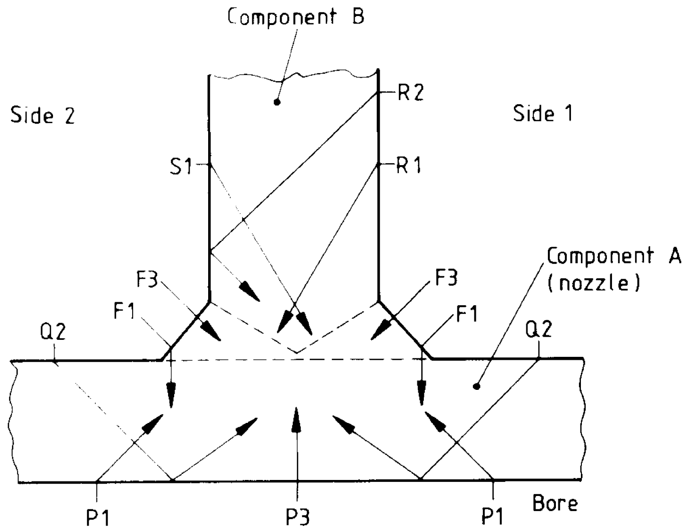
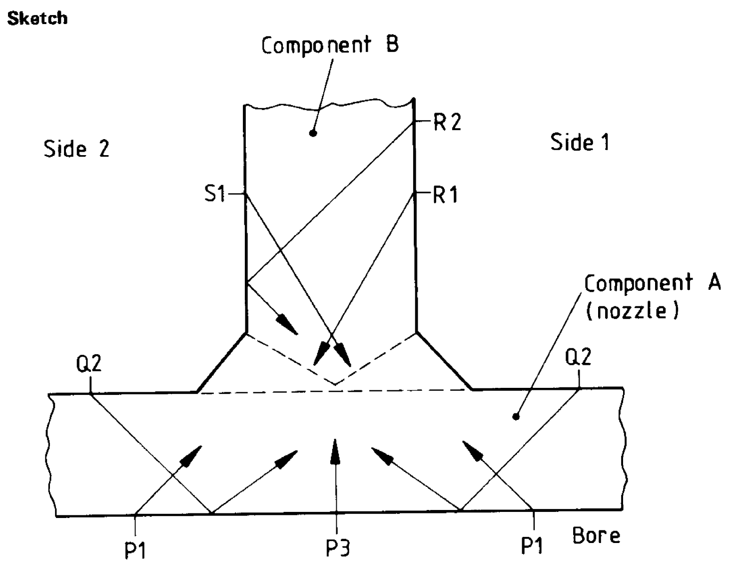
<table>
<tr><td colspan="2">Sketch

</td><td>Surface condition:
a) Thicknesses up to 50 mm or with access to bore A: SP6.
b) Thicknesses over 50 mm and without access to bore A: SP7.</td></tr>
<tr><th>Nozzle 15 mm to 100 mm thick</th><th>Bore A accessible</th><th>Bore A not accessible</th></tr>
<tr><td>Nozzle surface</td><td>Scan Q2 1 angle from both sides (or scan P1 from both directions)</td><td>Scan Q2, 1 angle from both sides</td></tr>
<tr><td>Nozzle bore</td><td>Scan P3, 1 probe
Scan P1, 1 angle from both directions (or scan Q2 from both sides)</td><td>—</td></tr>
<tr><td>Sides 1 and 2 of component B</td><td>Scans R1 and S1 (0–½ skip) 2 angles, or scan R1 to R2 (0–1 skip) 2 angles if thickness of B is less than 50 mm</td><td>Scan R1 and S1 (0–½ skip) 2 angles, or scan R1 to R2 (0–1 skip) 2 angles if thickness of B is less than 50 mm</td></tr>
<tr><td>Weld fillet surface
(where thickness > 50 mm)</td><td>—</td><td>Scan F1, 1 angle from both sides
Scan F3, 1 probe from both sides</td></tr>
</table>

Table 21 — Set-through nozzle welds. Double-sided: Examination Level 2

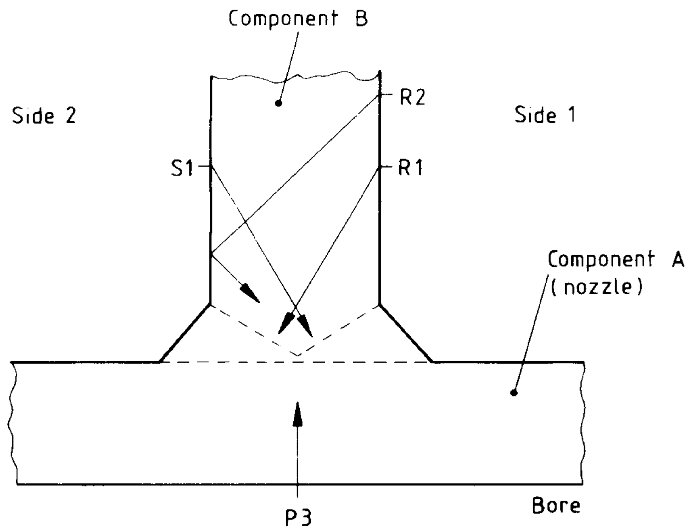


Surface condition:
SP6

Nozzle 15 mm to 100 mm thick	Bore A accessible	Bore A not accessible
Nozzle surface	Scan Q2, 1 angle from both sides (or scan P1 from both directions)	Scan Q2, 1 angle from both sides
Nozzle bore	Scan P1, 1 angle from both directions (or scan Q2 from both sides) Scan P3, 1 probe	—
Sides 1 and 2 of component B	Scan R1 to R2 (0–1 skip) 1 angle, or scans R1 and S1 (0–½ skip) 1 angle	Scan R1 to R2 (0–1 skip) 2 angles, or scans R1 and S1 (0–½ skip) 2 angles

Table 22 — Set-through nozzle welds. Double-sided: Examination Level 3

Sketch



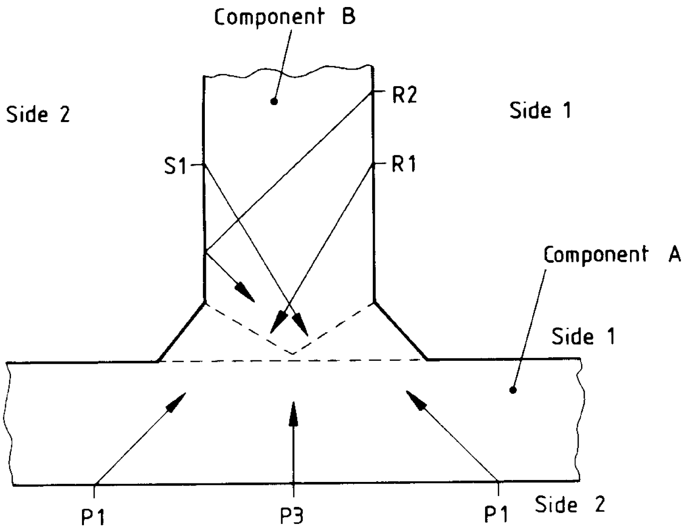
Surface condition: SP6		
Nozzle 15 mm to 100 mm thick	**Bore A accessible**	**Bore A not accessible**
Nozzle surface	—	—
Nozzle bore	Scan P3, 1 probe	—
Sides 1 and 2 of component B	Scan R1 to R2 (0–1 skip) 1 angle or scans R1 and S1 (0–½ skip) 1 angle	Scan R1 to R2 (0–1 skip) 2 angles or scans R1 and S1 (0–½ skip) 2 angles

15 Specific requirements for structural T-joints

Table 23 to Table 25 give the requirements for full or partial penetration single- or double-sided welds, the parent plates being set at near right angles to one another in one thickness range.

Table 23 — Structural T-Joints: Examination Level 1

Sketch



Surface condition: SP6	
Parent material 10 mm to 100 mm thick	
Component A	Scan P1, 1 angle from both directions Scan P3, 1 probe
Component B	Scans R1 and S1 (0–½ skip) 2 angles, or for thicknesses < 50 mm Scan R1 to R2 (0–1 skip) 2 angles
Separate root scan (single-sided welds only)	Scan R1, 1 angle

Table 24 — Structural T-Joints: Examination Level 2

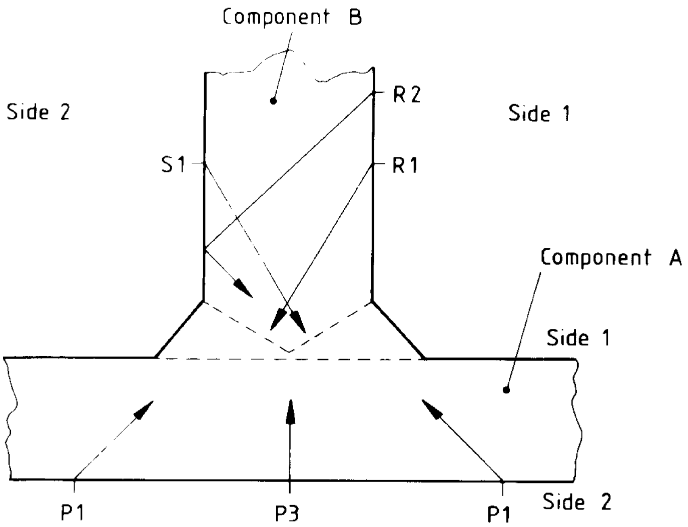
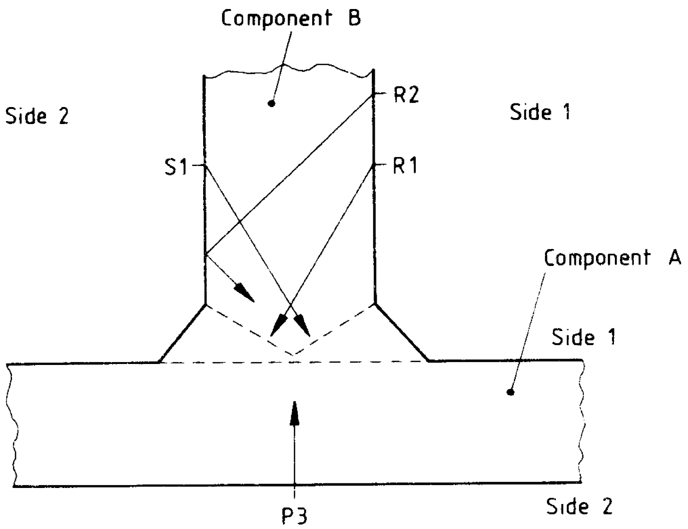
Sketch 	**Surface condition:** SP6
Parent material 10 mm to 100 mm thick	
Component A	Scan P1, 1 angle from both directions Scan P3, 1 probe
Component B	Scans R1 and S1 (0–½ skip) 1 angle, or for thicknesses < 50 mm Scan R1 to R2 (0–1 skip) 1 angle
Separate root scan (single-sided welds only)	Scan R1, 1 angle

Table 25 — Structural T-Joints: Examination Level 3

Sketch 	**Surface condition:** SP6
Parent material 10 mm to 100 mm thick	
Component A	Scan P3, 1 probe
Component B	Scans R1 and S1 (0–½ skip) 1 angle, or for thicknesses < 50 mm Scan R1 to R2 (0–1 skip) 1 angle
Separate root scan (single-sided welds only)	Scan R1, 1 angle

16 Specific requirements for cruciform joints

Table 26 to Table 28 give the requirements for full or partial penetration single- or double-sided welds, the parent plates being set at near right angles to one another in one thickness range.

Table 26 — Cruciform joints: Examination Level 1

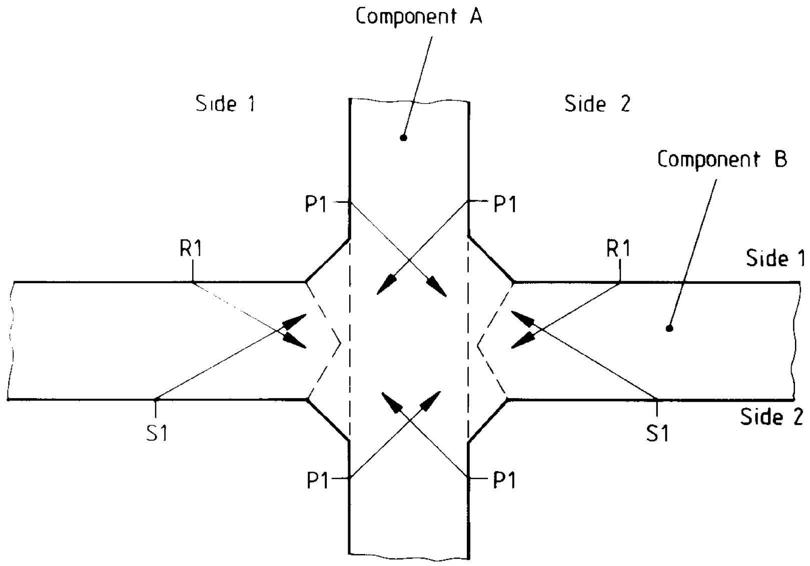
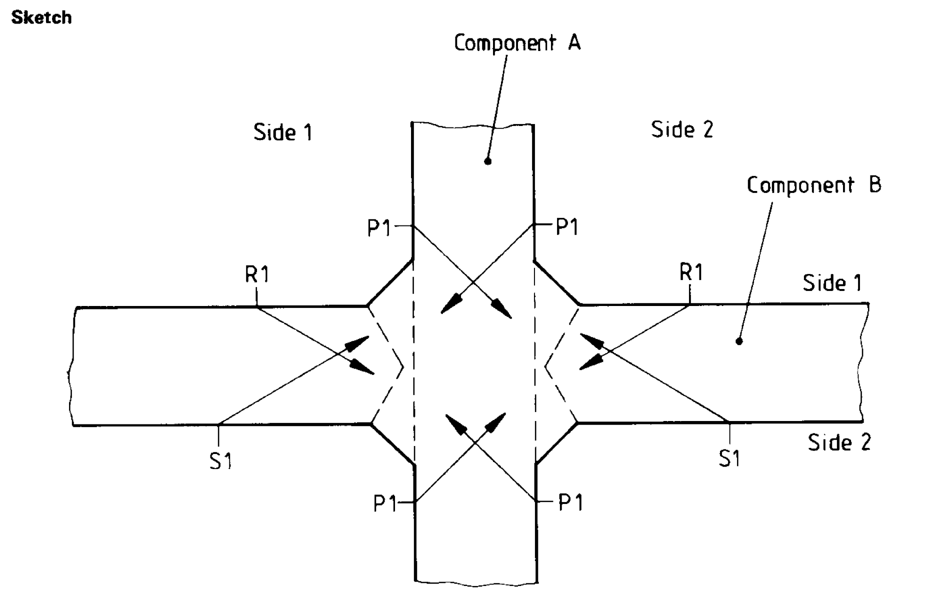
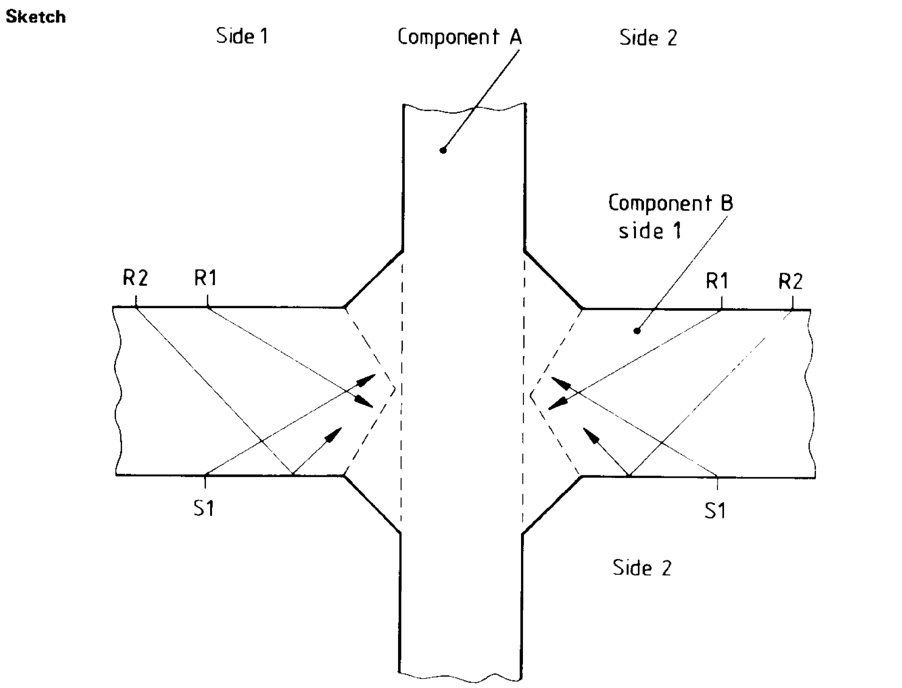
Sketch  	**Surface condition:** SP6
Parent material 10 mm to 100 mm thick	
Component A	Scan P1, 1 angle from both directions and both surfaces
Component B	Scans R1 and S1 (0–½ skip) 2 angles from both sides of component A
Separate root scan (single-sided welds only)	Scan R1, 1 angle from both sides of component A

Table 27 — Cruciform joints: Examination Level 2



Surface condition: SP6	
Parent material 10 mm to 100 mm thick	
Component A	Scan P1, 1 angle from both directions and both surfaces
Component B	Scans R1 and S1 (0–½ skip) 2 angles from both sides of component A
Separate root scan (single-sided welds only)	Scan R1, 1 angle from both sides of component A

Table 28 — Cruciform joints: Examination Level 3



Surface condition: SP6	
Parent material 10 mm to 100 mm thick	
Component A	—
Component B	Scans R1 and S1 (0–½ skip) 2 angles from both sides of component A, or for thickness < 50 mm Scan R1 to R2 (0–1 skip) 2 angles from both sides of component A
Separate root scan (single-sided welds only)	Scan R1, 1 angle from both sides of component A

17 Evaluation of imperfections

17.1 General considerations

The procedures used for the evaluation of imperfections will depend in part on the purpose of the examination, i.e. whether for quality control purposes or for assessing fitness-for-purpose. Recommendations for the preparation of acceptance standards for quality control purposes are contained in Appendix A.

For a fracture mechanics assessment, or the application of certain acceptance standards, the metallurgical nature of the imperfection, e.g. whether or not it is a crack, may be an important factor. However, this knowledge can only be inferred from the ultrasonic measurement of its shape, size, orientation and position in the weld in relation to the metallurgy of the welding process and parent materials.

The evaluation of indications described in the following subclauses recognizes the fact that small discontinuities having a single reflecting surface cannot be sized by the normal probe movement methods and also that, provided they are isolated and their echo height is not large, they are extremely unlikely to have an adverse effect on weld performance. The echodynamic pattern method is applied at an early stage in the evaluation procedure to separate these discontinuities from potentially serious imperfections which may show a much lower echo height.

When assessing an imperfection in relation to the acceptance standard, the maximum value of the echo height which can be obtained from any angle relative to the imperfections shall be used.

The evaluation procedure shall be as shown in the flow diagram in Figure 3.

17.2 Preliminary evaluation

For Examination Level 1, any indication observed during scanning that is significantly higher than the "grass" level shall be investigated to determine its echodynamic pattern.

For Examination Levels 2 and 3, only those indications whose echo heights, when maximized by adjustment of the probe positions, exceed the evaluation level,i.e. the DAC curve at the minimum scanning sensitivity (see Table 2), shall be investigated further.

To determine the echodynamic pattern, the indication shall be investigated by probe movement in two mutually perpendicular directions. Angle probe scans shall be made in a direction towards or away from the reflector, and at right angles to this direction. Normal probe scans shall be made along the length of the weld and across its width. The characteristic features of the different patterns are described in Appendix L.

Indications which show Pattern 1 behaviour in both directions, i.e. point reflectors (see **M.4**), shall be disregarded provided they are isolated and their maximum echo height does not exceed the recording/acceptance level specified in the acceptance standard.

NOTE The recording/acceptance level for longitudinal, transverse and horizontal imperfections may be different to each other.

In the absence of any level being specified in the application standard, the values given in Table 29 shall be applied.

Indications which show Pattern 2 or Pattern 3a/3b in either direction, indications which exceed the recording/acceptance level, and those from numerous or clustered discontinuities shall be further investigated and recorded in accordance with **17.3**, **17.4** and **17.5**.

17.3 Location and confirmation of imperfection

The position of the suspect imperfection shall be accurately determined in relation to the weld cross section from the range of the signal along the time base, the predetermined beam angle, and the position and orientation of the probe in relation to one or more datum points/lines on the weld (see Appendix M).

NOTE The precise location of imperfections is facilitated by using a flaw location scale, of which there are several types, or by making accurate sketches.

Having initially located the apparent imperfection position, this shall be confirmed from the opposite side/surface of the weld or by the use of a probe having a different beam angle, or a combination of both. This step is essential to ensure that the indication is not from a normal geometrical feature of the weld or caused by a wave mode change.

Table 29 — Recommended recording levels for point reflectors

Examination Level	1	2	3
Normal beam scans	DAC – 6 dB	DAC	DAC + 6 dB
Longitudinal imperfection scans	DAC – 6 dB	DAC	DAC + 6 dB
Transverse imperfection scans	DAC – 6 dB	DAC – 6 dB	Not applicable

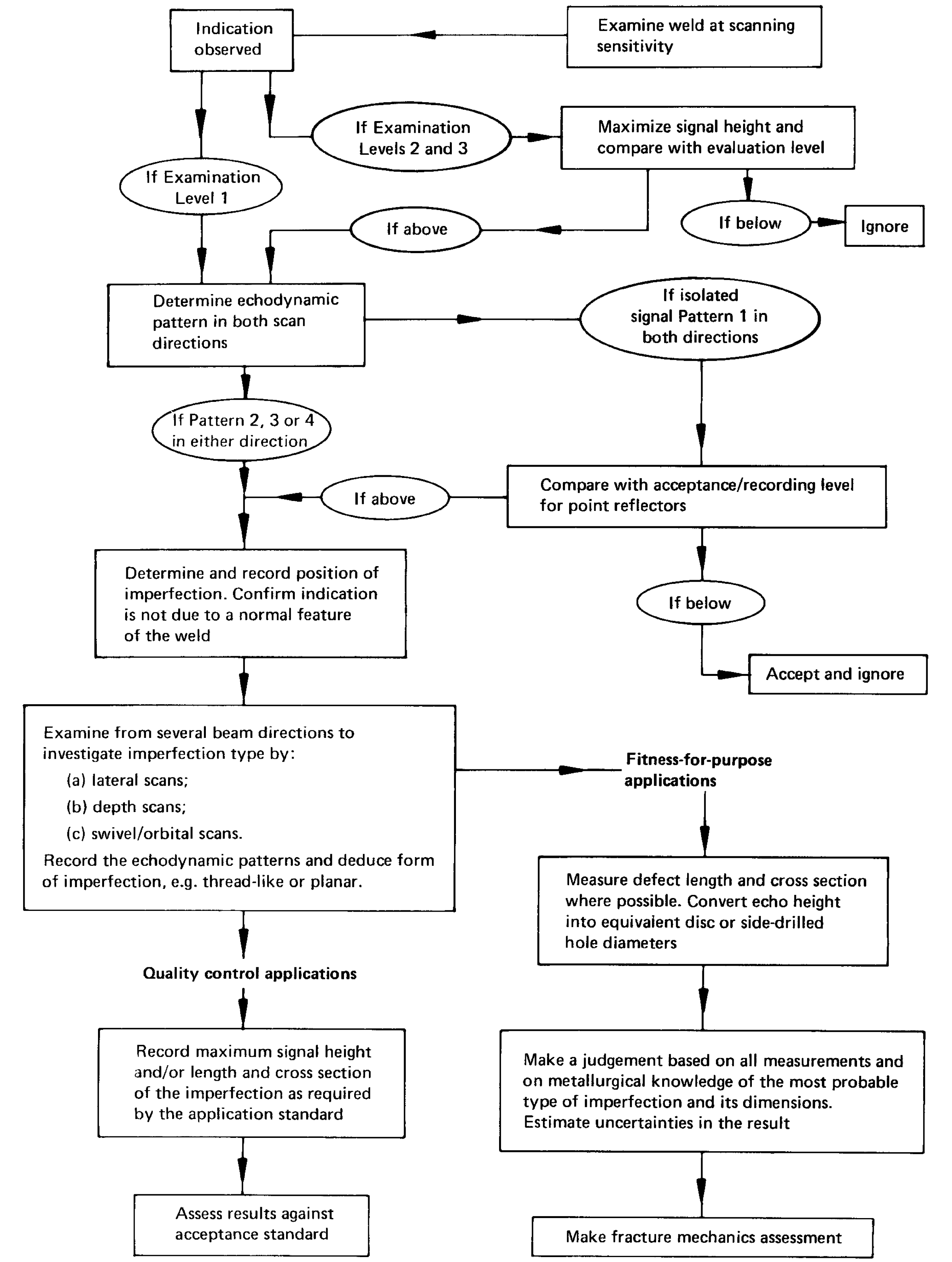


Figure 3 — Flow diagram for evaluation of ultrasonic indications

17.4 Information to be determined by the operator

The minimum information about each imperfection necessary to meet the requirements of Examination Levels 1, 2 and 3 shall be as detailed in Table 30.

NOTE 1 The measurement of actual dimensions of the imperfections takes precedence over the simpler echo height measurement as the level of examination rises from 3 to 1.

NOTE 2 Recommendations for the preparation of acceptance standards compatible with the requirements of Table 30 and with the capabilities of ultrasonic inspection are contained in Appendix A.

17.5 Characterizing and sizing

Sizing of imperfections shall be carried out at a range not exceeding the half-skip position, except where specifically agreed between the contracting parties [see **3.3** f)].

Where required, following location and confirmation of an imperfection, the methods detailed in Appendix M shall be employed, as appropriate, in order to classify the imperfection as being one of a number of basic types and shapes. Imperfections shall be sized according to Appendix N.

18 Presentation of results

For each weld examined, the operator shall submit a signed report containing the following information:

a) job identification and material;

b) identification of detailed test procedure (see clause **7**);

c) stage of manufacture at which examination was made, including state of heat treatment;

d) identity of operator and certification status;

e) date of test;

f) sketch of weld configuration as inspected showing all relevant dimensions, and one or more cross-sectional views;

g) type of ultrasonic flaw detector used (including serial number);

h) details of probes used, including make, type and frequency;

i) calibration block used;

j) test sensitivity and evaluation/recording levels applied;

k) method of correction employed for attenuation and transfer loss;

l) sketch showing extent of scanning, in particular, detailing areas which, due to the geometry or surface condition of the component, could not be fully examined in accordance with the detailed test procedure;

m) a report on the parent metal examination describing any local heterogeneities (e.g. laminations, surface imperfections, areas of high attentuation) which may adversely affect the weld examination at such locations; if no such heterogeneities are found, a statement to this effect shall be included in the operator's report;

n) test results in accordance with the requirements in Table 30 (see **17.4**), and including imperfection location in relation to the reference datum points shown in the detailed test procedure;

NOTE A suggested notational system for recording imperfection dimensions is illustrated in Appendix P.

o) for defects which lie outside the acceptance criteria, a plotted illustration of such defects.

The operator's report shall either include a statement regarding the acceptability or otherwise of each of the recorded imperfections in relation to the acceptance standard or shall be accompanied by such a statement by a supervisor or other responsible person.

Table 30 — Imperfection information required to meet Examination Levels

Examination Level	Type of imperfection	Information to be determined
1	Point	Maximum echo height
	Thread-like	Maximum echo height and length
	Volumetric	Length and maximum cross-sectional dimensions
	Planar	Length and through-thickness dimension
	Multiple	Enclosing volume and average echo height
	Root profile	Length and depth
2	Point	Maximum echo height
	Thread-like	Maximum echo height and length
	Volumetric	Length and maximum cross-sectional dimensions
	Planar	Length and through-thickness dimensions
	Multiple	Enclosing volume and average echo height
	Root profile	Length and maximum echo height
3	Point	Maximum echo height
	Thread-like	Maximum echo height
	Volumetric	Length and maximum echo height
	Planar	Length and maximum echo height
	Multiple	Enclosing volume and average echo height
	Root profile	Length and maximum echo height
4	Point	By agreement (see **3.2**)
	Thread-like	By agreement (see **3.2**)
	Volumetric	By agreement (see **3.2**)
	Planar	By agreement (see **3.2**)
	Multiple	By agreement (see **3.2**)
	Root profile	By agreement (see **3.2**)

Appendix A Recommendations for setting acceptance standards for quality control purposes

Acceptance standards can be drawn up with the aim of either:

a) maintaining satisfactory levels of workmanship, i.e. the quality control approach, or

b) setting maximum imperfection levels, beyond which there is a serious risk of component failure, i.e. the fitness-for-purpose approach.

Where the importance of achieving maximum weld integrity is increased, the quality control approach has to become more searching and less tolerant to imperfections. In particular, there has to be a greater emphasis on the measurement of actual imperfection size, rather than on monitoring echo height, whenever this is possible.

As far as is consistent with the above principles, quality control levels for ultrasonic inspection should be set in terms of easily measurable parameters which have true relevance to both workmanship and service performance. If sensibly applied, this approach will lead to more rapid and economical testing of a more consistent standard without increased risk of service failure.

Table 31 details the parameters that need to be specified in order to achieve a fairly comprehensive control of weld quality.

In setting the specific acceptance values, account should be taken of the purpose of the three Examination Levels, and the wide differences that exist between them with regard to the comprehensiveness of the weld examination. For example, there is little point in setting stringent acceptance criteria for Examination Level 3 when these may be below the level for reliable detection.

Table 31 — Imperfection parameters to be specified in the recommended form of acceptance standard for quality control applications (see note 1 for a key to the identification system used in the table)

Imperfection type	Examination Level 1	Examination Level 2	Examination Level 3
Isolated point imperfection (spherical or planar)			
Longitudinal	Maximum echo height exceeding IsA1.	As for Examination Level 1 except IsA2.	As for Examination Level 1 except IsA3.
Transverse	Maximum echo height exceeding IsT1.	As for Examination Level 1 except IsT2.	Not applicable.
Thread-like imperfection (slag line)	Maximum echo height exceeding ThA1 where ThA1 < IsA1.	Maximum echo height exceeding ThA2 where ThA2 < IsA2.	Maximum echo height exceeding ThA3 where ThA3 ⩽ IsA3.
	Maximum individual or aggregate length ThL1 for a defect having a maximum echo height above ThB1 where ThB1 < ThA1.	As for Examination Level 1 except ThL2 and ThB2.	Not applicable.
Volumetric imperfection	Maximum cross-sectional dimension in any direction exceeding VIC1.	As for Examination Level 1 except VIC2.	Maximum echo height exceeding VIA3.
	Maximum individual or aggregate length VIL1 for an imperfection showing a cross-sectional dimension exceeding VID1 where VID1 < VIC1.	As for Examination Level 1 except VIL2 and VID2.	Maximum individual or aggregate length VIL3 for a defect showing an echo height exceeding VIB3 where VIB3 < VIA3.
Planar imperfection (other than surface breaking defect, longitudinal)	Maximum through-thickness dimension exceeding PIC1.	As for Examination Level 1 except PIC2.	Maximum echo height exceeding PIA3.
	Maximum individual or aggregate length PIL1 irrespective of cross section.	Maximum individual or aggregate length PIL2 for a defect showing a through-thickness dimension exceeding PID2 where PID2 < PIC2.	Maximum individual or aggregate length PIL3 for a defect showing an echo height exceeding PIB3, where PIB3 < PIA3.

Planar imperfection (near surface longitudinal)	Maximum through-thickness dimension exceeding PsC1.	As for Examination Level 1 except PsC2.	Maximum echo height exceeding PsA3.
	Maximum individual or aggregate length PsL1 irrespective of cross section.	Maximum individual or aggregate length PsL2 for a defect showing a through-thickness dimension exceeding PsD2 where PsD2 < PsC2.	Maximum individual or aggregate length PsL3 for a defect showing an echo height exceeding PsB3 where PsB3 < PsA3.
Planar imperfection (transverse)	Maximum echo height exceeding PtA 1.	As for Examination Level 1 except PtA2.	Not applicable.
	Any defect showing Pattern 2 or 3 response in the through-thickness direction regardless of dimensions.	Maximum through-thickness dimension exceeding PtD2 or transverse dimension exceeding PtL2.	Not applicable.
Intermittent imperfection	Considered as one imperfection unless either the distance along the weld between adjacent defects exceeds Y1 times the length of the shorter imperfection, or the distance apart in cross section exceeds Z1.	As for Examination Level 1 except Y2 and Z2.	As for Examination Level 1 except Y3 and Z3.
Multiple (cluster) imperfections	Maximum cube dimension J1 within which the average echo height exceeds K1.	As for Examination Level 1 except J2 and K2.	As for Examination Level 1 except J3 and K3.

Table 31 — Imperfection parameters to be specified in the recommended form of acceptance standard for quality control applications (see note 1 for a key to the identification system used in the table)

Imperfection type	Examination Level 1	Examination Level 2	Examination Level 3
Root concavity	Maximum depth exceeding RtC1.	Maximum echo height exceeding RtA2.	As for Examination Level 2 except RtA3.
	Maximum individual or aggregate length RtL1 over which the depth exceeds RtD1 where RtD1 < RtC1.	Maximum individual or aggregate length RtL2 over which the echo height exceeds RtB2 where RtB2 < RtA2.	As for Examination Level 2 except for RtL3 and RtB3.
Excess root penetration	Maximum depth exceeding EpC1.	Maximum echo height exceeding EpA2.	As for Examination Level 2 except EpA3.
	Maximum individual or aggregate length EpL1 over which the depth exceeds EpD1, where EpD1 < EpC1.	Maximum individual or aggregate length EpL2 over which the echo height exceeds EpB2 where EpB2 < EpA2.	As for Examination Level 2 except EpL3 and EpB3.

NOTE 1 The different parameters are identified in the table by a system in which the first two letters identify the type of imperfection, the third letter the type of parameter (scan), and the final digit the Examination Level.

Types of imperfection
Is: Isolated imperfection
Th: Thread-like imperfection
VI: Volumetric imperfection
PI: Planar imperfection (longitudinal)
Ps: Planar imperfection (near surface) (longitudinal)
Pt: Planar imperfection (transverse)
Rt: Root concavity
Ep: Excess root penetration

Types of parameter
A: echo height, longitudinal imperfection
B: echo height, longitudinal imperfection
C: cross-sectional dimension
D: cross-sectional dimension
J: cube dimension (cluster imperfections)
K: average echo height (cluster imperfections)
L: imperfection length
T: echo height (transverse imperfections)
Y: longitudinal distance between imperfections
Z: through-thickness distance between imperfections

NOTE 2 The aggregate length of an imperfection is based on a weld length 3 times the wall thickness or 90 mm whichever is the larger. The weld length shall be measured on the outer surface of a curved component.

NOTE 3 Length and cross-sectional measurements to be expressed in millimetres.

NOTE 4 Imperfection echo heights are to be expressed as the number of dB above or below the 3 mm DAC curve.

NOTE 5 For the purposes of this table the term "near surface" is defined as a zone adjacent to any free surface of the weld having dimensions of 8 mm or $T_D/4$ whichever is the smaller, where T_D is the throat depth of the weld.

Appendix B Surface profile conditions and consequent testing limitations

B.1 General

This appendix defines five different categories of weld surface preparation for linear butt welds and two categories for non-linear welds, and describes the levels of test coverage and the standard of test that can be achieved with each.

The categories are as follows:

Linear butt welds

SP1: undressed

SP2: partially dressed to a smooth profile

SP3: partially dressed to a near-flat profile

SP4: fully dressed

SP5: fully dressed (special conditions)

Non-linear welds

SP6: as-welded

SP7: dressed flat

The surface requirements for Examination Levels 1, 2 and 3 are specified in Table 3 to Table 28. In choosing the most appropriate category when working to Examination Level 4, attention should be paid to the geometry and access to the joint, to its thickness, and to the implications of the acceptance criteria for imperfection detection and sizing accuracy.

Conditions SP1 and SP2 may be sufficient in many circumstances, although it is recommended that SP3 be the minimum quality for welds greater than 80 mm thick. In general, SP3 will be satisfactory for imperfection detection for procedures meeting the requirements of this Part of BS 3923, except that SP4 is the minimum necessary when scanning for transverse imperfections in critical components. Category SP5 may be required locally for the critical examination of known imperfections where acceptability is to be assessed on a fitness-for-purpose basis.

NOTE For each category relating to butt welds, the parent metal thickness on the two sides of the weld may not be exactly equal and there may be an unavoidable slope across the weld which may limit the extent of scanning.

Category SP6 is the normal standard for the weld fillet of non-linear joints. Category SP7 is only required when the joint geometry or access for inspection necessitates scanning from the weld surface itself to obtain satisfactory weld coverage.

The different categories of surface condition are illustrated schematically in Figure 4.

B.2 All surface profile categories

Unless otherwise specified under the individual surface category, the surface finish (i.e. fine-scale roughness) of all surfaces on which scanning is to be carried out shall not exceed 6.3 µm R_a (see BS 1134). A surface finish not exceeding 3.2 µm R_a shall be used for shear wave testing at a frequency of 4 MHz or above.

B.3 Surface profile category SP1: undressed

B.3.1 *General*

No dressing is required except where necessary to remove the source of any confusing ultrasonic signals.

B.3.2 *Inspection*

B.3.2.1 The lower part of the weld and heat-affected zone can be tested for longitudinal imperfections by half-skip techniques. The remainder can be examined by full-skip techniques if the bore is suitably shaped and inaccessible for half-skip examination from the other surfaces. Imperfections in the parent material adjacent to the weld, which would interfere with the shear wave testing of the weld, can be detected with normal probes.

B.3.2.2 The weld and heat-affected zone cannot be examined with normal probes.

B.3.2.3 Echoes from the weld cap may prevent detection of imperfections in or near the weld surface.

B.3.2.4 Transverse imperfection detection is difficult because the probe cannot be placed on the weld.

B.4 Surface profile category SP2: partially dressed to a smooth profile

B.4.1 *General*

The weld cap shall be dressed to a smooth profile, substantially flat across the central portion and blending with the parent material on either side. No attempt is required to dress the cap flush with the parent material.

B.4.2 *Inspection*

B.4.2.1 The examination of the weld for longitudinal imperfections is less restricted than for the undressed condition. The top and bottom parts of the weld can be examined by half-skip techniques, but complete half-skip coverage is restricted by the step at the edge of the weld. The restricted parts can be examined by skip techniques, if the bore is suitably shaped.

B.4.2.2 Normal probes can be placed on the weld but complete coverage is restricted by the step at the edge of the weld.

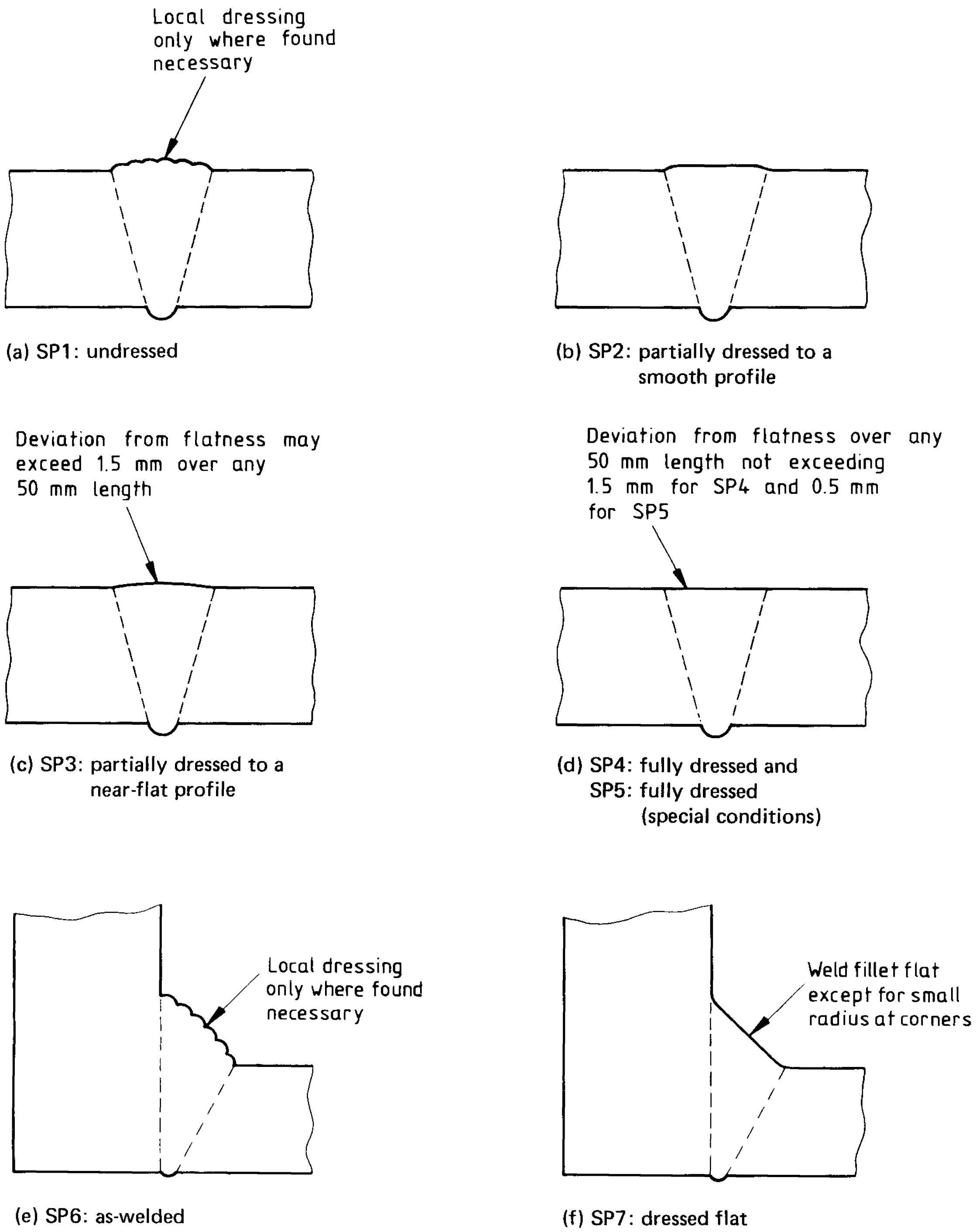


Figure 4 — Schematic representation of the different categories of surface condition

B.4.2.3 The detection of near-surface weld imperfections is better than in the undressed condition because the smooth profile reduces confusing echoes.

B.4.2.4. Transverse imperfection detection is restricted, but less so than for the undressed condition, in particular, the top of the weld can be scanned over most of its area.

B.5 Surface profile category SP3: partially dressed to a near-flat profile

B.5.1 *General*

The weld cap shall be dressed essentially flat and smoothly blended with the adjacent parent material to allow probes to be scanned across the heat-affected zone on to the weld without loss of coupling. The specific requirements of SP4 may not be met at all positions along the weld.

B.5.2 *Inspection*

B.5.2.1 The full weld section can be examined for longitudinal imperfections by half-skip techniques.

B.5.2.2 Normal probe testing of the parent material, heat-affected zones and most of the weld body is possible.

B.5.2.3 Testing of the weld and heat-affected zones for transverse imperfections is possible by half-skip scanning from the weld surface.

B.5.2.4 When scanning over regions where deviations from flatness occur, there will be some loss of both test sensitivity and sizing accuracy compared to that achievable on an SP4 or SP5 surface.

B.6 Surface profile category SP4: fully dressed

B.6.1 *General*

The weld, and where necessary the adjacent parent material, shall be dressed to a sufficiently high standard to allow the probes to be scanned smoothly over the surface while maintaining satisfactory and reproducible coupling. To this end, the following conditions shall be met.

a) The maximum deviation of the surface from its ideal shape shall be less than 1.5 mm in any 50 mm length of surface. On flat or straight sections, this shall be assessed by measuring the maximum gap which can develop under a 50 mm long straight edge placed against the surface. This gap shall be less than 1.5 mm. On curved sections, it shall be assessed by measuring the maximum gap which can develop under a 50 mm long template curved to the nominal radius. This gap shall be less than 1.5 mm.

b) The surface finish of all parts of the surface from which scanning is to be carried out, shall be equal to, or better than 3.2 µm R_a for frequencies of 4 MHz and above, or 6.3 µm R_a where examination at lower frequencies is required.

B.6.2 *Inspection*

This category allows the highest standard of imperfection detectability, although in certain cases, sizing accuracy may be lower than achievable on surface finish SP5.

NOTE A minimum standard of SP4 should be specified where a critical examination for transverse imperfections is called for.

B.7 Surface profile category SP5: fully dressed (special conditions)

B.7.1 *General*

This condition is as specified for SP4 (see **B.6**), except that in **B.6** a) the maximum deviation of shape shall be 0.5 mm, instead of 1.5 mm, in any 50 mm length of surface.

B.7.2 *Inspection*

SP5 allows the highest standard of ultrasonic testing, subject to any restrictions imposed by counterboring and access, and shall be specified only upon explicit agreement prior to contract, except where local dressing is required for imperfection sizing (e.g. in Table 3 to Table 6).

B.8 Surface profile category SP6: as-welded (non-linear welds)

No dressing is carried out except where necessary to remove the source of confusing ultrasonic signals.

B.9 Surface profile category SP7: dressed flat (non-linear welds)

The weld fillet shall be dressed smooth and flat across its width, except at the corners where a small radius is necessary to blend into the parent material. The surface roughness shall not exceed 3.2 µm R_a.

This category shall only be specified where it is required to carry out scans with the probe placed on the weld surface, and the weld fillet is more than 30 mm wide.

Appendix C Guidance on probe selection

C.1 General

The choice of probe for any application should take into account the following features of the weld to be examined:

a) joint thickness and diameter;

b) joint geometry;

c) surface conditions of the weld;

d) metallurgical structure of the weld and parent materials;

e) type, position and orientation of possible weld imperfections.

The choice of probe will also depend in part on whether it is to be used for the initial detection and preliminary evaluation of imperfections, or for their detailed characterization and sizing.

Probe selection is generally a compromise and should be based on the factors detailed in **C.2** to **C.7**.

C.2 Frequency

Probe frequency has an effect on the following features of probe performance.

a) **Resolution.** An increase in the ultrasonic frequency will decrease the pulse length and reduce the angle of beam spread for a given transducer size. These effects will improve the resolution in range and resolution normal to the beam axis respectively, and hence the accuracy of imperfection sizing.

b) **Attenuation.** High frequency waves are more rapidly attenuated in their passage through the parent material and weld metal, and this effect becomes increasingly important at long beam path ranges and in materials having a coarse metallurgical structure. For practical purposes shear wave angle probes of 4 MHz to 6 MHz can be used up to ranges of 200 mm in materials of normal grain structure but, at longer ranges or in more highly attenuative materials, the probe frequency should be in the range 2 MHz to 3 MHz. Compression wave probes can be used satisfactorily at much longer ranges.

c) **Coupling.** Lower frequency probes are more tolerant of surface roughness than probes of 4 MHz to 6 MHz and are advisable if the operator is obliged to assess imperfections by echo height on surfaces of variable roughness.

d) **Minimum discontinuity size.** It is generally accepted that the minimum discontinuity that can be detected is about half the ultrasonic wavelength, provided the noise is not excessive.

e) **Reflection characteristics.** In the same way that a low frequency probe will have a wider beam in the far field than a higher frequency probe of the same size, so the reflected beam from a discontinuity will also be wider. This effect aids the detection of unfavourably orientated imperfections particularly if large, smooth and planar, e.g. the unfused root in certain double-sided welds.

C.3 Transducer size

The smaller the transducer, the smaller the length and width of the near field and the larger the beam spread in the far field at a given frequency.

Small probes having 5 mm to 10 mm diameter transducers (or rectangular transducers of equivalent area) are therefore most useful when working at short beam path ranges. For longer ranges, i.e. greater than 100 mm for normal probes and greater than 200 mm for angle probes, a transducer diameter of 15 mm to 25 mm is more suitable.

On curved surfaces, particularly if concave, far greater uniformity of coupling can be obtained with a probe having a small contact face (see also **C.5**).

C.4 Pulse length

For a given frequency a probe may vary considerably in the degree of damping applied to the transducer and consequently in the length of the ultrasonic pulse produced. For most purposes a short pulse is advantageous as it gives better range resolution. However, when using the DGS system for measuring equivalent disc reflector diameters, more consistent results may be obtained with a longer pulse probe on account of its narrower frequency spectrum.

C.5 Probe shoe shape

When testing components of less than 150 mm diameter it is generally found advantageous to shape the probe shoe to the contour of the scanning surface, where the design of the probe allows. This prevents probe rock, improves coupling, and reduces the effect of the curved surface on the shape of the transmitted beam.

If the probe shoe is shaped, curved test blocks for the determination of the probe parameters, calibration of the time base, and setting of the reference sensitivity will probably be required.

C.6 Probe angle

The choice of fixed probe angles available for practical weld examination is limited to zero degrees (i.e. compressional wave normal probe) and between 35° and 80° (i.e. shear wave angle probes). Variable angle probes are now available and the use of these is permissible for special applications.

NOTE Compressional wave angle probes are now available for austenitic welds, but are not required and should not be used on ferritic steel welds.

An important principle in choosing the probe beam angles is to promote the detection of any planar discontinuities by specular (mirror-like) reflection. This is because specular signals are usually strong and clear. There are three common configurations of probe and planar reflector by which specular signals can be obtained:

a) by directing the beam to strike the expected plane of the discontinuity at normal incidence, e.g. the examination of a weld fusion face by a probe giving normal incidence;

b) for planar discontinuities which form 90° corners with a surface of the joint, by directing a beam from a shear wave probe into the corner at an angle of incidence which avoids amplitude loss due to mode conversion [see the paragraph following c)], e.g. the root inspection of single-sided in-line butt welds using a 45° shear wave probe at half-skip;

c) by using separate transmitting and receiving probes as in the tandem technique; such more complex arrangements might be used for special applications.

In choosing a probe angle it has to be remembered that a beam incident on a reflecting surface at approximately 30° will undergo a mode conversion with a consequent loss in reflected shear wave energy of up to 20 dB. This is of particular significance when evaluating corner reflectors, for which purpose the probe should be chosen to give an incident angle to the discontinuity of between 40° and 55°. If lack of access prevents this being achieved, an incident angle of between 65° and 75° should be used, although there will be some loss of shear wave energy due to mode conversion.

When shear wave beams are incident on large reflectors at between 25° and 35°, the strong compressional wave beam produced often gives rise to large spurious signals which may appear to originate from areas in the weld which are actually sound.

Where possible, shear wave probes with angles less than 38° should be avoided due to the probable generation of subsidiary compressional wave beams. Similarly, angles above 70° to 75°, depending on surface contour and roughness, should be avoided due to the production of spurious surface wave echoes.

C.7 Single/twin crystal probes

The single crystal probe is the most widely used type for weld examination and should be preferred at all ranges above a value that is from 15 mm to 30 mm, depending on dead zone length. Certain highly damped single crystal probes may be satisfactory down to ranges of 2 mm to 5 mm on well-dressed surfaces.

At longer range, the sensitivity is generally better than for twin crystal probes, and the variation in axial intensity with range is more predictable.

Twin crystal probes are generally used for scanning close to the test surface as there is no apparent dead zone to mask any imperfection echoes. The separate transmitting and receiving transducers are generally "toed-in" by a few degrees (i.e. focused) to improve short range sensitivity, but their performance falls off rapidly on either side of the focal range.

Twin crystal normal probes have the advantage over most single crystal types of allowing shaping to fit the contact surface. Their plastic shoes also allow more constant coupling than a hard faced probe.

Appendix D Counterboring and access for scanning

D.1 Counterboring

Counterboring can cause difficulties in ultrasonic examination for the following reasons.

a) Echoes from an abrupt step close to the weld root can be confused with root imperfection indications.

b) When full-skip testing, a stepped-bore may give rise to additional echoes which confuse interpretation beyond the half-skip range.

c) A steeply tapered bore will cause deviation of the beam, and may generate strong echoes due to mode changes.

d) Machining marks on the counterbore can cause confusing echoes.

To overcome these problems, the type and extent of the counterbore should be designed accordingly, and the ultrasonic operator should have detailed knowledge of the counterbore employed and take this into account when examining the weld.

The following four conditions of counterbore are acceptable:

1) CB1: parallel counterbore with step well clear of the bounce position for full-skip examination of the nearside of the weld;

2) CB2: parallel counterbore with step clear of weld root but not necessarily beyond the bounce position of CB1;

3) CB3: parallel counterbore with step position carefully controlled such that the lower part of the weld may be inspected within half-skip range in front of the counterbore, and the upper part between half-skip and full-skip range with the bounce from the inside surface occurring behind the counterbore;

4) CB4: tapered counterbore, consisting of a shallow, well defined, taper (5°).

These conditions are illustrated, and the relevant dimensions given, in Figure 5.

D.2 Access for scanning

D.2.1 ***General***

Restrictions on the access for scanning may take two forms:

a) preventing the operator from manipulating the probe on the chosen scanning surface, e.g. down the length of a small diameter branch;

b) restricting the range of movement of the probe on the scanning surface due to sudden changes in surface contour or the presence of a physical obstruction.

D.2.2 ***Bore access***

Access for scanning from the bores of components is limited by the distance down the bore that the operator has to reach, termed "length of reach", *H*, and by the bore diameter, *D*. Unrestricted access, allowing imperfection detection and sizing to be carried out, is obtained when *H* is less than *D*, provided that *D* is not less than 175 mm.

Partially restricted access, allowing imperfection detection but limiting imperfection sizing, is obtained when *H* is greater than *D* but less than 2*D*, again provided that *D* is not less than 175 mm, and that *H* is not more than 750 mm. Outside of these values no useful examination is possible.

D.2.3 ***Restriction to scanning zone***

Table 32 gives a guide to the minimum lengths of unobstructed straight *L* necessary to meet the requirements of Examination Levels 1, 2 and 3. For the purposes of this table, the term "straight" includes curved surfaces of uniform radius. Sketches of the main types of weld showing the positions from which the values of *L* are measured are illustrated in Figure 6.

Geometrical features of the design may sometimes prevent the distances called for in the table from being attained in practice. However, provided the length of straight on both sides of the weld is not less than the parent material thickness plus 20 mm, and the surface condition is SP3 or better, full coverage of the weld is generally possible, albeit to a lower standard, particularly with regard to sizing accuracy.

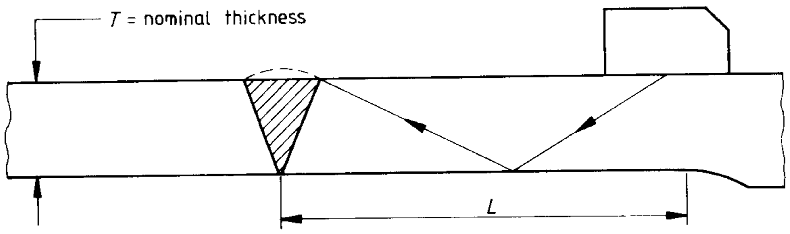
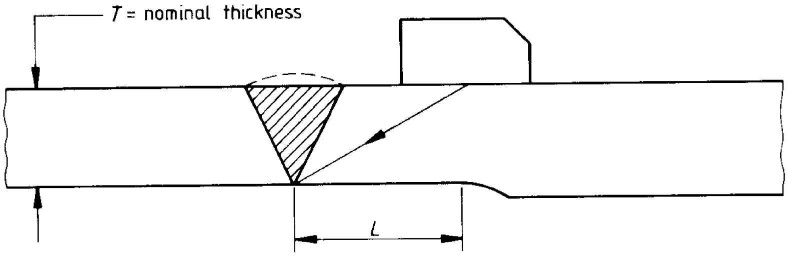
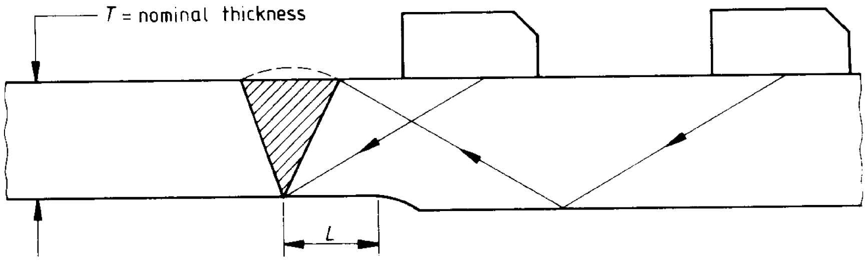
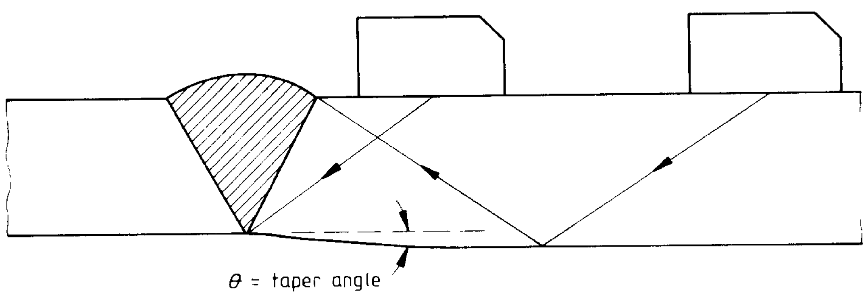
	Wall thickness, *T*	Counterbore Length, *L*
	mm	mm
 (a) Counterbore option CB1	⩽ 40 > 40	⩾ 4 *T* ⩾ 3 *T*
 (b) Counterbore option CB2	< 20 20 to 40 40 to 80 > 80	⩾ 12.5 ⩾ 15 ⩾ 20 ⩾ 25
 (c) Counterbore option CB3	< 20 20 to 40 40 to 80 > 80	12.5^{+5}_{0} 15^{+5}_{0} 20^{+5}_{0} 25^{+5}_{0}
 (d) Counterbore option CB4	$\theta \leqslant 5°$	

Figure 5 — Four acceptable options of counterbore

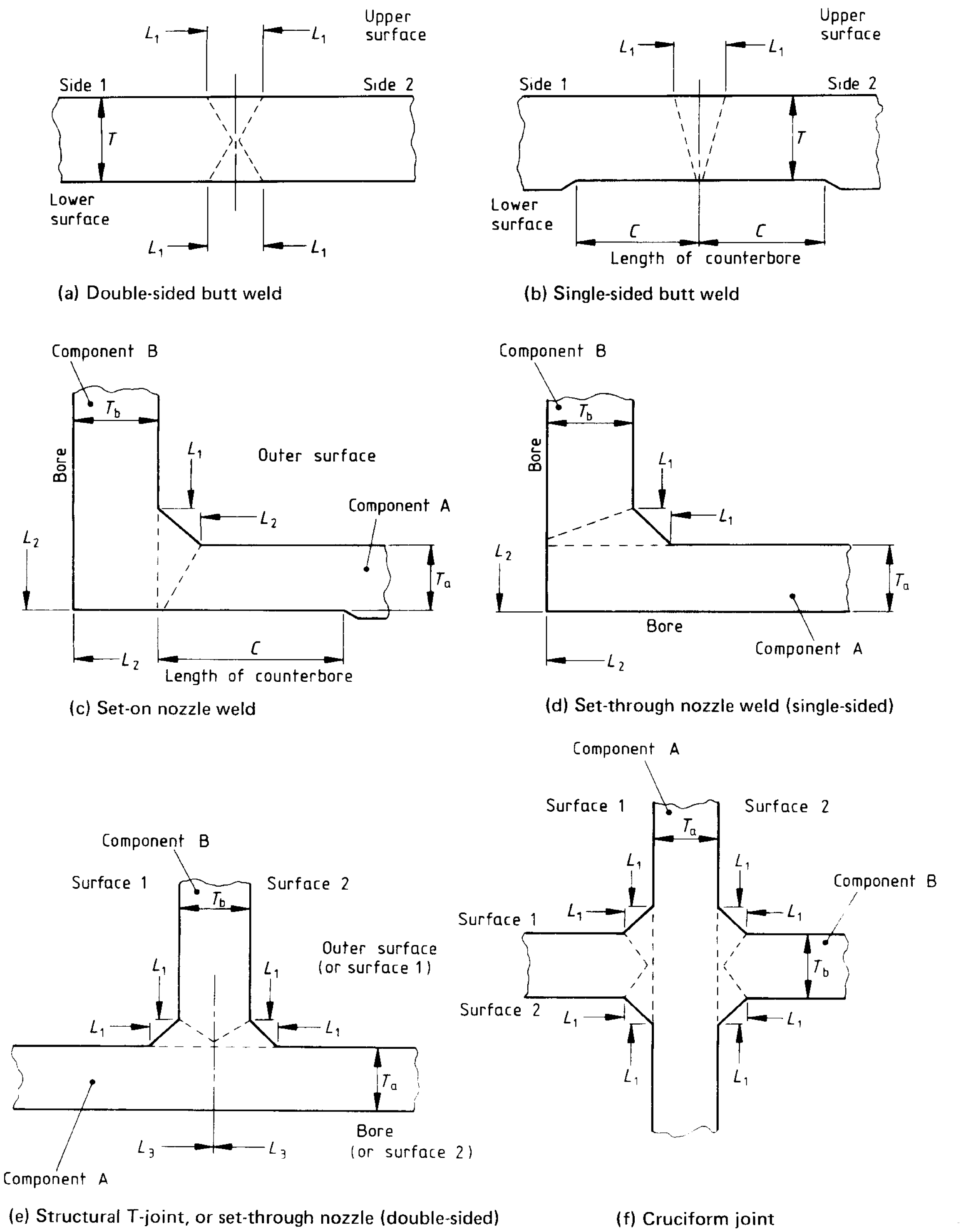


Figure 6 — Sketches showing the position from which the values of *L* (length of straight) and *C* (length of counterbore) are measured

Table 32 — Minimum length of straight, L, necessary to meet the requirements of Examination Levels 1, 2 and 3 for different types of welded joint

Weld type	Scanning surface		Length of straight, L	
			Examination Levels 1, 2 and 2A	**Examination Levels 2B and 3**
Butt double-sided	Upper	Sides 1 and 2	$L_1 \geqslant 2T + 100$ for $T \leq 35$ $L_1 \geqslant 2T + 20$ for $T > 35$	As Examination Level 1
	Lower	Sides 1 and 2	$L_1 \geqslant 2T + 100$ for $6 < T < 35$[a] $L_1 \geqslant 2T + 20$ for $T > 100$	$L_1 \geqslant 100$ for $T > 100$
Butt single-sided	Upper	Sides 1 and 2	$L_1 \geqslant 2T + 100$ for $T < 50$ $L_1 \geqslant 2T + 20$ for $T > 50$	As Examination Level 1
Set-on branch	Component A	Outer	$L_1 \geqslant 2T_a + 100$ for $T_a < 50$ $L_1 \geqslant 2T_a + 20$ for $T_a > 50$	As Examination Level 1
		Bore	$L_2 \geqslant 1.5\ T_b + 2T + 20$	—
	Component B	Outer	$L_1 \geqslant 2T_b + 20$[b]	$L_1 \geqslant 2T_b + 20$ for $T_a > 50$
		Bore	$L_2 \geqslant 1.5T_a$[c]	—
Set-on nozzle	Component A	Outer	$L_1 \geqslant 2T_a + 100$ for $T_a < 50$ $L_1 \geqslant 2T_a + 20$ for $T_a > 50$	As Examination Level 1
		Bore	$L_2 \geqslant 1.5T_b + 2T_a + 20$[d]	
	Component B	Outer	$L_1 \geqslant 2T_b + 20$[e]	
		Bore	$L_2 \geqslant 1.5T_a$[c]	$L_2 \geqslant 1.5T_a$ for $T_a + 50$[c]
Set-on stub	Component A	Outer	$L_1 \geqslant 6T_a + 20$	As Examination Level 1
Set-through nozzle, single-sided	Component A	Outer	$L_1 \geqslant 2T_a + 20$	—
		Bore	$L_2 \geqslant 1.5T_b + T_a + 20$[f]	$L_2 \geqslant 1.5T_b$[f]
	Component B	Outer	$L_1 \geqslant 2T_b + 100$ for $T_b < 50$ $L_1 \geqslant 2T_b + 20$ for $T_b > 50$	As Examination Levels 1 and 2
		Bore	$L_2 \geqslant 2T_b + T_a + 100$ for $T_b < 50$ $L_2 \geqslant 2T_b + T_a + 20$ for $T_b > 50$	As Examination Levels 1 and 2
Set-through nozzle, double-sided	Component A	Outer	$L_1 \geqslant 2T_a + 20$	—
		Bore	$L_3 \geqslant T_b + T_a + 20$[f]	$L_3 \geqslant T_b + 20$[f]
	Component B	Side 1	$L_1 \geqslant 2T_b + 100$ for $T_b < 50$ $L_1 \geqslant 2T_b + 20$ for $T_b > 50$	As Examination Levels 1 and 2
		Side 2	$L_1 \geqslant 2T_b + 100$ for $T_b < 50$ $L_1 \geqslant 2T_b + 20$ for $T_b > 50$	As Examination Levels 1 and 2

[a] Examination Level 1 only.
[b] Examination Levels 1 and 2 where no access to bore of B.
[c] Where bore of B is accessible.
[d] Not required for Examination Level 2 if $T_a < 50$ and bore of B is accessible.
[e] Examination Levels 1 and 2 where no access to bores of A or B.
[f] Where bore of A is accessible.

Table 32 — Minimum length of straight, L, necessary to meet the requirements of Examination Levels 1, 2 and 3 for different types of welded joint

Weld type	Scanning surface		Length of straight, L	
			Examination Levels 1, 2 and 2A	Examination Levels 2B and 3
Structural T-joints	Component A	Side 1	—	—
		Side 2	$L_3 \geqslant T_b + T_a + 20$	$L_3 \geqslant T_b + 20$
	Component B	Side 1	$L_1 \geqslant 2T_b + 100$ for $T_b < 50$ $L_1 \geqslant 2T_b + 20$ for $T_b > 50$	As Examination Levels 1 and 2
		Side 2	$L_1 \geqslant 2T_b + 20$	As Examination Levels 1 and 2
Cruciform joints	Component A	Side 1	$L_1 \geqslant T_a + 20$	—
		Side 2	$L_1 \geqslant T_a + 20$	—
	Component B	Side 1	$L_1 \geqslant 2T_b + 100$ for $T_b < 50$ $L_1 \geqslant 2T_b + 20$ for $T_b > 50$	As Examination Levels 1 and 2
		Side 2	$L_1 \geqslant 2T_b + 100$ for $T_b < 50$ $L_1 \geqslant 2T_b + 20$ for $T_b > 50$	As Examination Levels 1 and 2
Node joints	Components A and B	Outer and bore	No restriction to length of straight normally encountered.	

NOTE Guidance equations for probe "stand-off" calculations are based on a combination of highest practical probe angle (lowest dip angle) and maximum plate/pipe thickness within each specified range. As a general rule the minimum "stand-off" for full-skip testing is given by the equation $L_1 = 2T + 100$ mm and for half-skip by the equation $L_1 = 2T + 20$ mm, where L_1 is the minimum stand-off and T is the plate thickness.

Appendix E Location of root: in-line butt welds

E.1 General

Before commencement of testing it is very important that the exact position of the weld root is known. This is particularly so when testing single-sided welds where the root is undressed and inaccessible.

Wherever practical, one side of the joint shall be marked prior to welding at a stipulated distance from the weld centre line. This shall be done in such a way as not to interfere with subsequent scanning of the weld.

When premarking of the material has not been carried out, the ultrasonic methods described in **E.2**, **E.3** or **E.4** shall be used to position the weld root in single-sided welds.

Where the weld root is at right angles to the longitudinal axis of the pipe, the first action shall be to establish a datum line around the pipe parallel to the root, i.e. at right angles to the pipe axis, from which all the basic measurements referred to are taken.

NOTE These are essentially trial and error methods and there will be many instances where these methods do not accurately position the centre of the root.
An offset run or one that is not straight are obvious exceptions.

E.2 Normal probe method

This method is only applicable where the weld cap has been dressed sufficiently smooth and flat to enable probe contact to be maintained over the width of the weld.

A normal probe, having a narrow beam at the beam path range of the weld root shall be traversed across the ground surface of the weld and the protrusion of the root detected by the presence of an additional echo at a slightly longer range than the back wall echo.

A similar effect is obtained when a backing material has been used, provided there has been fusion on to the backing ring. The probe position shall be adjusted to bring this additional echo to maximum height, and the position of the root marked off from the centre of the probe as shown in Figure 7. This shall be repeated at intervals along the weld and the points joined to give a continuous centre line.

E.3 Angle probe method 1

This method can be used when the parent metal on either side of the weld is of the same thickness.

Using a narrow beam, high resolution angle probe the weld root shall be scanned from one side and the probe positioned to maximize the root echo. The probe position P1 shall be marked on the surface of the material, and the beam path length D recorded. The probe shall then be transferred to the other side of the weld and the probe positioned (P2) so that the root echo is also at beam path length D.

NOTE This may not be at the position for maximum echo height from this side of the weld.

The position of the weld root, assuming normal root penetration, will be exactly between positions P1 and P2, as shown in Figure 8.

E.4 Angle probe method 2

This method is applicable when the parent materials are of either equal or unequal thickness. The thicknesses of the parent materials adjacent to the weld shall first be measured ultrasonically and the beam path length D_1 and the surface distance d_1 for one side of the weld calculated. Using a shear wave probe of suitable angle, the root shall be scanned from this side of the weld and any echo at path distance D_1, or slightly more shall be maximized at position P1 and the appropriate surface distance d_1 marked off. This shall be repeated from the other side of the weld, using values D_2 and d_2, and position P2 (see Figure 9).

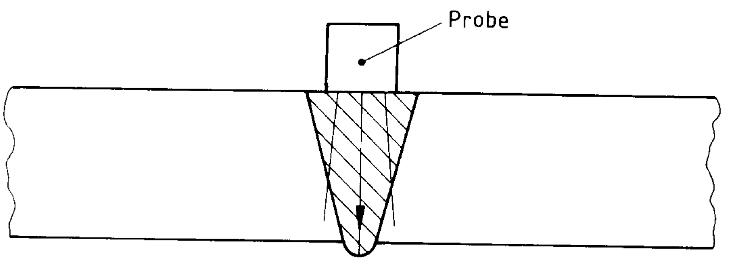


Figure 7 — Locating the root using a normal probe

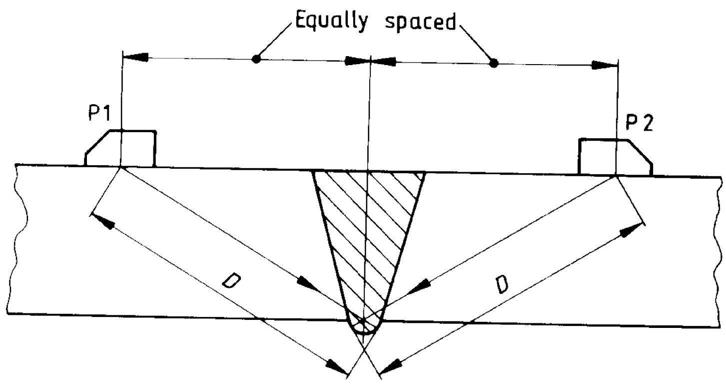
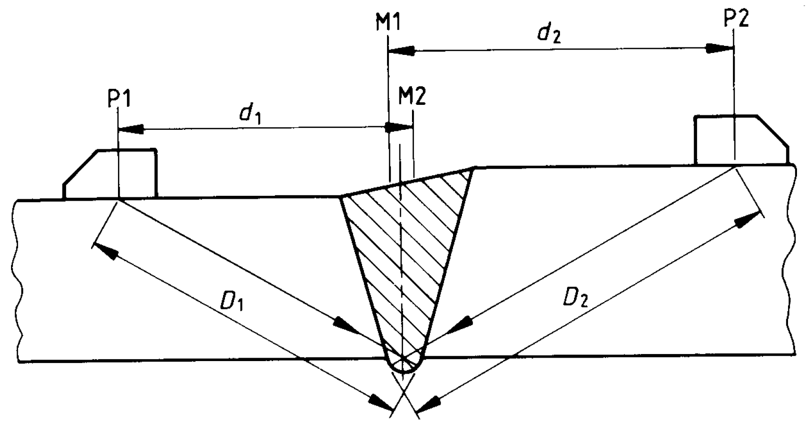


Figure 8 — Locating the root using angle probes: method 1



NOTE The midpoint between the marked positions M1 and M2 is the centre line of the root.

Figure 9 — Locating the root using angle probes: method 2

Appendix F Methods for the examination of weld root

F.1 Single-sided weld methods

F.1.1 *Method*

A fixed root scan, at the half-skip position, shall be performed by utilizing a guide strip or bar so that the distance from the probe index to the root will remain constant (see Figure 10).

The probe shall be moved continuously along the weld, and all echoes noted that occur at a path distance equal to or less than the calculated value to the centre of the weld root. When such echoes are observed they shall be maximized by moving the probe forward in order to determine their position or extent through the weld thickness.

When this scan is limited to one side of the weld only, e.g. on some branch or nozzle welds, it is particularly important that the vertical extent of reflecting surfaces on the far side of the weld shall be determined, as this is the only way in which serious root imperfections at this position can be distinguished from the normal root bead.

The technique requires a high resolution shear wave angle probe. The beam angle will depend on the parent metal thickness and curvature of the surface, and shall be chosen to avoid:

a) approaching too close to the weld cap or to any unevenness on the surface caused by weld dressing;

b) the use of excessive beam path lengths, with consequent loss in ranging accuracy.

NOTE 1 In choosing a beam angle, it has to be remembered that a beam incident on a reflecting surface near 30° will undergo a mode conversion which may give rise to spurious indications. There will also be a loss of shear wave energy of up to 200 dB.

NOTE 2 The use of compressional wave probes for the detection of corner echoes should always be avoided because of the very high loss in reflected beam energy due to mode change.

The probe(s) to be used, and the time base of the flaw detector, shall be calibrated in accordance with the requirements of **5.4**.

The test sensitivity shall be in accordance with **10.2.2** (or, for Examination Level 4, as agreed between the contracting parties).

NOTE 3 A guide to the ultrasonic interpretation of the main types of root condition, where there is access to both sides, is contained in Figure 11.

Although illustrated for through-bead welds, the same principles shall be applied to welds with backing material.

F.1.2 *Coverage*

The root shall be scanned along the full length of the weld from both sides of the weld in turn. Where it is not possible to scan from the second side of the weld, the capability of the technique is seriously reduced.

The rate of scanning round the weld shall not exceed 25 mm/s.

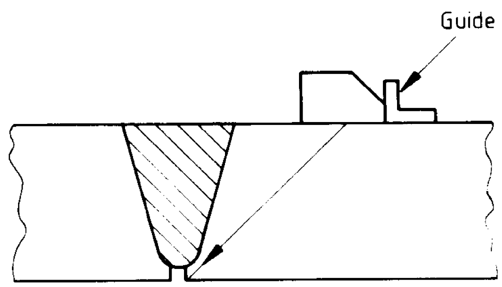
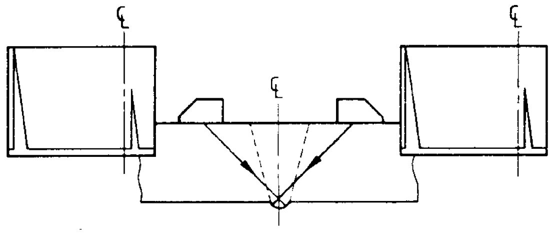
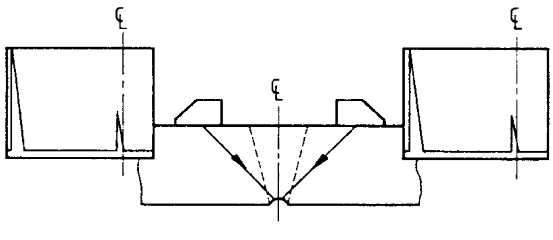


Figure 10 — Use of guide strip for checking weld root and plotting excess penetration or incomplete root penetration



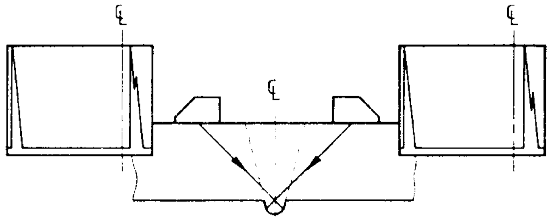
NOTE Single sharp echo slightly to right of centre line position, from both sides of weld.

(a) Satisfactory weld root



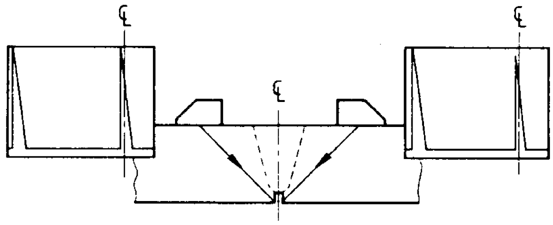
NOTE Small echo slightly to left of centre line position, from both sides of weld.

(b) Root concavity



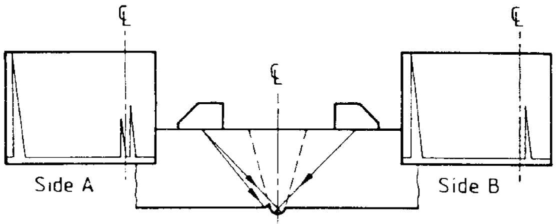
NOTE Single echo either sharp or showing subsidiary maxima, generally of higher amplitude and at slightly longer range than for a normal penetration weld, from both sides of weld.

(c) Excess penetration



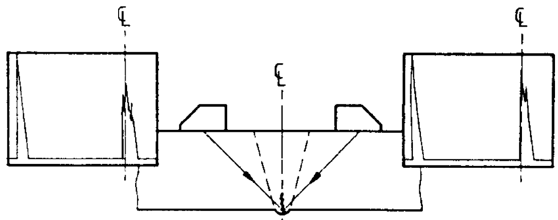
NOTE Single strong echo very slightly to the left of the centre line position, from both sides of weld.

(d) Incomplete root penetration



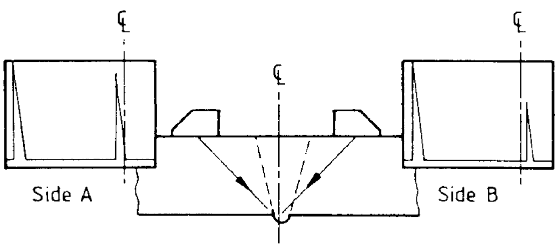
NOTE Echo from bead penetration from both sides of weld, plus small additional echo to the left of the centre line position on side A. Probe movement shows only very small vertical dimension.

(e) Root undercut

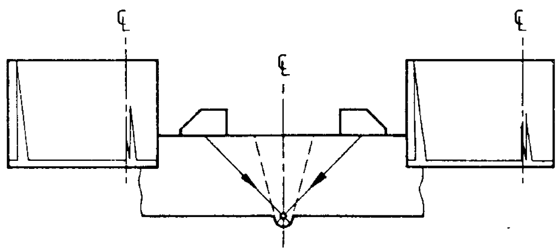


NOTE Echo at centre line position from both sides of weld. Echo may be sharp or show subsidiary maxima, as illustrated, and measurable vertical dimension with probe movement from both sides of weld. If imperfection is small an additional echo from the penetration bead may be obtained from both sides of weld.

(f) Root centre line crack



(g) Crack or lack of fusion at edge of root bead



(h) Pipe or pipes in weld root

Figure 11 — Ultrasonic echo response from different types of weld root condition

F.2 Double-sided weld methods

F.2.1 *Methods*

On double-sided welds the root shall be scanned at not more than 20° from the normal to the root plane, either as part of the general weld examination or as a separate scan as shown in Figure 12.

NOTE In the case of a longitudinal weld in a cylindrical component, as shown in Figure 13, near specular reflection may occur on much thicker sections.

Where the above conditions cannot be met using one probe only, the tandem technique, illustrated in Figure 14, shall be employed. Two separate probes of the same angle and frequency shall be used, one acting as transmitter, the other as receiver. Both shall be maintained at the correct distance from the weld centre line as the probes are moved together along the length of the weld.

NOTE 1 A probe angle of 45° is recommended for the tandem scan, a nominal frequency of 4 MHz to 5 MHz for thicknesses below about 75 mm, and 2 MHz to 2½ MHz for greater thicknesses. In general, a scanning sensitivity some 6 dB to 10 dB lower than the values given in **10.2.2** will be found satisfactory.

NOTE 2 The performance in tandem is not significantly altered by putting the receiver probe in front of the transmitter. Nevertheless, calibration should be carried out with the probes in the same relative positions as during the scan.

Imperfection sizing by this method is difficult, but an approximate measure of the size of large imperfections can be obtained using the 6 dB drop technique by moving one probe gradually forwards and the other probe backwards by the same amount so that their beam axes continue to intersect along the plane of the imperfection. Smaller imperfections should be assessed from their echo height in comparison with known criteria.

Tandem probe scanning is a specialized technique and, before its use for critical applications, it is advisable to consult published literature for further details.

F.2.2 *Coverage*

When using one probe, the root area shall be scanned by to and fro movement of the probe in relation to the weld centre line along scan lines having a pitch not exceeding 0.9 times the transducer width. The full length of the weld shall be scanned from both sides on one surface only or, in the case of restricted access, from both surfaces on one side only. The rate of probe movement along the scan lines shall not exceed 100 mm/s.

When using the tandem technique the weld root shall be scanned continuously along its length from one or both sides on one surface. The rate of movement along the weld shall not exceed 25 mm/s.

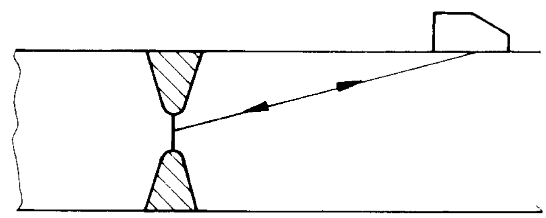


Figure 12 — Detection of incomplete root penetration in thin sections using a shallow angle probe

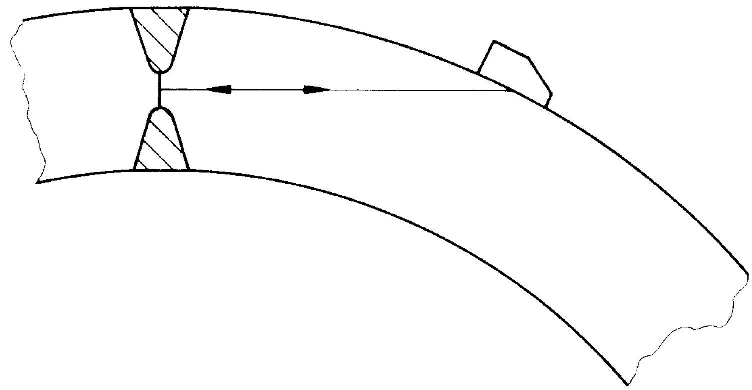
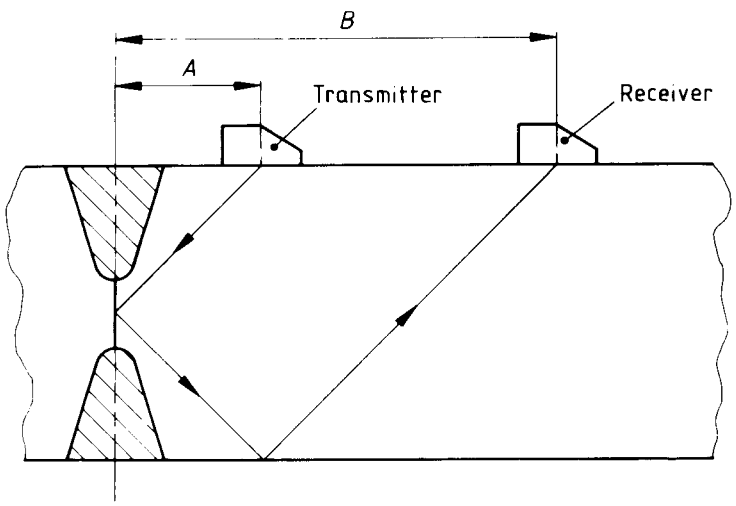


Figure 13 — Detection of incomplete root fusion in thick sections (curved)



NOTE Distances A and B are maintained constant during scan along weld.

Figure 14 — Tandem technique for detection of incomplete root penetration in thick sections

Appendix G Method for weld scan with normal probes

G.1 Method

A single or twin crystal probe having good near surface resolution shall be used.

NOTE For section thicknesses over 50 mm, separate probes may have to be used for the upper and lower parts of the weld.

The nominal probe frequency shall be not less than 4 MHz.

The time base shall be accurately calibrated and, where appropriate, marked to indicate the maximum and minimum acceptable ranges for over penetration and root concavity respectively.

The test sensitivity shall be in accordance with **10.2.2** (or, for Examination Level 4, as agreed between the contracting parties).

In cases where the weld surface is not parallel to the lower surface, the effect of angularity of the beam shall be noted and taken into account with regard to the accuracy of the information obtained.

G.2 Coverage

For examination of the root condition, the weld shall be scanned continuously along its length at a rate not exceeding 25 mm/s.

The full volume of the welded zone shall be examined along scan lines either parallel to or at right angles to the axis of the weld. The pitch of the scan lines shall not exceed 0.8 of the transducer width, and the rate of probe movement along the scan lines shall not exceed 100 mm/s.

Appendix H Methods for weld scan for longitudinal imperfections

H.1 Method: in-line butt joints

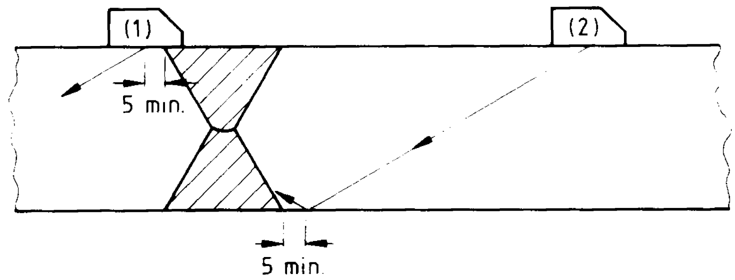
The full weld cross section including the HAZ shall be scanned from at least two directions using a probe having a beam angle within 10° of the normal to the fusion face.

NOTE 1 Where the angle of the fusion face is different on either side of the weld, or changes part way through the section thickness, two or more probe angles are needed to meet this requirement.

NOTE 2 Attention is drawn to the effect on incident angle at the weld of testing on curved surfaces, such as longitudinal welds in cylindrical components (see Figure 2). Not only does the beam angle become shallower with increasing depth through the weld but, for any particular combination of beam angle and radius of curvature, there is a maximum testable thickness.

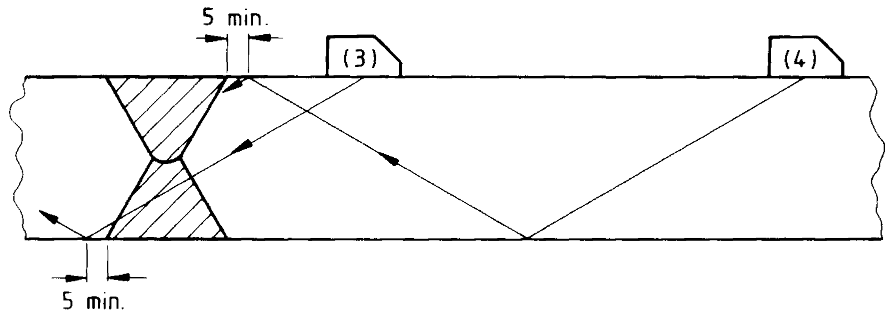
Whether or not they are required for examination of the fusion faces, at least two probe angles shall be used on section thicknesses over 15 mm for more severe Examination Levels in order to detect the more irregularly orientated imperfections.

For the initial detection of imperfections the weld shall be scanned up to the half-skip position (as illustrated in Figure 15). Where this is not practicable, scanning shall be between the half- and full-skip positions (as in Figure 16). In either case scanning shall be to the requirements of Table 3 to Table 6, or as agreed under Examination Level 4.



All dimensions are in millimetres.

Figure 15 — Half-skip examination of weld between probe positions (1) and (2)



All dimensions are in millimetres.

Figure 16 — Half- to full-skip examination of weld between probe positions (3) and (4)

If half-skip scanning is employed from one surface only, an additional scan using a probe of high near surface resolution shall be carried out for the detection of near surface imperfections. Dressing of the weld surface to a minimum standard of SP3 is required in this case.

Scanning between the half- and full-skip positions shall only be employed when the back wall of the parent material is parallel to the test surface and free from steps or excessive roughness in the area over which the beam is reflected.

H.2 Method: non-linear joints

H.2.1 ***General***

This category includes set-on and set-through connections, structural T-joints, cruciform joints and node joints.

The common requirements for these welds are that the full weld cross section and HAZ shall be scanned from at least one direction, and preferably a minimum of two, and that both fusion faces (with the exception of cruciform joints), wherever possible, shall be scanned within 20° of the normal.

Due to the general need to use several scans from different directions to examine the fusion faces, no additional scans are required for the weld body unless stated.

The manner in which these requirements are best met depends on the type of joint (see **H.2.2** to **H.2.7**).

H.2.2 ***Set-on branch and nozzle welds*** (Figure 17)

The side wall of component A shall be scanned:

a) between the half- and full-skip positions from the outer surface of A (scan Q2), or

b) up to the half-skip position from the bore of A (scan P1), or

c) a combination of a) and b).

In choosing which of these scans to adopt, the following points shall be taken into account.

1) Scan P1 may fail to detect imperfections very close to the bore, particularly if the root is not dressed-off flush.

2) A steep side wall on a thick nozzle could lead to very long beam path lengths when working at the full-skip position, and require the use of a lower frequency probe with resultant loss in resolution.

3) Restricted access to the bore may make scan P1 impossible or, at least, more difficult to carry out than scan Q2.

The side wall of component B shall be scanned from the bore of B wherever possible using a normal probe of 4 MHz to 5 MHz (scan S3). The diameter of the probe shall be chosen for its minimum beam width at the fusion face.

Where there is no access for scanning from the bore of B, the B-fusion face shall be examined by a combination of the following scans:

i) scans P1 and P2 in the bore of A, using the shallowest practicable angle for the lower and middle parts of the weld, and a somewhat steeper angle (scan P1 only) for the upper part of the weld in the area of the fillet;

ii) scan Q1 using a shallow beam angle;

iii) scan F1 from the fillet surface where this has been dressed flat and is sufficiently wide (30 mm min.) to allow some degree of probe movement;

iv) scan R2 using a steep angled probe of between 38° and 45°.

NOTE As noted in **9.5.1**, particular attention should be paid to the changes in joint geometry around the weld circumference when selecting probe angles and scanning surfaces.

H.2.3 ***Set-on stub welds*** (Figure 17)

The only scans normally practicable on this type of joint are scans Q1 and Q2 from the outer surface of the stub.

The side wall of component A shall be scanned between the half- and full-skip position (scan Q2) using a beam angle within 10° of the normal to the fusion face.

The lower half of the side wall of component B shall be scanned using the shallowest practicable beam angle (either up to half-skip, or between the half-skip and full-skip positions), and the upper half using a steeper beam angle in order to reach the upper toe of the fillet.

H.2.4 ***Set-through nozzle welds, single-sided*** (Figure 18)

This type of joint presents similar ultrasonic features to set-on nozzles, except that components A and B are reversed in relation to the joint geometry, and many of the comments noted for set-on branches and nozzles are equally applicable to the current joints.

Where possible the side wall of component A shall be scanned from the bore of component A (scan P3) with a normal beam probe that has either been radiused to fit the bore (applicable only to twin crystal probes) or is of a sufficiently small diameter to make satisfactory ultrasonic contact with the bore, and can be used without excessive rocking.

If the bore of A is inaccessible, the side wall shall be scanned using a combination of scans S1, R1, R2, Q2 and F2 as necessary to cover the full depth of the side wall at the optimum angle(s).

The side wall of component B shall be scanned at an angle within 10° of the normal, using scans R2 or S1 or a combination of both, depending on the parent material thickness and the consequent maximum beam path distances required at the optimum angles, and on access to the bore of B.

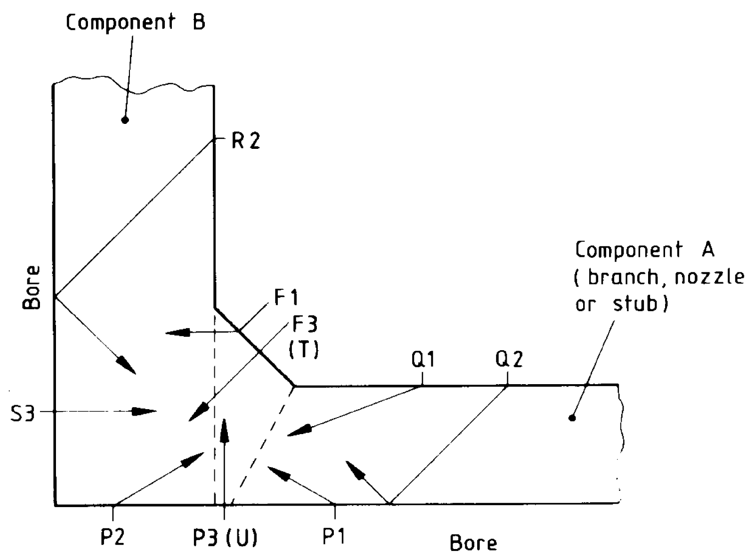


Figure 17 — Section through set-on branch, nozzle or stub weld

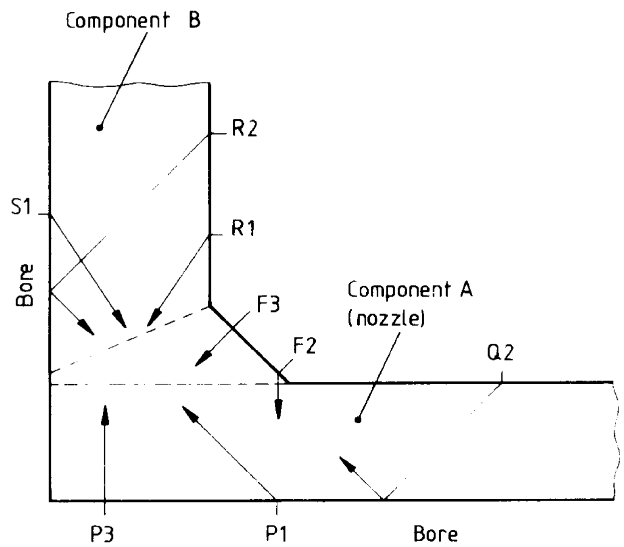


Figure 18 — Section through set-through nozzle weld (single-sided)

H.2.5 ***Structural T-joints and double-sided set-through nozzle joints*** (Figure 19)

The methods of examination shall be similar to those specified for single-sided set-through nozzle joints except that the current joints have to be considered as two separate single-sided welds set back-to-back.

H.2.6 ***Cruciform joints*** (Figure 20)

A feature of this type is that the side walls of component A cannot be examined with a beam normal to the fusion faces.

The A side walls shall be scanned with the shallowest practicable angle probes from the upper and lower surfaces of component B on both sides of component A. Scanning shall be up to the half-skip position (scans S1 and R1) or between the half- and full-skip positions (scans S2 and R2) if the thickness of B is less than 50 mm.

The side walls of components B shall be examined as for structural T-joints.

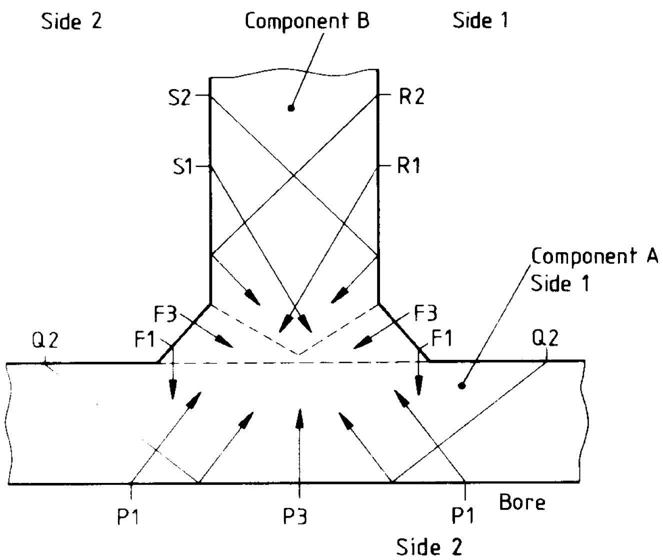


Figure 19 — Section through structural T-joint or set-through nozzle weld (double-sided)

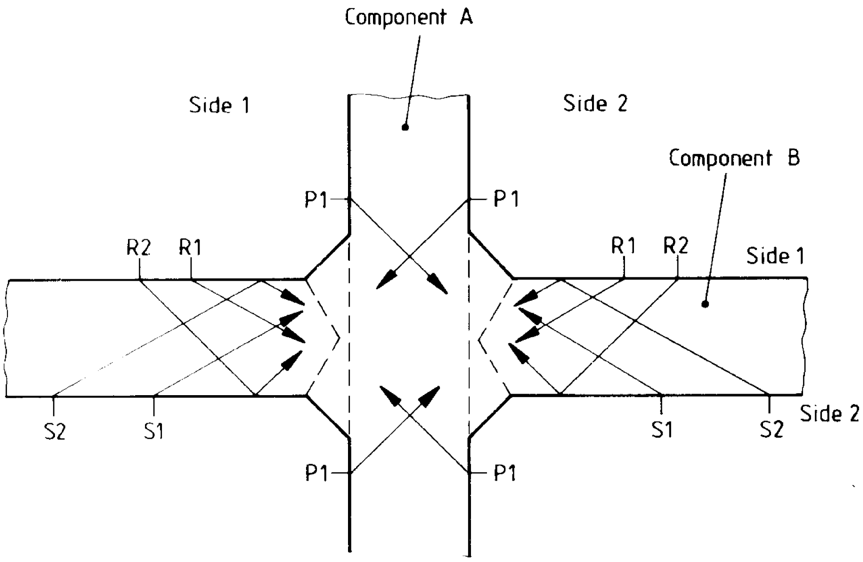


Figure 20 — Section through cruciform joint

H.2.7 ***Node joints*** (see Figure 21 to Figure 26)

A characteristic of oblique node joints is the very severe change in joint geometry around the circumference with consequent change in the weld coverage obtainable with any particular probe. For this reason, cross-sectional views of the joint normal to the weld axis shall be drawn for a minimum of three positions (A, B and C) as illustrated in Figure 21 and Figure 22.

NOTE 1 Additional cross-sectional views at intermediate positions D and E, and at any position where it is necessary to accurately position or size a discontinuity, are strongly recommended.

Each view shall show the actual weld profile, determined using a pin profile gauge or by similar means, and the true curvature along the scanning plane of the parent material from which scanning is to be carried out. The latter shall be determined on the joint to be tested either by means of a flexible curve or by calculation as shown in Figure 26.

NOTE 2 Confirmation of the skip distance and the corresponding beam path range for any position around the joint can be obtained in the following way.

Separate transmitting and receiving probes of the same angle as to be used for the weld examination towards each other along a line normal to the weld axis, and their positions adjusted to obtain maximum through-transmission echo height. The probes will then be at a distance apart equal to the skip distance and, if the time base is calibrated in the normal way, the position of the echo will indicate the beam path range to the half-skip position.

The circumference of the joint shall be divided into a minimum of three inspection zones, but preferably five, and the cross-sectional views through the joint and parent material shall be used to select the optimum probe angles and scanning surfaces, and particularly to determine the limits of the scanning zones at different positions around the circumference.

Where access is available, both surfaces of component A shall be scanned up to the half-skip position (scans Q1 and P1) using three probe angles. If the bore is inaccessible, additional scans on the outer surface shall be carried out between the half- and full-skip positions (scan Q2) using a minimum of two probe angles.

The B side wall of the weld shall be scanned from the bore of component B using a normal probe of 4 MHz to 5 MHz (scan S3). Additional angle probe scans shall be made from this surface (scans S1 and S2) to supplement the examination of the A side wall and to detect toe cracking in component B.

If the bore of component B is inaccessible for scanning, the effectiveness of the examination will be seriously reduced.

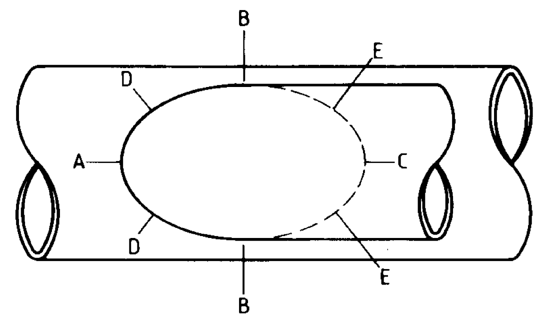


Figure 21 — Plan view of typical oblique node joint showing positions of weld cross sections

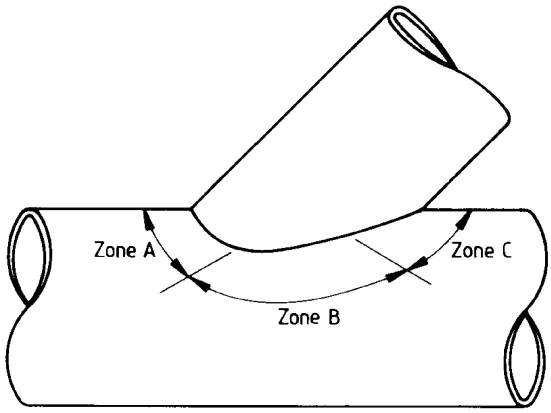


Figure 22 — Side view of node joint showing division into scanning zones

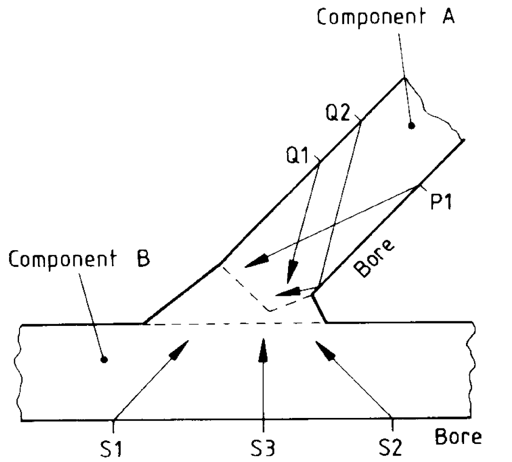


Figure 23 — Section through zone A of node joint

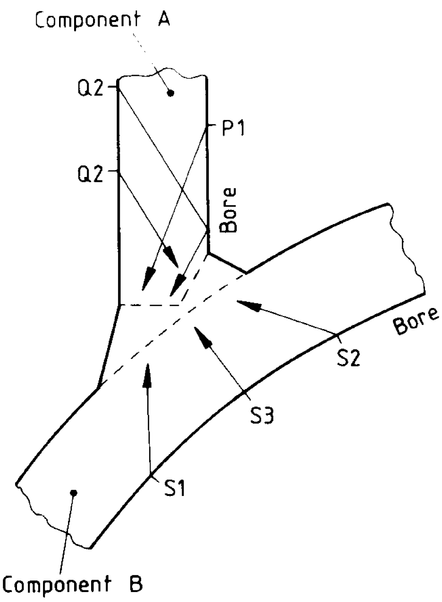


Figure 24 — Section through zone B of node joint

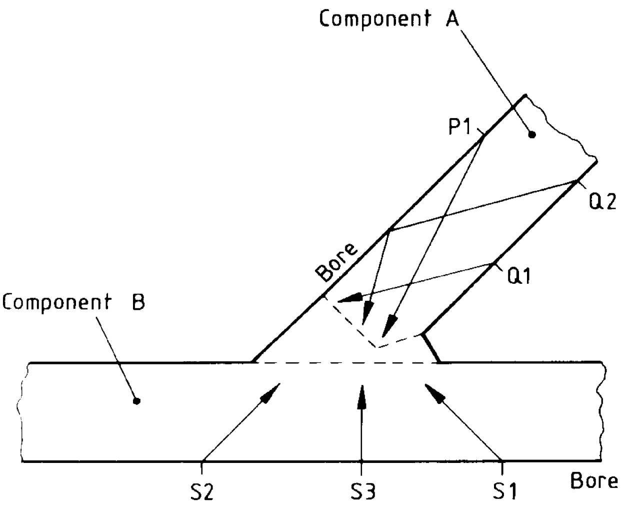
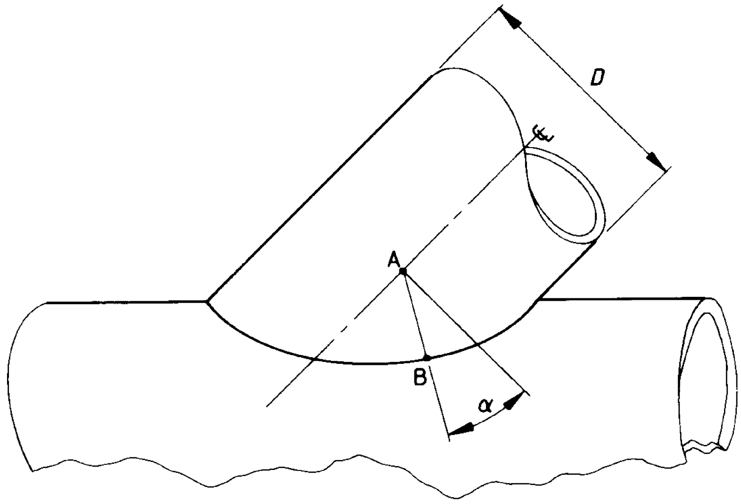


Figure 25 — Section through zone C of node joint



D is the diameter of component;

AB is the scan line normal to weld axis at point B

D_1 is the effective diameter along scan line AB and

$$D_1 = \frac{D}{\cos\alpha}$$

Figure 26 — Calculation of effective diameter at any angle to the axis of a circular component

H.3 Coverage

The full length or circumference of the weld shall be examined along scan lines at right angles to the weld axis. The length of the scan lines shall be such as to give full coverage of the weld cross section including the heat-affected zones, except where scans are intended to cover only specific areas of the weld.

The pitch of the scan lines shall not exceed 0.8 of the transducer width.

The rate of probe movement shall not exceed 100 mm/s.

NOTE During angle probe scanning, a slight oscillating rotational movement, up to 10° on either side of the normal to the weld axis, may be applied to the probe in order to aid the detection of imperfections lying at a slight angle to the weld axis.

Any restrictions caused by lack of access, geometry or inadequate weld surface dressing shall be recorded by the operator, and the effect of this on achieving full coverage of the weld to the agreed acceptance levels shall be stated on the report.

Appendix J Methods of weld scan for transverse imperfections

J.1 Method: in-line butt joints, weld surface dressed

The probe angle(s) shall be chosen to ensure that the beam is within 20° of the normal to the vertical plane throughout the full weld section, and where possible within 10° of the normal. For material thickness above 15 mm at least two probe angles shall be used.

Welds in flat material and longitudinal welds in cylindrical components shall be examined in both directions along their length. Dressed welds over 50 mm thick and undressed welds over 35 mm thick shall be examined from both surfaces, where accessible. Welds below these thicknesses shall be examined from at least one surface. For welds over 15 mm thick, two or more probe angles shall be used, and scanning shall normally be up to half-skip position (see note 1). Welds below 15 mm thick shall be examined with at least one probe angle, and up to the full-skip position.

Circumferential welds in cylindrical components shall be examined from the outer surface in both directions along the weld up to the half-skip position using as many probe angles as necessary to ensure that the beam is within 20° of the normal to the radial plane at all depths through the weld thickness.

NOTE 1 On welds up to 50 mm thick, scanning may be extended to cover the half- to full-skip position, provided this does not involve the use of excessive beam path lengths, and the back wall is smooth and concentric with the outer surface.

An additional angle probe scan in both directions shall be carried out to examine the near surface zone of the weld.

In general all scanning shall be carried out with a 4 MHz to 5 MHz probe because of the higher resolution and greater sensitivity to small reflectors.

NOTE 2 On weld thicknesses above about 75 mm, particularly where there is access for scanning from only one surface, the lower attenuation characteristics and greater tolerance to unfavourably orientated imperfections of lower frequency (2 MHz to 3 MHz) probes are advantageous.

Calibration shall be in accordance with clause **5**, and the test sensitivity shall be in accordance with **10.2.2** (or, for Examination Level 4, as agreed between the contracting parties).

The maximum test range shall not exceed 200 mm for 4 MHz to 5 MHz probes. Above this range 2 MHz to 3 MHz probes shall be used.

J.2 Method: in-line butt joints, weld surface not dressed

With the exception that additional scans for the near surface zone are not applicable, the scans to be applied shall be as for dressed welds (**J.1**).

Calibration, sensitivity, probe frequency and maximum beam path ranges shall be as detailed in **J.1**.

J.3 Method: structural, T-, cruciform and corner joints

The scans to be employed are shown in Figure 27. Scan PT shall be applied to T-joints and corner joints, and scan ST to all three joint types.

NOTE 1 The probe angle should be as shallow as practicable consistent with avoiding excessively long beam paths.

NOTE 2 It is recommended that scanning is carried out with probes of both 4 MHz to 5 MHz and 2 MHz to 3 MHz, as the use of the lower frequency may improve the chances of detecting unfavourably orientated reflectors, and also enables a longer beam path to be used without excessive attenuation.

Calibration shall be in accordance with clause **5**, and the test sensitivity shall be in accordance with **10.2.2** (or, for Examination Level 4, as agreed between the contracting parties).

J.4 Coverage: in-line butt joints

Where the weld cap has been dressed flush with the parent materials, the full length of weld shall be examined in both directions along a number of parallel scan lines across the width of the weld and HAZ as shown in Figure 28.

The pitch of the scan lines shall not exceed 0.8 of the transducer width, and the rate of probe movement shall not exceed 100 mm/s.

During scanning a slight oscillatory rotational movement shall be applied to the probe in order to aid the detection of imperfections lying at a slight angle to the transverse plane.

Where the weld cap has not been dressed, the full length of the weld shall be examined in both directions from both sides of the weld, with the probe constantly oscillated as shown in Figure 29. The rate of probe movement shall not exceed 100 mm/s.

Any restrictions caused by lack of access, geometry or inadequate weld surface dressing shall be recorded by the operator, and the affect of this on achieving full coverage of the weld to the agreed acceptance levels shall be stated on the report.

J.5 Coverage: structural, T-, cruciform and corner joints

Scan PT shall be carried out in both directions along parallel scan lines covering the full width of the weld. The pitch of the scan lines shall not exceed 0.8 of the transducer width.

NOTE 1 During scanning a slight oscillatory rotational movement, up to 10° on either side of the weld axis, may be applied to the probe in order to aid the detection of imperfections lying at a slight angle to the transverse plane.

Scan ST shall be carried out in both directions along a single scan line on each side of the weld as close as possible to the weld fillet. The angle (θ) at which the probe is maintained relative to the weld axis shall be calculated to ensure that the ultrasonic beam passes through the centre of the weld on the opposite side of the joint.

NOTE 2 If necessary, in order to cover the full weld section, this scan should be repeated at one or more different angles to the weld axis.

A slight oscillatory rotational movement of the probe during scanning shall be used to aid coverage of the full weld volume.

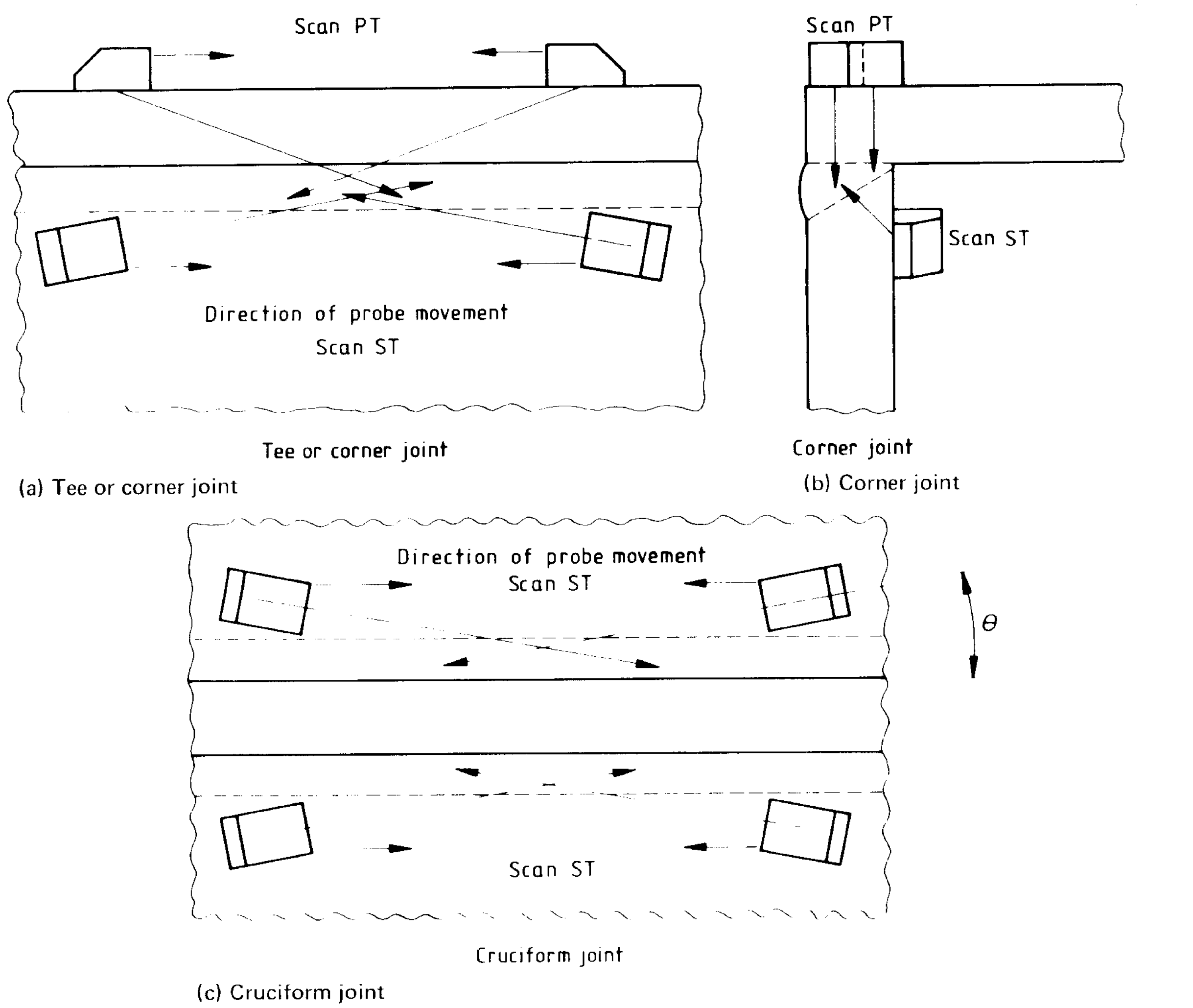


Figure 27 — Scans for transverse imperfections: non-linear joints

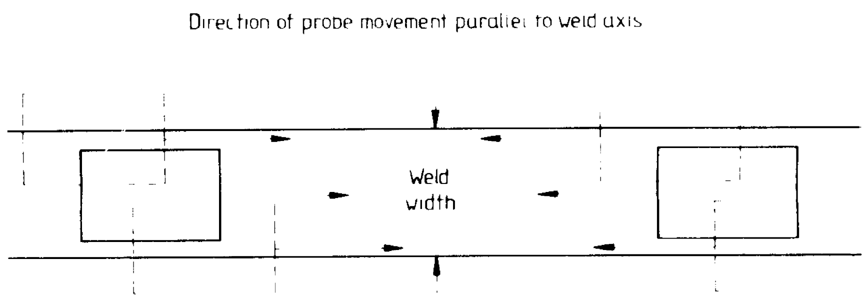
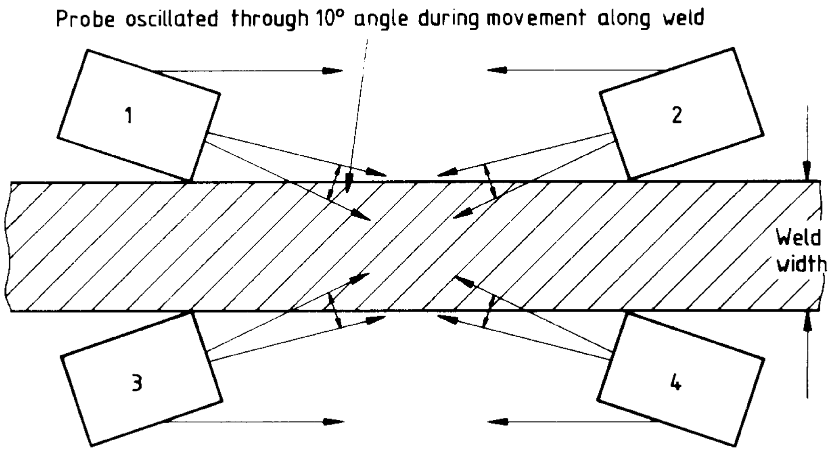


Figure 28 — Scan for transverse imperfections: weld surface dressed flush



NOTE Direction of probe movement parallel to weld axis.
NOTE Scans (1) to (4) to be carried out in turn.

Figure 29 — Scan for transverse imperfections: as-welded surface

Appendix K Preparation of distance/amplitude correction (DAC) curve

K.1 Test block

The form of test block suitable for plotting a DAC curve for either a normal or angle probe is shown in Figure 30. The size of the block and the number and spacing of the target holes shall be such that the full testing range for the weld examination shall be covered by at least four approximately equally spaced holes. The holes shall be of 3 mm diameter, drilled transverse to the beam axis (side-drilled holes) and used in either the 0 to half-skip or half-to full-skip positions.

For 0 to half-skip or near surface examination, the distance of the nearest hole to the test surface of the block shall not exceed *T*/8 or 6 mm, whichever is the larger. The remaining holes shall be approximately equally spaced through the thickness.

The test block shall be either:

a) in the form of a general purpose block made to the requirements of **3.1**, **3.2** and clauses **4**, **5** and **6** of BS 2704:1978, i.e. of uniform low attenuation material and machined to specified dimensional tolerances and surface finish, or

b) of the same acoustic properties, surface finish and shape as the component under examination.

NOTE In the case of type a), correction for attenuation and coupling losses may be necessary before the DAC curve can be directly applied.

Where the parent material has an outside radius of less than 250 mm, a curved test block having an outside radius within ± 25 % of that of the parent material shall be used.

If the surfaces of the parent material are neither parallel nor concentric, then a test block of type b) shall be used.

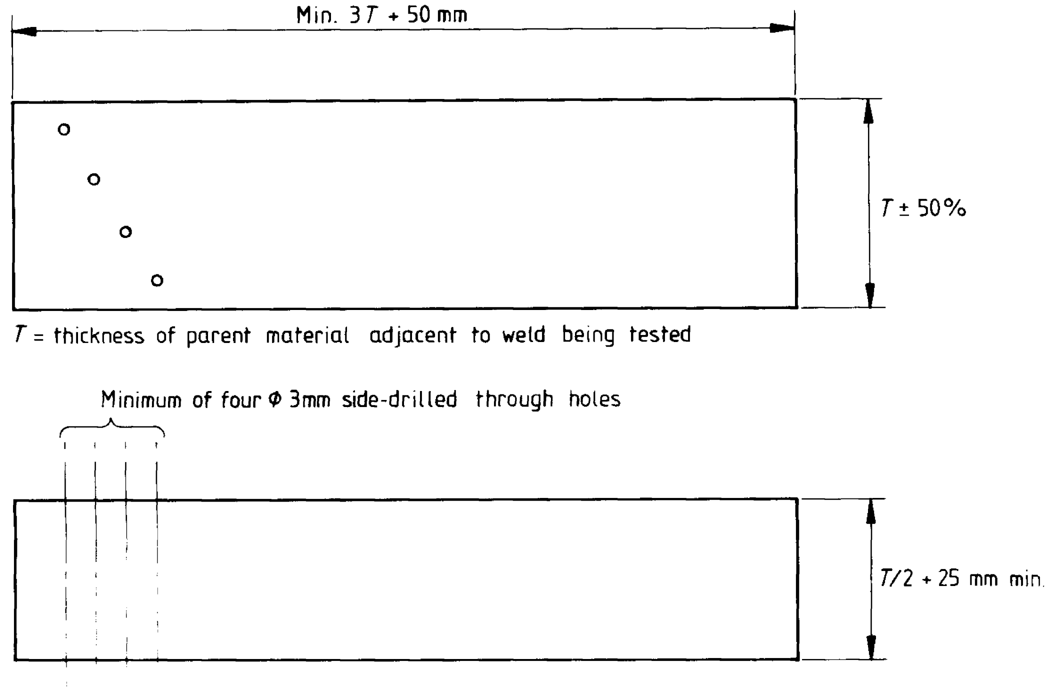


Figure 30 — Test block for DAC curve

K.2 Detailed procedure

The DAC curve shall either be plotted directly on the flaw detector screen (see Figure 31) or plotted as a separate graph. In the latter case the amplitude of the indication in either decibels or millimetres is plotted vertically (Y-axis) and the beam path range horizontally (X-axis).

The steps required shall be as follows.

a) Calibrate the time base to accommodate the full testing range to be used.

b) Select the target holes to be used for the DAC curve and adjust the probe position to obtain maximum echo height from the hole giving the highest amplitude.This will not necessarily be the shortest range echo.

c) Adjust the gain to give an 80 % full screen height echo from this hole, and either mark the position of the echo tip on the screen or plot the echo height and beam path range on a separate graph.

d) Without altering the equipment gain, adjust the probe position to obtain maximum amplitude from each of the other holes in turn and either mark the echo tip on the screen or plot on a separate graph.

e) Join the marked points on the screen, or on the graph, to obtain the DAC curve for that particular probe.

f) Record the sensitivity at which the DAC curve was plotted by reference to the gain setting and echo height from a suitable test block, e.g. the 100 mm radius of A2 block. This will enable the sensitivity to be easily reset to the DAC level without the use of the special DAC test block.

K.3 Correction for attenuation and transfer loss

K.3.1 ***General***

When setting the minimum scanning sensitivity or when measuring echo heights in relation to the 3 mm DAC curve, allowance shall be made for differences in excess of 2 dB in attenuation or coupling efficiency between the parent material of the weld and the test block used to plot the DAC curve.

NOTE The methods for normal and angle probes detailed in **K.3.2** and **K.3.3** involve the use of a single correction value incorporating compensation for both attenuation and transfer loss.

Alternative methods based on the measurement of absolute values of attenuation and transfer loss (as distinct from comparative values) are described in Appendix Q. The latter methods are the more suitable for use in conjunction with the DGS system.

K.3.2 ***Method for normal probes***

The steps required shall be as follows.

a) Calibrate the time base.

b) Position the probe on the DAC test block to obtain a series of back wall echoes A_1, A_2, A_3, A_4, etc.

c) Note the gain setting (in dB) required to bring each echo in turn up to 80 % full screen height and plot this value against the beam path range for each echo (see curve A of Figure 31).

d) Reposition the probe on the material to be measured to obtain a series of back wall echoes B_1, B_2, B_3, etc. and repeat step c) plotting curve B.

e) Extrapolate both curves back to zero range.

f) The loss in echo amplitude due to attenuation and reduced coupling deficiency is the difference in gain between the two curves at the appropriate range.

K.3.3 ***Method for angle probes***

This method requires the use of an identical pair of shear wave probes having a beam angle within the range 40° to 50° and the same frequency as the probe(s) to be used for the subsequent weld examination.

The steps required shall be as follows.

a) Calibrate the time base using a single angle probe.

b) Position the two angle probes on the DAC test block to give a V beam path as shown in Figure 32 a), with the probes operating as separate transmitter and receiver. Maximize the echo height by adjustment of probe position, and record the flaw detector gain setting (A_1), in dB, required to bring the echo to 80 % full screen height.

c) Reposition the two probes on the DAC block to give a W beam path as shown in Figure 32 b), and again maximize the echo height and record the gain setting (A_2) for an 80 % full screen height echo.

NOTE If the DAC test block is insufficiently long to enable the probes to be placed in this position, an alternative method of arriving at the same value for A_2 is described in **K.3.4**.

d) Repeat step c) for a third position [see Figure 32 c)] if the length of the test block permits (gain setting A_3), otherwise this step can be omitted.

e) Repeat steps b) and c) with the probe on the material under test, and record gain settings B_1 and B_2 respectively. Repeat step d) to give gain setting B_3 if possible; otherwise this step can be omitted.

f) Plot the curve through points A_1 and A_2 (and A_3), and the curve through points B_1 and B_2 (and B_3), as shown in Figure 33.

g) Extrapolate both curves back to zero range.

h) The loss in echo amplitude due to attentuation and reduced coupling efficiency is the difference in gain ($G_2 - G_1$ in Figure 33) between the two curves at the appropriate range. The basic DAC curve, plotted in accordance with **K.2** can now be replotted to incorporate these corrections.

K.3.4 ***Alternative method for angle probes***

Where the DAC test block is insufficiently long to allow the probes to be placed to give a W beam path, in order to obtain gain setting A_2 the following procedure shall be adopted.

a) Carry out steps a) and b) of **K.3.3**.

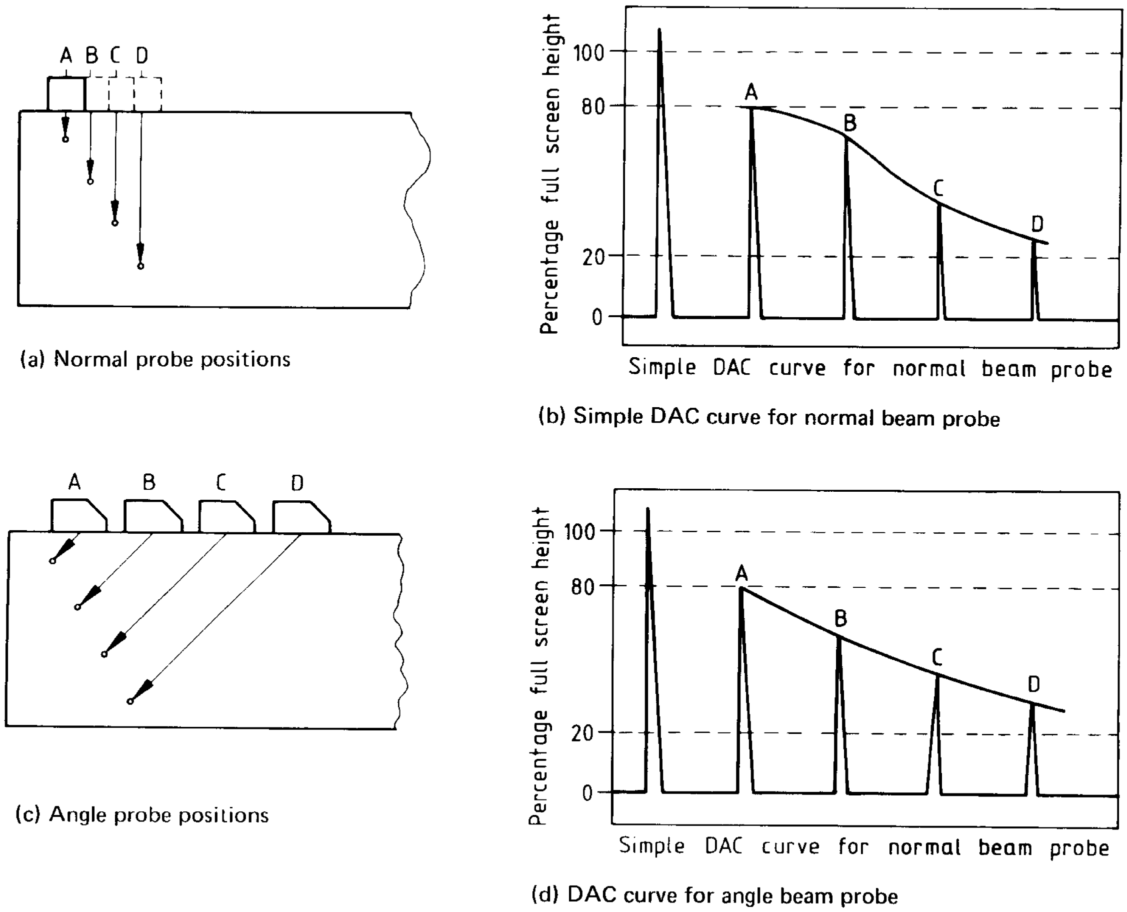
b) Using only one of the above angle probes, maximize the echo from the corner of the test block at the half-skip position and record the gain setting A_4 to bring the echo to 80 % full screen height.

c) Repeat step b) with the probe in the full-skip position and record gain setting A_5.

d) Calculate the gain setting A_2 (in dB) from the following equation:

$$A_2 = A_1 + (A_5 - A_4)$$

e) Proceed as described in steps e), f), g) and h) of **K.3.3**.



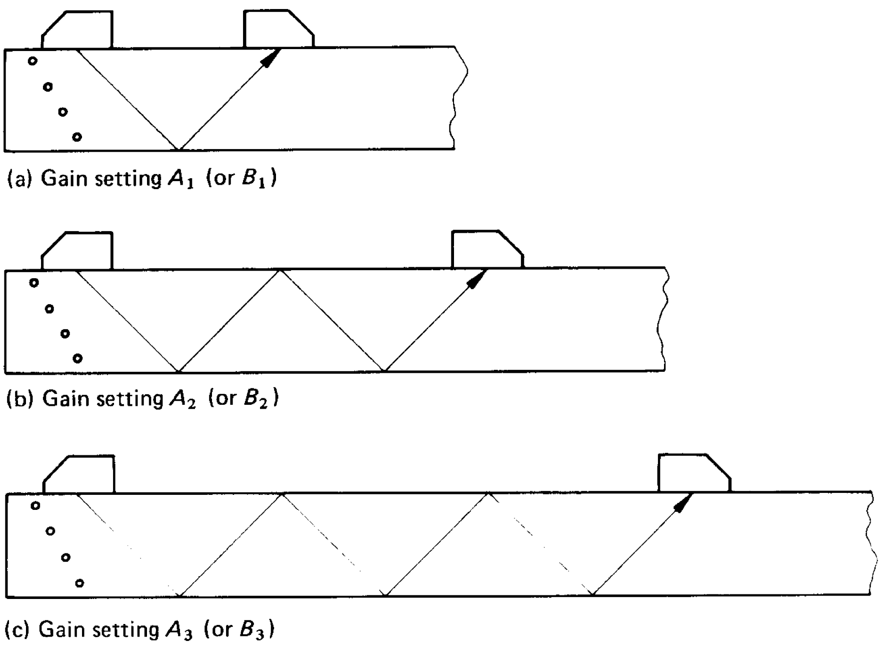
(a) Normal probe positions

(b) Simple DAC curve for normal beam probe

(c) Angle probe positions

(d) DAC curve for angle beam probe

Figure 31 — Plotting the DAC curve

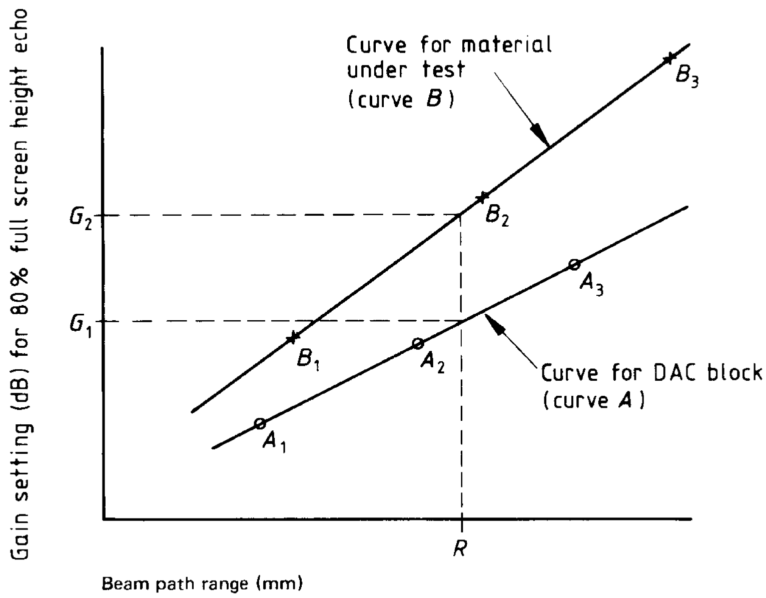


(a) Gain setting A_1 (or B_1)

(b) Gain setting A_2 (or B_2)

(c) Gain setting A_3 (or B_3)

Figure 32 — Probe positions for plotting DAC correction curves



NOTE Correction for attenuation and transfer loss at range R equals ($G_2 - G_1$) decibles

Figure 33 — Method of determining correction factor for DAC curve

Appendix L Echodynamic patterns

L.1 Types of echodynamic patterns

L.1.1 *Pattern 1*

The A-scan presentation shows a single sharp echo which rises smoothly in amplitude to a single maximum before falling smoothly to zero. Figure 34 shows Pattern 1 from a point reflector.

L.1.2 *Pattern 2*

The A-scan presentation shows a single sharp echo for all probe positions. As the probe is scanned the amplitude rises smoothly to a plateau, which is held with or without minor (± 4 dB) amplitude variations with further probe movement, before falling smoothly to zero. Figure 35 shows Pattern 2 from a large smooth planar reflector near normal incidence.

L.1.3 *Pattern 3a*

The A-scan presentation shows a single ragged echo for all probe positions. As the probe is scanned, the echo shows large (+ 6 dB) random fluctuations in amplitude. Figure 36 shows Pattern 3a from a large irregular reflector near normal incidence.

L.1.4 *Pattern 3b*

The A-scan presentation shows an extended train of signals (subsidiary peaks) within a bell-shaped pulse envelope. As the probe is scanned, each subsidiary peak travels through the pulse envelope, rising to its own maximum amplitude towards the centre, and then falling.

The overall signal shows large (+ 6 dB) random fluctuations in amplitude. Figure 37 shows Pattern 3b from a large irregular reflector at oblique incidence.

L.1.5 *Pattern 4*

The A-scan presentation shows a cluster of signals which may be resolved or unresolved in range. Figure 38 shows Pattern 4 from a multiple imperfection. As the probe is scanned, the signals rise and fall at random, each separate signal, if resolved, showing Pattern 1 response.

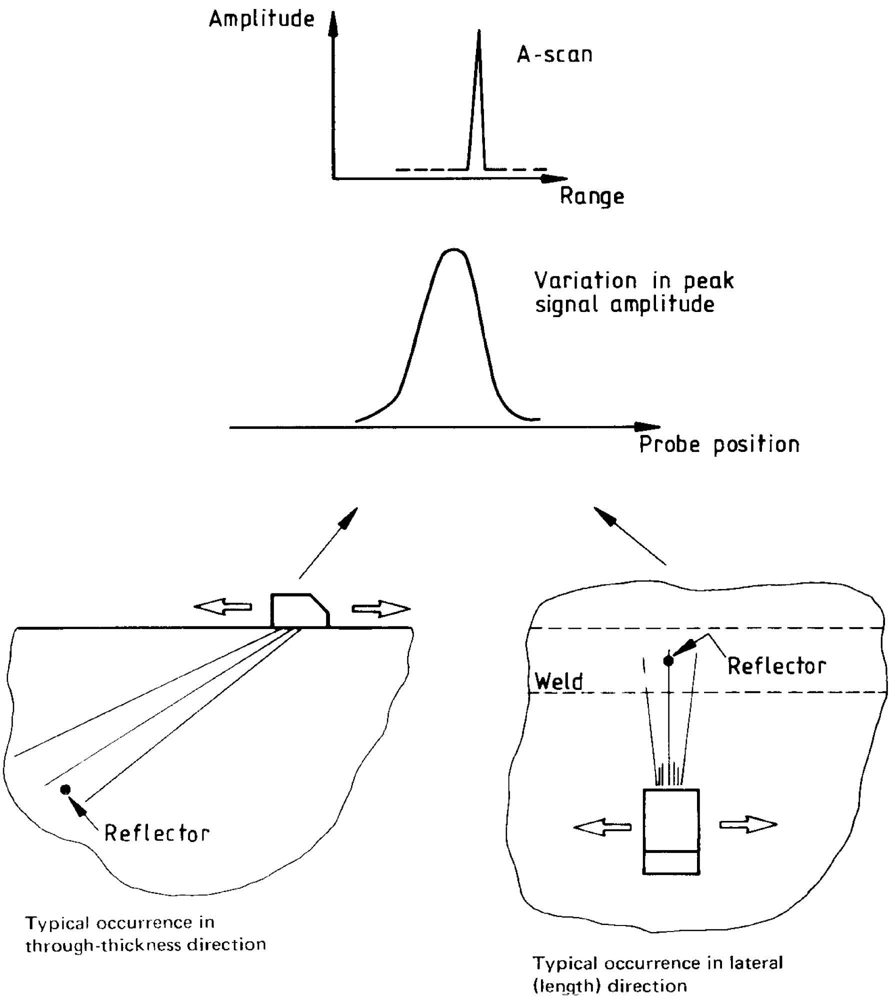


Figure 34 — Echodynamic pattern from a point reflector

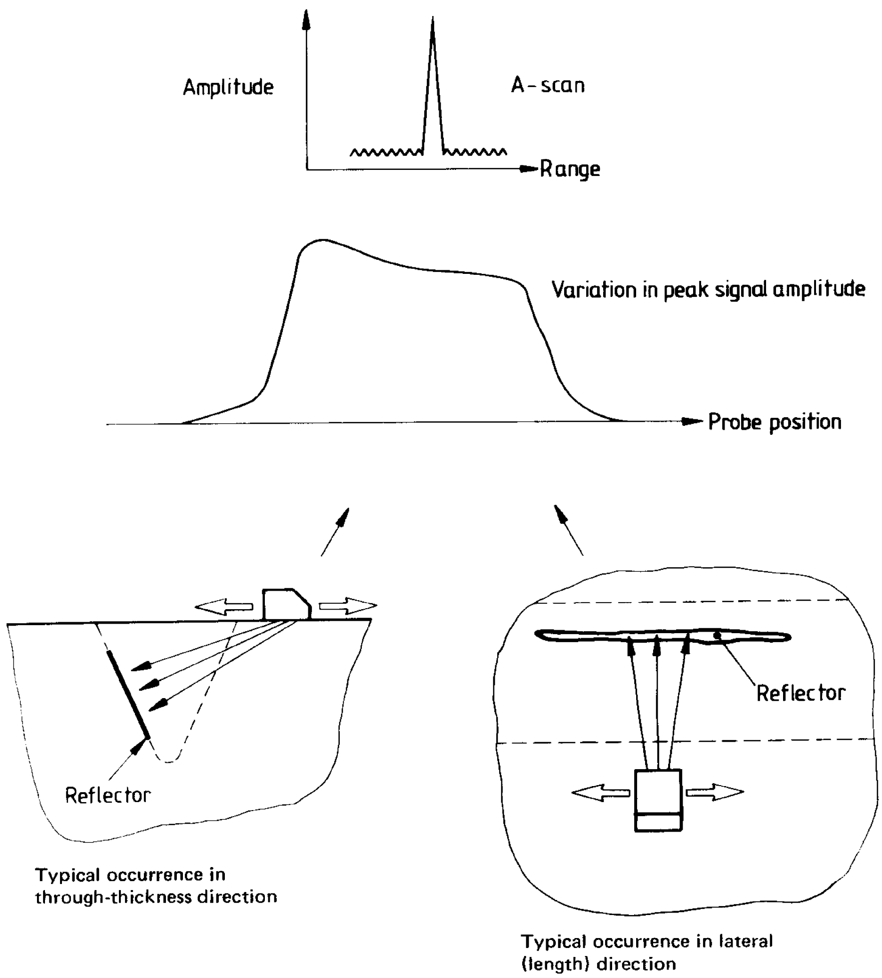


Figure 35 — Echodynamic pattern from a large smooth planar reflector near normal incidence

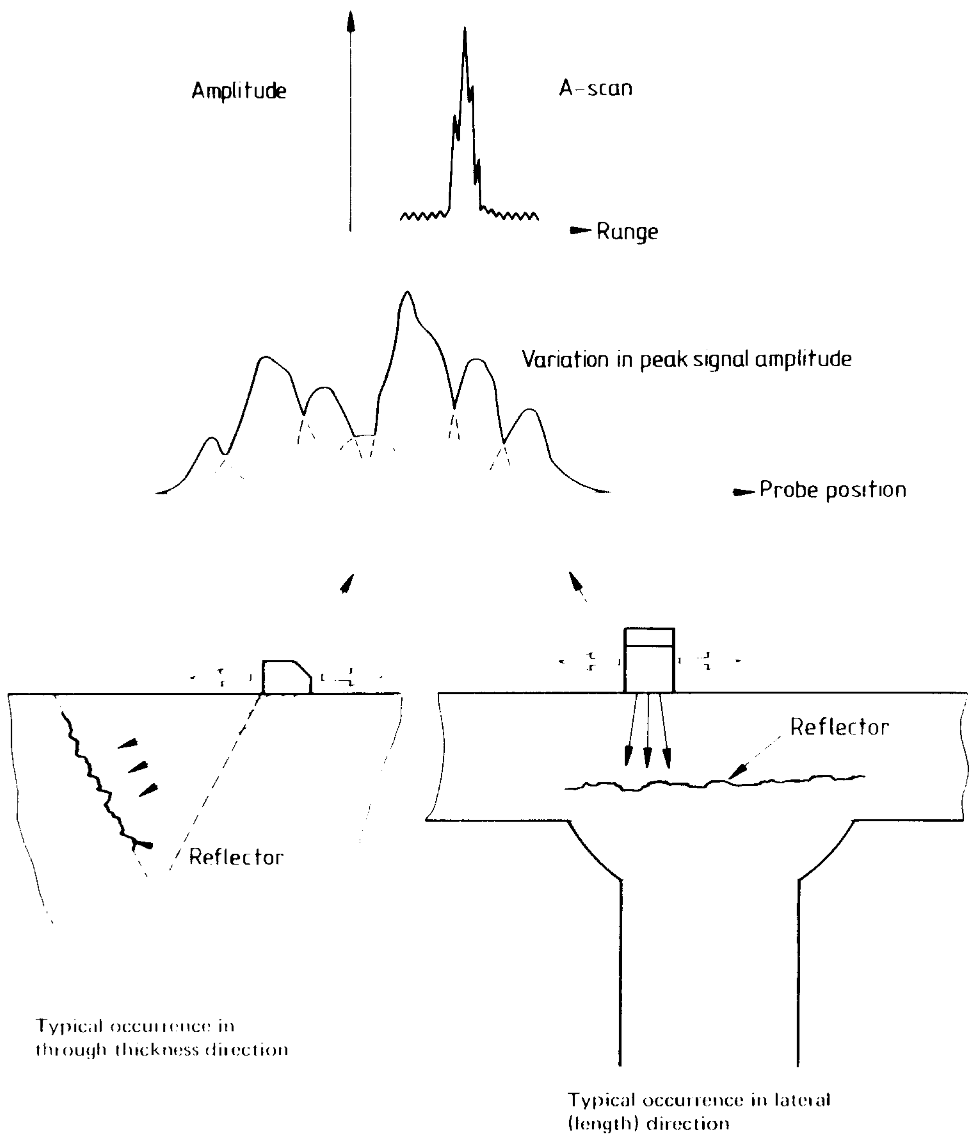


Figure 36 — Echodynamic pattern from a large irregular reflector near normal incidence

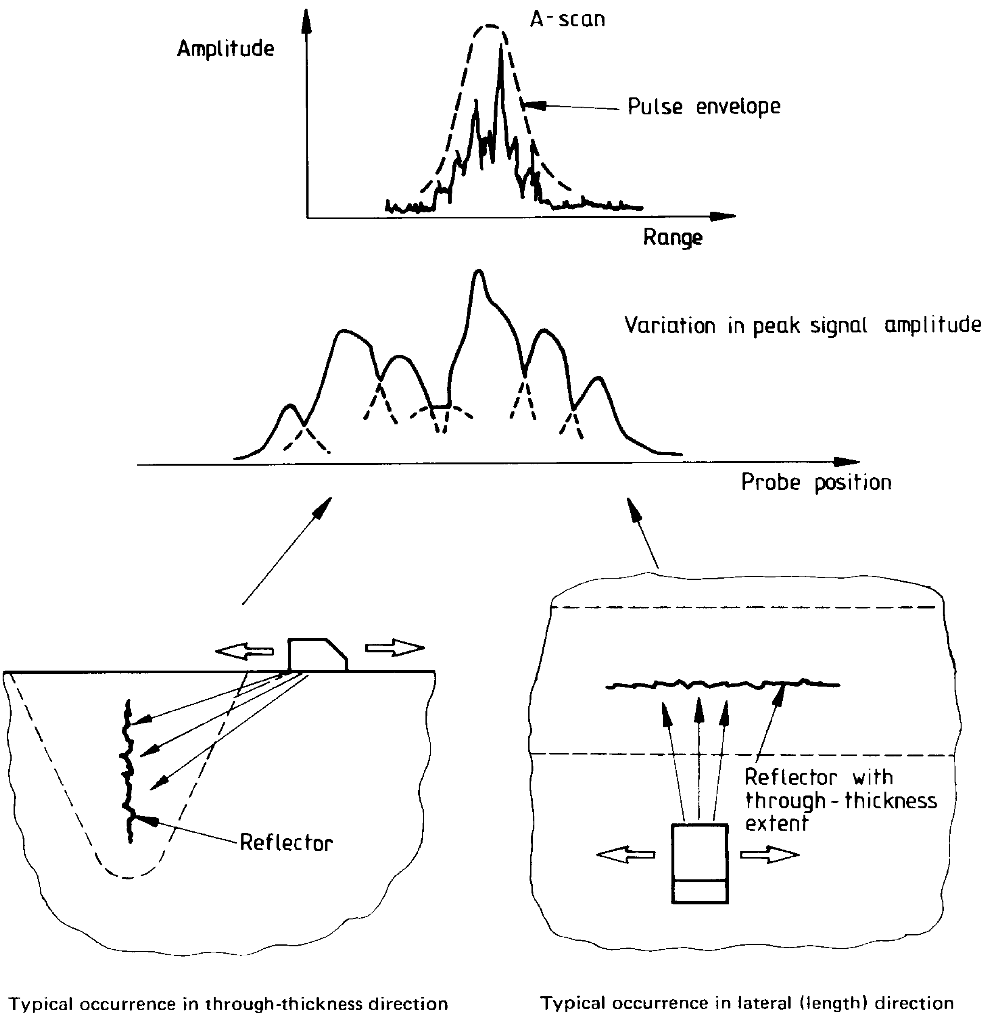


Figure 37 — Echodynamic pattern from a large irregular reflector at oblique incidence

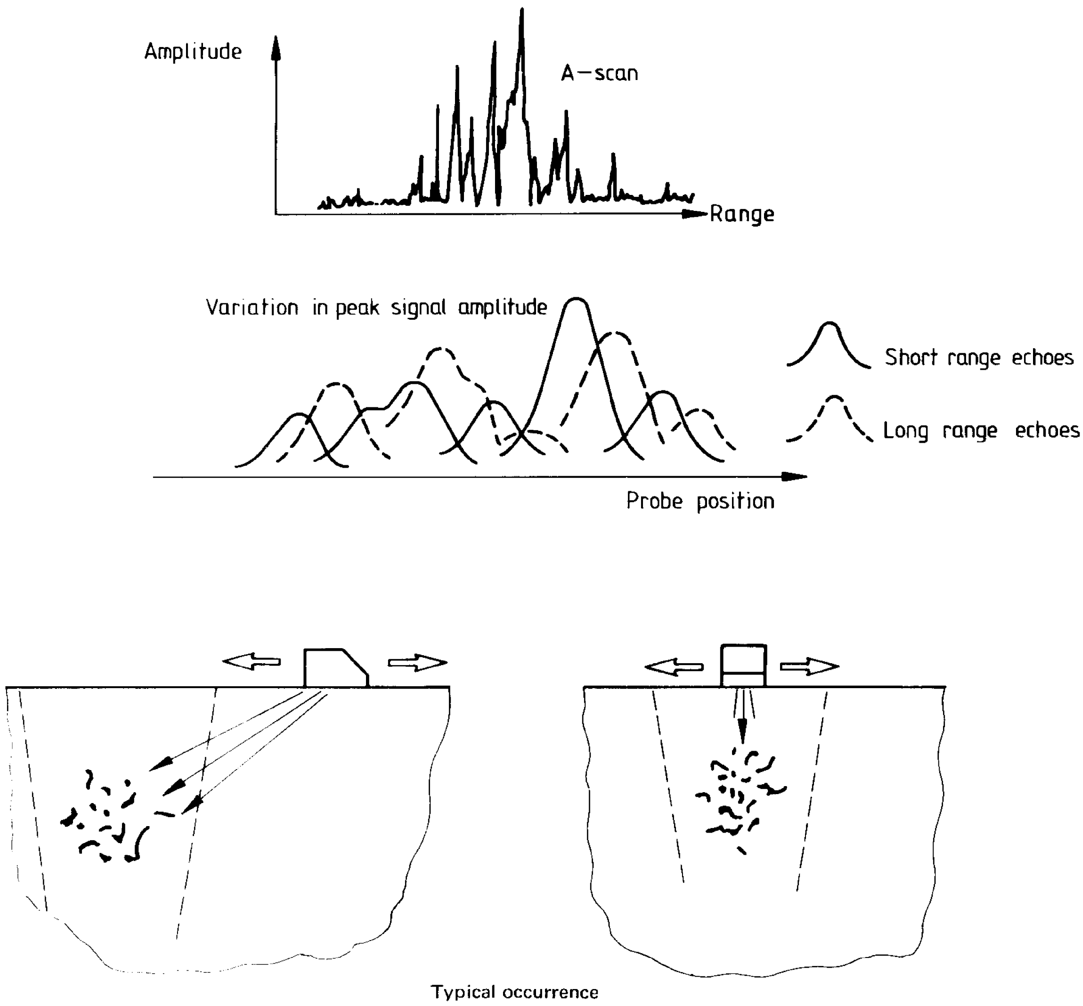


Figure 38 — Echodynamic pattern from a multiple imperfection

L.2 Differentiation of echodynamic patterns

Particular care is necessary at long beam path ranges if Patterns 1 and 2 are to be reliably separated, since the plateau effect may be difficult to detect unless the reflector is very large. At ranges in excess of 200 mm, the 20 dB drop points on either edge of the reflector are plotted, and the distance between them compared with the 20 dB beam width. For Pattern 1 the apparent discontinuity size will be zero, for Pattern 2 the apparent size will be positive.

Extra care is also necessary when scanning on curved surfaces, as the echodynamic pattern can be significantly altered. Two examples, shown in Figure 39 and Figure 40, illustrate this point. In the first a point reflector shows an echodynamic response more closely resembling Pattern 2 than Pattern 1. In the second example, the response from the reflector is of Pattern 3a, whereas on a flat surface Pattern 3b is obtained.

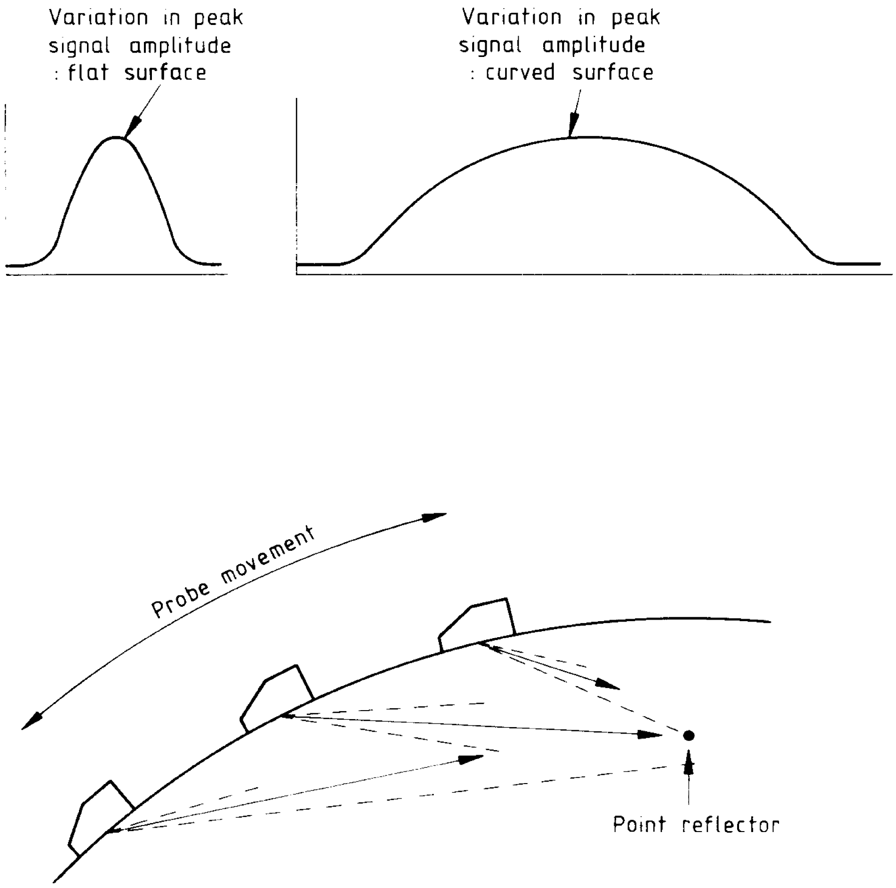


Figure 39 — Effect of curved surface on the echodynamic behaviour of a point reflector

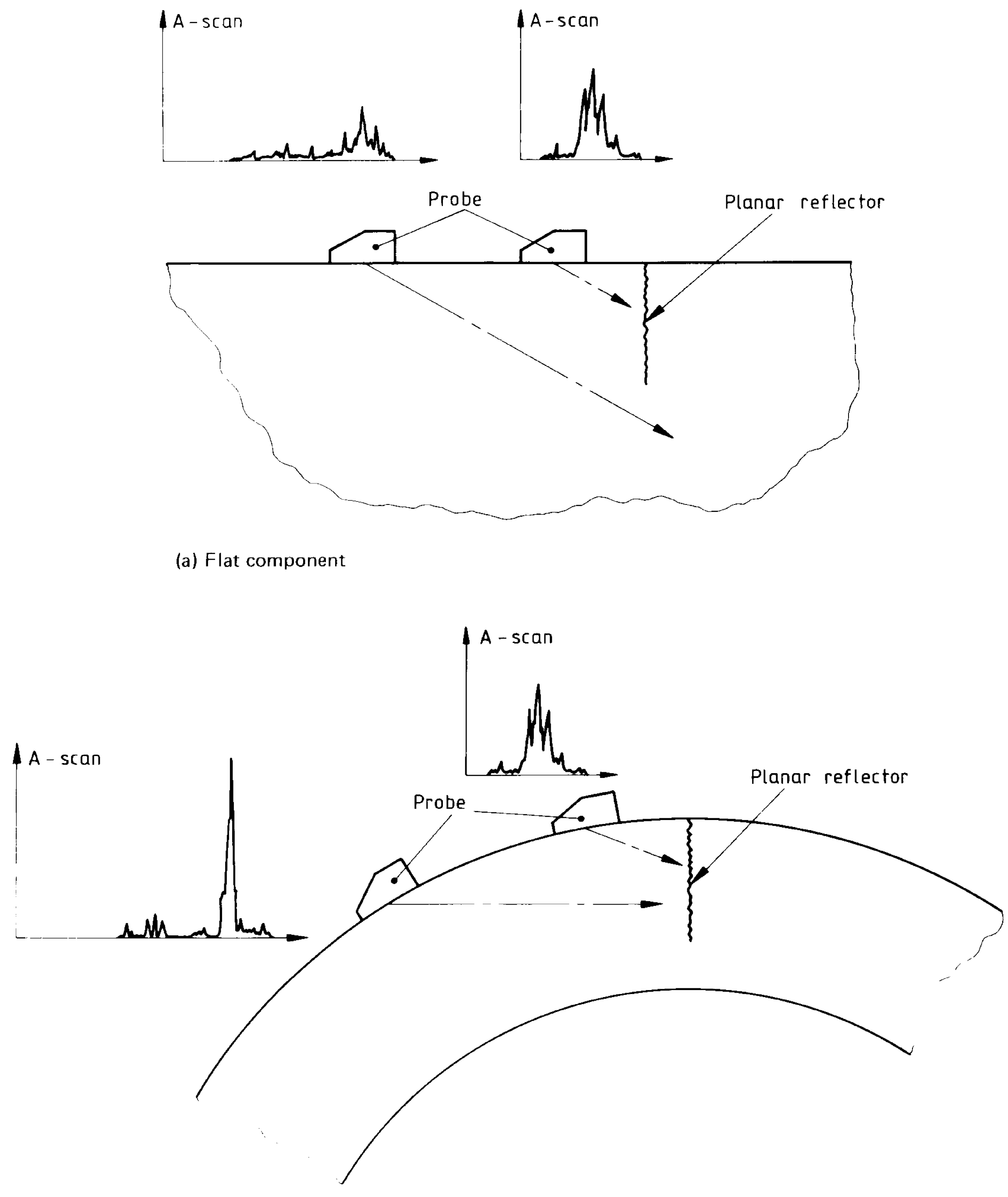


Figure 40 — Effect of curved surface on the A-scan response from a planar reflector

Appendix M Location and characterization of imperfections

M.1 Location

The method of imperfection location is shown in Figure 41.

M.2 Illustration of terms

The meanings of the terms lateral, depth, swivel and orbital scans are illustrated in Figure 42.

M.3 General approach to characterization

Imperfections are characterized by observing their echodynamic patterns as the probes are scanned in two directions, across and along the imperfection. Other important information is given by the variations in signal amplitude with swivel and orbital scans, and with the direction of incidence of the ultrasonic beam.

A diagram which summarizes the echodynamic approach to the characterization of imperfections using lateral and depth scans only is shown in Figure 43. **M.4** gives guidance for particular types of imperfections.

NOTE 1 The recognition of defect type can rarely be made with only one probe or one scan. Rather, the operator should carry out a number of scans, including depth, lateral, swivel and orbital scans, with more than one beam direction, and hence identify the defect's type as that type which allows a self-consistent interpretation of all the ultrasonic information.

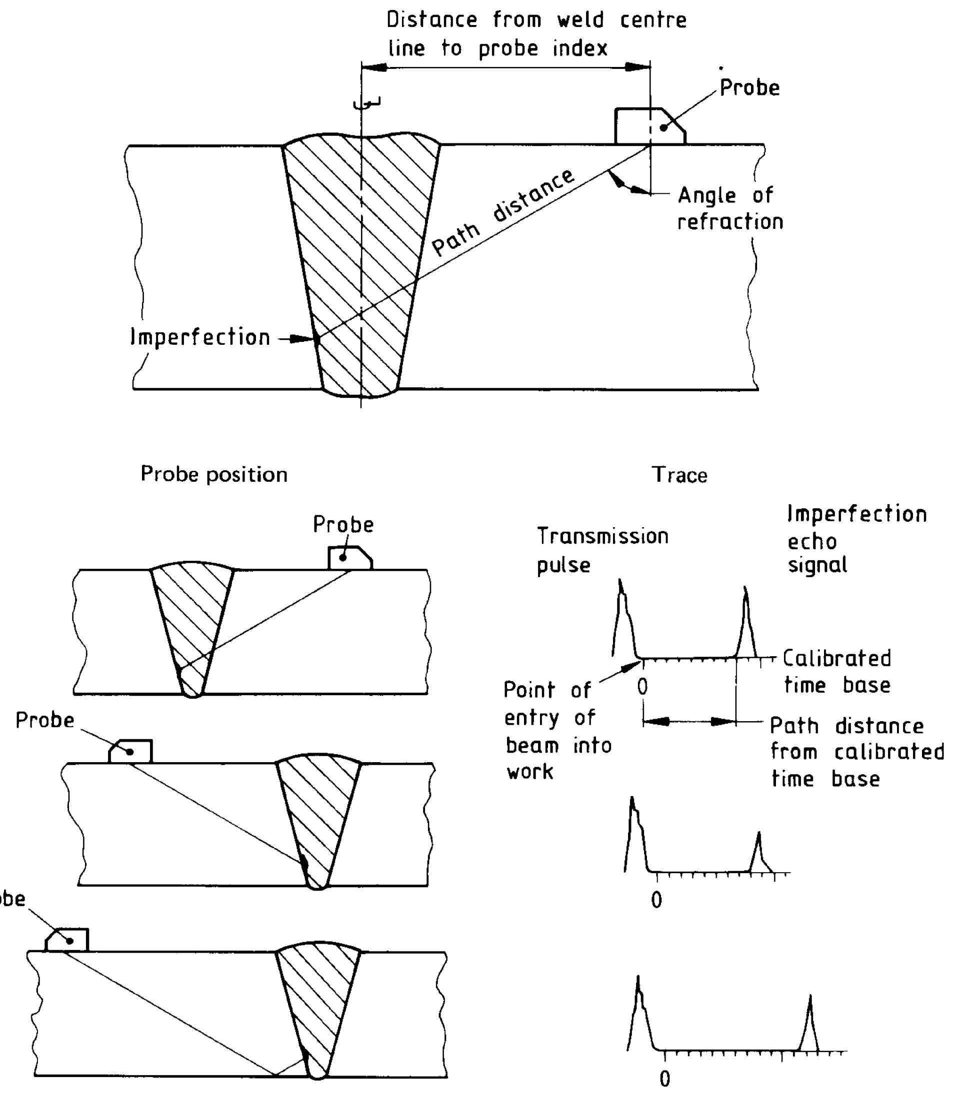


Figure 41 — Determination of imperfection location from various probe positions

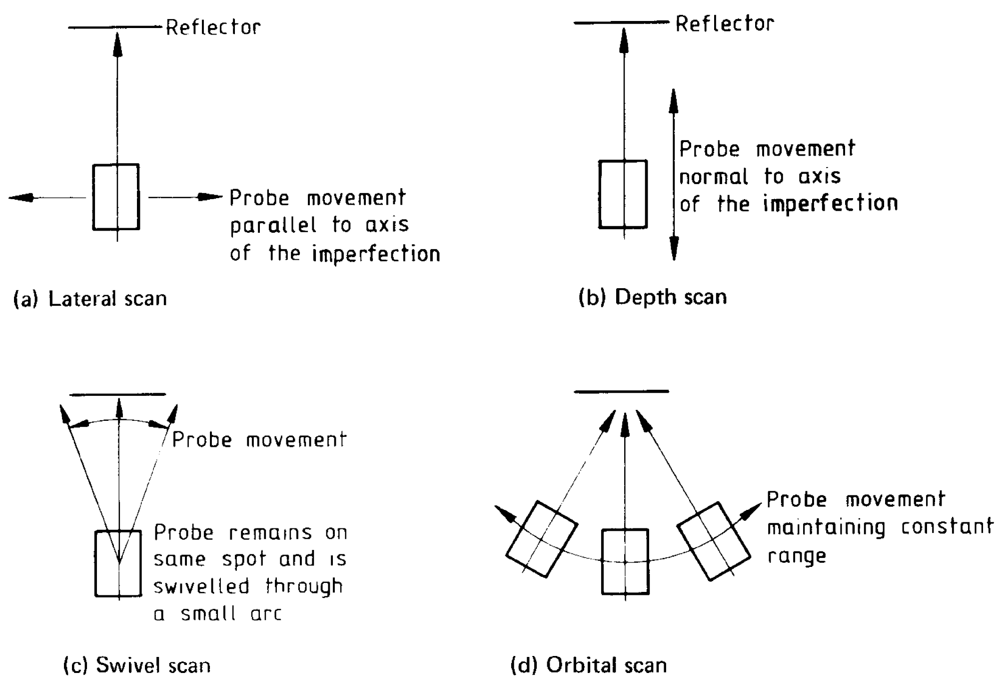


Figure 42 — Scanning directions used for characterization of imperfections

NOTE 2 Sizing may be carried out simultaneously with characterization or as a separate operation.

The selection of methods for sizing the various types of imperfection shall be in accordance with **M.4**. Details of how the different sizing methods shall be applied are contained in Appendix N.

M.4 Types of imperfection and their recognition

M.4.1 Spherical point imperfection (e.g. gas pore or small slag inclusion)

M.4.1.1 *Characterization.* Both lateral and depth scans show echodynamic Pattern 1, as also does the swivel scan. On orbiting the imperfection, the beam path range and echo amplitude remain constant. Examination from different directions and with different beam angles shows a relatively constant echo height after making allowance for differences in beam path length.

M.4.1.2 *Sizing.* For quality control purposes, the echo height (in dB) shall be measured in relation to the 3 mm diameter DAC curve. The actual size is generally impossible to determine.

M.4.2 Planar point imperfection (e.g. small area of lack of fusion face)

M.4.2.1 *General.* This imperfection is of similar size range to that in **M.4.1** but of a flattened rather than spherical form.

M.4.2.2 *Characterization.* Both lateral and depth scans show echodynamic Pattern 1, as does the swivel scan. On orbiting the imperfection, the echo height falls on either side of the normal to the plane of the imperfection. The larger the reflector the more rapid is the rate of fall. Examination from different directions and angles also shows a marked reduction in echo height on either side of the normal to the plane of the imperfection.

M.4.2.3 *Sizing.* For quality control purposes the maximum echo height (in dB) shall be measured in relation to the 3 mm diameter DAC curve. If the actual size is required reference shall be made to the DGS curve for the equivalent disc-shaped reflector diameter, which represents the minimum possible size of the imperfection.

NOTE The true size may be considerably larger than this, depending on the orientation, precise shape and surface irregularity of the imperfection, but will be less than the minimum size measurable by probe movement methods.

M.4.3 Thread-like imperfection (e.g. fine slag line)

M.4.3.1 *General.* This imperfection has length but no ultrasonically measurable cross section.

M.4.3.2 *Characterization.* This imperfection generally exhibits Pattern 1 behaviour for the depth scan and Pattern 2, or less likely Pattern 3a, for the lateral scan. Both swivel and orbital scans show a rapid fall in echo height on either side of the normal to the plane of the imperfection.

If the imperfection is approximately cylindrical in cross section, examination from different directions and angles shows only minor variations in echo height after correcting for beam path length, provided the beam is normal to the longitudinal axis of the imperfection.

If the imperfection is flattened in cross section, e.g. a narrow band or lack of fusion-face fusion, examination from different directions/angles shows a marked reduction in echo height on either side of the normal to the plane of the imperfection.

M.4.3.3 *Sizing.* If the imperfection shows Pattern 2 behaviour on the lateral scan, the length shall be measured by the 6 dB drop method; if Pattern 3a, either the maximum amplitude or 20 dB beam profile method shall be used.

For quality control purposes the cross section of the imperfection shall be evaluated in terms of the maximum echo height, expressed in dB, relative to the 3 mm diameter DAC curve.

M.4.4 Volumetric imperfection (e.g. large irregular or globular slag inclusion)

M.4.4.1 *General.* This imperfection has both measurable length and cross section.

M.4.4.2 *Characterization.* The lateral scan generally shows either echodynamic Pattern 2 or 3a. The depth scan shows Pattern 3a or 3b.

The swivel scan shows a response rather similar to Pattern 3b with the highest echoes generally being observed when the beam is normal to the longitudinal axis of the imperfection. The orbital scan also shows irregular variation in echo height on either side of the normal to the axis of the imperfection.

This type of imperfection can be detected over a wide range of direction and beam angle with an irregular echo height response.

M.4.4.3 *Sizing.* The length shall be measured by the 6 dB drop method if Pattern 2 is observed, or by the maximum amplitude or 20 dB beam profile method for Patterns 3a or 3b.

The cross-sectional dimensions shall be measured by the maximum amplitude or 20 dB beam profile methods. These measurements shall be made from more than one direction and/or with more than one beam angle. The largest measured dimensions are likely to be the most accurate. A combination of measurements from two or more directions is often the best method, provided that the test surfaces are sufficiently flat and parallel to avoid introducing errors into the positioning of different surfaces of the reflector. More confidence is placed on positioning along the beam than on positioning across the width of the beam.

M.4.5 Planar imperfection (e.g. crack or lack of fusion face)

M.4.5.1 *General.* This imperfection has length and breadth, but negligible thickness, and may be smooth or rough surfaced.

M.4.5.2 *Characterization.* Both lateral and depth scans show either echodynamic Pattern 2 or 3a/3b.

A smooth surfaced imperfection will show a rapid fall in echo height on either side of the normal to the plane of the imperfection for both the swivel and orbital scans. A rough-surfaced imperfection will show a Pattern 3b response for the swivel scan, and an irregular variation in the height on either side of the normal for the orbital scan.

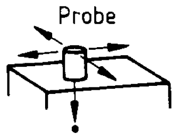
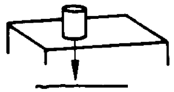
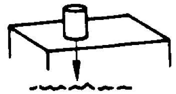
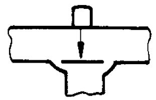
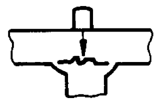
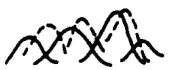
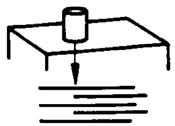
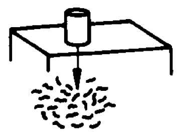
The echo height is very variable and depends on the orientation of the imperfection in relation to the ultrasonic beam, and on the roughness of its surface.

M.4.5.3 *Sizing.* The length and breadth shall be measured by the 6 dB drop method for Pattern 2, and by the maximum amplitude or 20 dB beam profile methods for Patterns 3a or 3b.

Measurements shall be made from more than one direction, and/or with more than one beam angle, and the largest measured dimension taken to be the most accurate.

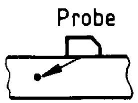
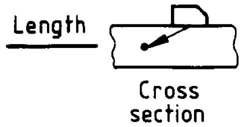
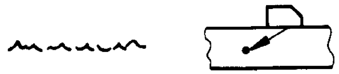
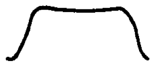
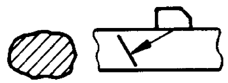
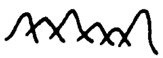
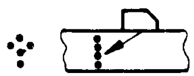
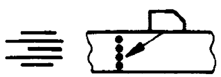
NOTE For Patterns 3a and 3b, accurate breadth measurement depends on identifying the outermost reflecting facet at each edge of the imperfection. This is often made easier by making the measurement at oblique incidence to the main plane of the imperfection, when the signals from individual facets are better separated from one another along the time base.

Smooth planar imperfections which are insufficiently broad to be sized from their Pattern 2 response in the through-thickness direction present particular problems. By examination from a number of different angles it may, however, be possible to detect and position the small crack-tip diffraction echoes from each edge of the imperfection. An alternative method is to measure the maximum echo height normal to the plane of the imperfection and to compare this with the echoes from specially prepared slots in a suitable test block. For certain orientations, e.g. vertical imperfections in a plane butt weld, this may require the use of a tandem probe technique.

Scan across width	Scan along length of reflector			
	Pattern 1	**Pattern 2**	**Pattern 3a**	**Pattern 4 (multiple)**
Pattern 1 	 Spherical or planar point reflector	 Thread-like reflector, e.g. slag line	 String of intermittent linear reflectors, or continuous fine planar one	
Pattern 2 		 Large smooth planar reflector, e.g. unfused land		
Pattern 3a 			 Large rough planar reflector, e.g lamellar test	
Pattern 4 (multiple) 		 Random cluster of linear reflectors		 Random cluster of small reflectors

a) Normal (straight beam) probes

Figure 43 — Guide to imperfection characterization by observation of the echodynamic pattern

Scan in through-thickness dimensions	Scan along length of reflector				
	Pattern 1 	Pattern 2 	Pattern 3 a) Normal incidence	Pattern 3 b) Oblique incidence	Multiple
Pattern 1 	 “Point” reflector	 Thread-like reflector	 String of intermittent reflectors		
Pattern 2 		 Large planar smooth reflector at normal incidence	 Line of smooth planar reflectors at normal incidence		
Pattern 3a (normal incidence) 	 Stack of small reflectors at normal incidence	 Stack of thread-like reflectors at normal incidence	 Large rough planar reflector at normal incidence		Multiple reflector occupying a volume envelope
Pattern 3a (oblique incidence) 	 Stack of small reflectors at oblique incidence	 Stack of thread-like reflectors at oblique incidence		 Large rough planar reflector at oblique incidence	

b) Angle beam probes

Figure 43 — Guide to imperfection characterization by observation of the echodynamic pattern *(concluded)*

M.4.6 Multiple imperfection (e.g. group of porosity or reheat cracks)

M.4.6.1 *General.* This is a cluster of closely spaced imperfections that is impractical to position or measure individually by ultrasonics.

M.4.6.2 *Characterization.* For both lateral and depth scans the echoes from the individual reflectors appear in random order at different positions along the time base, each individual signal showing Pattern 1 behaviour. The randomness of the echoes enables the type of imperfection to be distinguished from a multi-faceted crack.

NOTE 1 Some guide to the nature of the individual imperfections, i.e. whether spherical point or planar point reflectors, may be obtained by swivel and orbital scans.

NOTE 2 Average echo height measurements from different directions, and with different beam angles, may show a pronounced directionality in the reflection behaviour indicative of a cluster of planar point reflectors.

M.4.6.3 *Sizing.* The enclosing volume of the imperfection shall be measured by positioning individual reflectors around the extremities of the cluster. An approximate measurement of reflector density shall be attempted based on the number of signals visible along the time base at the same time.

For quality control purposes, a measurement shall be made at the optimum angle of the average echo height (in dB) relative to the 3 mm diameter DAC curve.

M.4.7 ***Intermittent imperfections***

M.4.7.1 *General.* This can be either intermittent in length, e.g. a broken slag line, or intermittent in depth, e.g. a series of parallel slag lines at different depths along the fusion face of the weld.

Unless the gaps are so small as to be insignificant it is important to distinguish between a continuous and an intermittent imperfection, particularly in the through-thickness direction.

M.4.7.2 *Characterization (lateral).* If the imperfection shows Pattern 2, 3a or 3b in the through-thickness direction it is unlikely to be intermittent along its length, except on a sufficiently large scale to be easily resolvable.

For imperfections showing Pattern 1 response, the scanning direction, beam angle, and size and frequency of probe shall be selected to give the narrowest practical beam width at the imperfection, and a careful lateral scan shall be carried out under uniform coupling conditions.

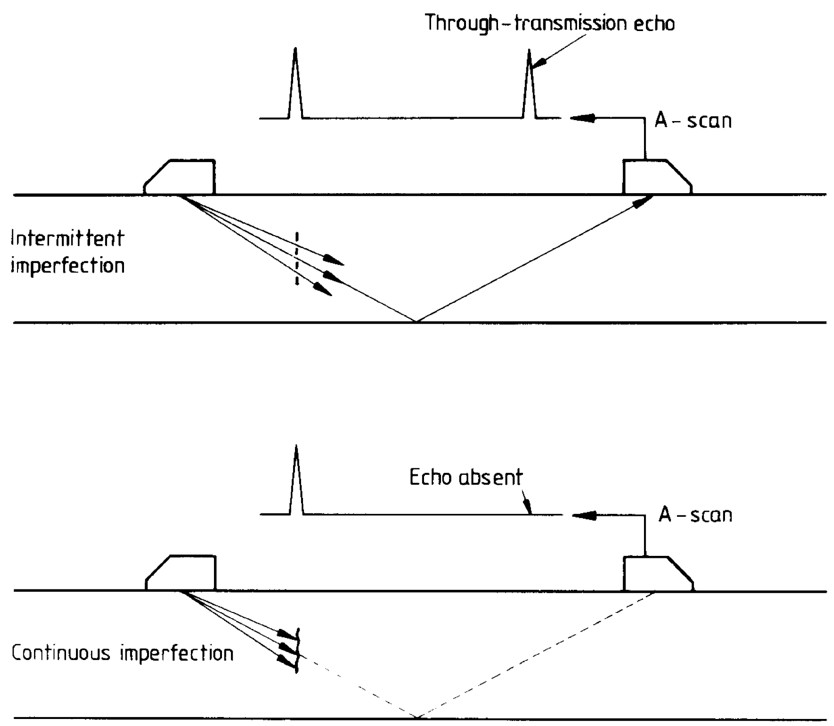


Figure 44 — Shadow technique for distinguishing between large continuous and intermittent imperfections

Marked dips in the echo height envelope along its length suggest that the imperfection is intermittent. This shall be confirmed by carrying out swivel and orbital scans adjacent to the apparent breaks, and noting that the echo height falls rapidly about the normal and that no significant secondary echoes are observed. Any other response suggests that the apparent break is in fact due to a change in lateral orientation.

M.4.7.3 *Characterization (in depth).* Careful depth scans shall be carried out across the imperfection, from at least two directions, at short beam path ranges, and the form of the echo envelope noted.

NOTE Significant dips, or complete breaks, suggest that the imperfection may be intermittent, but the chance of these effects being due to changes in imperfection orientation are greater than in the lateral direction.

Two additional methods shall be applied as appropriate. The first is to build up a composite through-thickness picture of the imperfection by plotting all the indications observed from a number of different directions and angles. Smooth flat scanning surfaces on either side of the weld and high plotting accuracy are necessary if this method is to be of value. The second method, which is useful if the breadth of the imperfection is at least comparable with the beam width, is the shadow technique, illustrated in Figure 44.

A strong transmitted signal through the affected area is positive proof of the absence of a continuous imperfection lying across the ultrasonic beam.

Unless there is conclusive evidence that the imperfection is intermittent in the through-thickness direction, it shall be assumed to be continuous.

Appendix N Imperfection sizing techniques

N.1 6 dB drop technique

N.1.1 *Principle and applications*

The 6 dB drop technique involves obtaining an echo from a position where the reflector extends across the full width of the ultrasonic beam and then moving the beam along the reflector until the echo has fallen by half (i.e. by 6 dB). It is then assumed that only one half of the beam is impinging on the reflector whose edge, therefore, lies along the beam axis (see Figure 45).

NOTE This technique should only be applied to imperfections larger. In the direction to be measured, than the ultrasonic beam width, and which show relatively little variation in echo height along this direction, i.e. Pattern 2 behaviour.

The technique is applicable to both normal and angle probes, and is most frequently used for the plotting of laminations in plate material, and for measuring the length of linear imperfection in welds. It can also be used to measure the through-thickness dimension of imperfections which lie essentially normal to the beam axis and which exhibit Pattern 2 behaviour such as extensive lack of side-wall fusion.

N.1.2 *Detailed procedure*

The steps required shall be as follows.

a) Check that the beam axis of the probe is free from "squint", and the beam profile is reasonably symmetrical about the axis.

b) Mark the crystal centre line on the probe case, and calibrate the time base.

c) Scan the probe along or across the imperfection and note the shape of the echo envelope. If the echo height varies slightly along the imperfection, the value just before the echo falls rapidly is taken as the level from which to carry out the 6 dB drop. See points A and A_1 in Figure 45.

d) Set the chosen value of the echo height to between 80 % and 100 % full screen height and traverse the beam off the edge of the imperfection until the echo height has fallen by 6 dB.

e) Plot the location of the edge of the imperfection from knowledge of the probe position, beam angle and range.

f) Repeat steps d) and e) at the opposite edge of the imperfection and determine its size from the distance between the plotted points.

In the case of a large planar imperfection, repeat steps c) to f) at several positions along the imperfection, or, if plotting a lamination, in several directions across the imperfection.

N.2 Maximum amplitude technique

N.2.1 *Principle and applications*

This technique relies on accurate plotting of the individual echoes from or adjacent to each edge of the imperfection. It differs from the 20 dB beam profile technique in that each echo is maximized by probe movement, and its origin plotted out along the beam axis (see Figure 46).

The technique can be applied to imperfections of any size, provided they exhibit Pattern 3a or 3b behaviour in the direction to be measured, and is equally applicable for measuring length or breadth.

It is important to make the correct choice of scanning direction and beam angle to obtain either an echo from the last reflecting "facet" or a crack-tip diffraction echo, and to correctly identify this echo on the flaw detector screen.

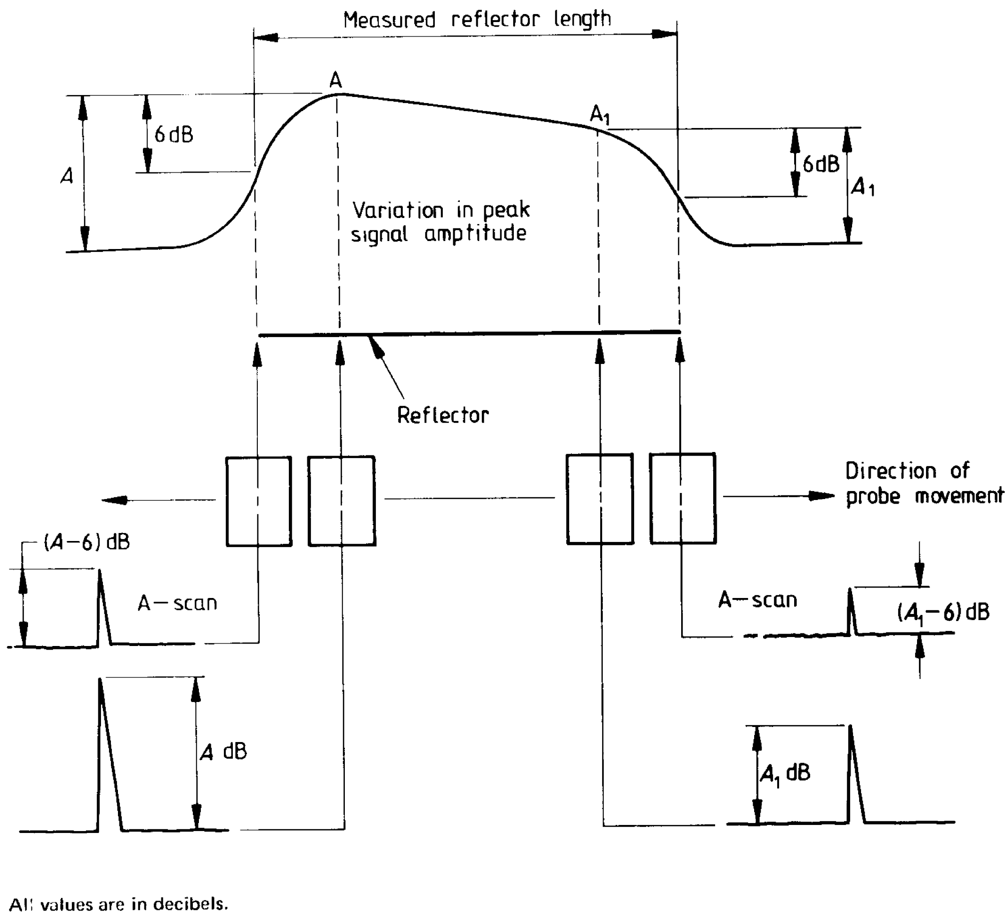


Figure 45 — 6 dB drop technique for imperfection sizing

N.2.2 *Detailed procedure*

The steps required shall be as follows.

a) Determine the precise beam angle and probe index position using a series of side-drilled holes as described in **6.2** of BS 4331-3:1974.

b) Carry out accurate calibration of the time base.

c) Scan the probe along or across the imperfection and at each edge identify the last significant echo before the beam moves completely off the imperfection. See points A and A_1 in Figure 46.

d) Maximize the last echo considered to be significant and record the probe position and beam path range of the echo.

e) Plot out the position of the edge of the imperfection along the beam axis and, from knowledge of the probe position, mark this point on a full scale drawing of the weld.

f) Repeat steps d) and e) for the other edge of the imperfection, and join the two plotted points to obtain its size, position and orientation.

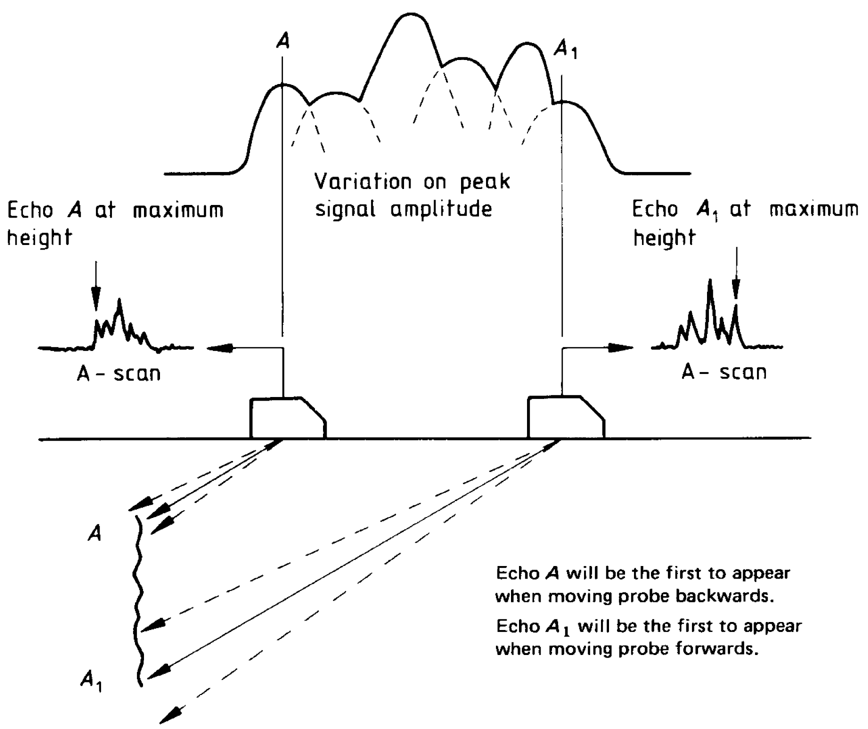
Wherever possible, repeat measurements shall be made from another direction and/or with another beam angle to ensure that the extremities of the imperfection have not been overlooked. Measurements shall also be made at several positions along the length of large planar or volumetric imperfections.

N.3 20 dB beam profile technique (20 dB drop)

N.3.1 ***Principle and applications***

As in the maximum amplitude technique (see **N.2**), the imperfection size using the 20 dB beam profile technique is determined by accurate positioning of the extremities of the imperfection. However, instead of using the beam axis for this purpose, the edges of the beam are used where the intensity has fallen to 20 dB below the axial level (see Figure 47).

This technique has the same range of application as the maximum amplitude technique, and can be used to measure imperfections of any size which exhibit Pattern 3a or 3b behaviour in the direction to be measured.



NOTE Defect edges A and A_1 are plotted along the beam axis when their individual echoes are at maximum height.

Figure 46 — Maximum amplitude technique for imperfection sizing

The same problems apply to identifying the correct echo at the edge of the imperfection on which to base the size measurement as described for the maximum amplitude technique.

N.3.2 ***Detailed procedure***

The steps required shall be as follows.

a) Plot the beam axis and 20 dB beam boundary on a series of side-drilled holes at different ranges as described in **6.2** of BS 4331-3:1974.

b) Carry out accurate calibration of the time base.

c) Scan the probe along or across the imperfection, and at each edge identify the last significant echo before the beam moves completely off the imperfection. See points A and A_1 in Figure 47.

d) Maximize the last echo considered to be significant by probe movement and set this echo to between 80 % and 100 % full screen height.

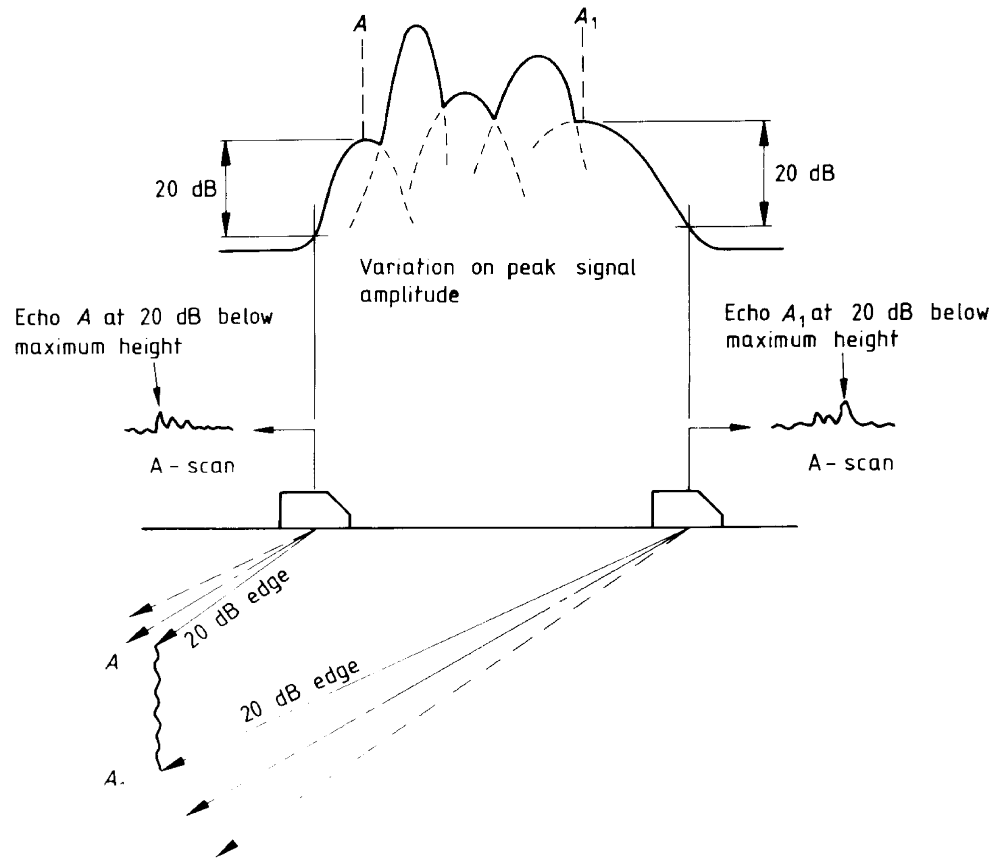
e) Decrease the gain by 20 dB, note the reduced echo height on screen, and return to the original setting.

f) Move the probe to traverse the beam slowly off the imperfection until the echo in question has fallen by 20 dB, i.e. to the position on the screen noted in step e). At this point record the probe position and the beam path range of the echo.

g) To check measurements made in f), traverse the beam further off the imperfection until the echo falls to the baseline, then reverse the probe movement until the echo returns to the height noted in step e), and remeasure the probe position and beam path range.

h) Plot out the position of the edge of the imperfection along the appropriate 20 dB beam boundary and, from knowledge of the probe position, mark this point on a full scale drawing of the weld.

i) Repeat steps d) to h) for the other edge of the imperfection, and join the two plotted points to obtain its size, position and orientation.



NOTE Defect edges *A* and A_1 are plotted along 20 dB beam edges.

Figure 47 — 20 dB beam profile technique for imperfection sizing

Wherever possible, repeat measurements shall be made from another direction and/or with another beam angle to ensure that the extremities of the imperfection have not been overlooked. Measurements shall also be made at several positions along the length of large planar or volumetric imperfections.

NOTE If this method is to be used for plotting the extent of the imperfections showing Pattern 2 response, e.g. the length of uniform thread-like imperfections, or the area of a plate lamination, it is essential that the beam profile to be used is plotted on a range of targets of similar geometrical form to the imperfection to be measured.

Appendix P Notational system for recording imperfection dimensions

A suggested system is illustrated in Figure 48.

Appendix Q Measurement of attenuation and transfer loss

Q.1 General

The methods described in this appendix differ from those described in Appendix K in that separate values for attenuation and transfer loss are determined. The attenuation value is an absolute measurement for the particular sample of material and test frequency, while the transfer loss is a measurement relative to the A2 test block (see BS 2704) for a particular probe and method of coupling.

The methods for both normal and angle probes require the surfaces of the material under test to be either parallel or concentric. They follow the generally adopted convention of measuring attenuation in terms of decibels per millimetre of total beam path travelled, this distance being twice the probe to target range.

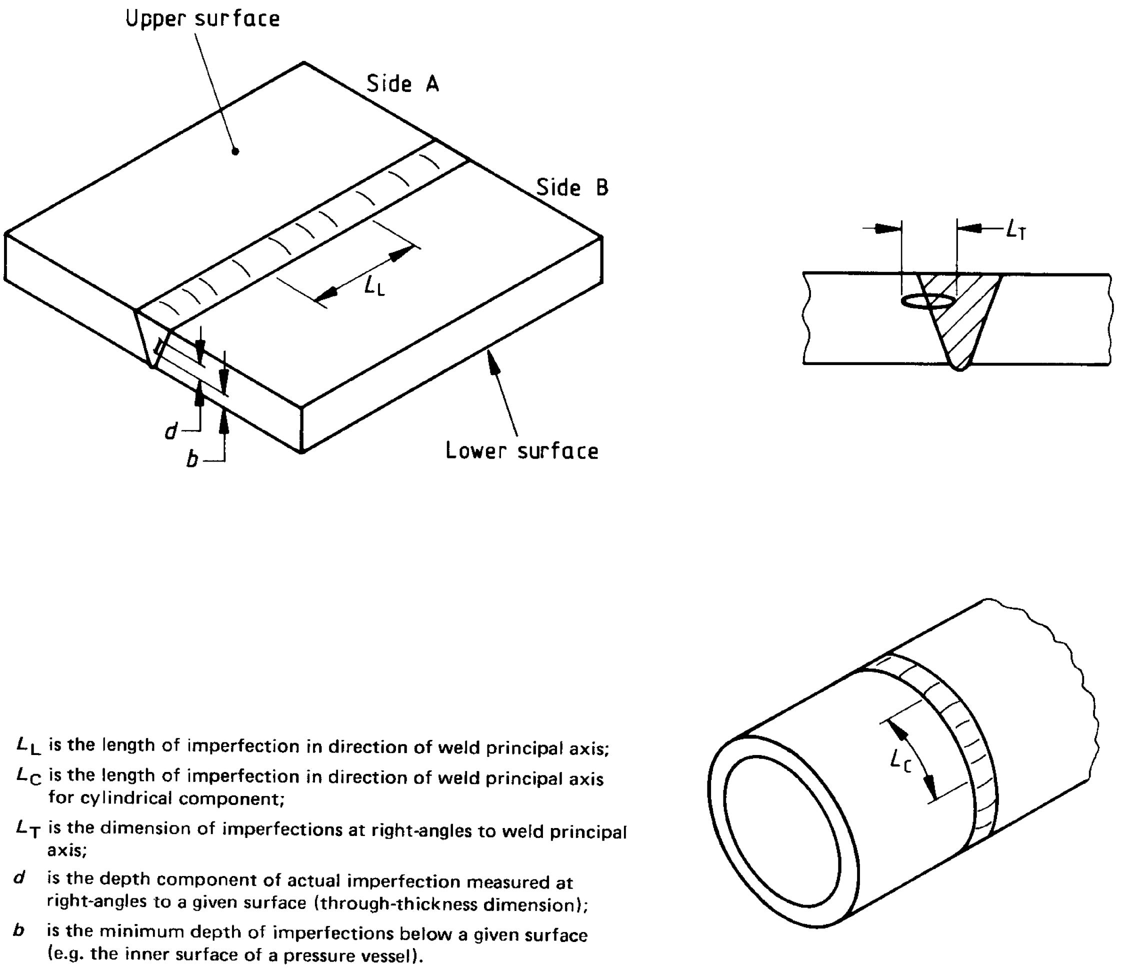


Figure 48 — Suggested notation system for recording location and size of imperfections

The separate values for attenuation and transfer loss may be used to correct the basic DAC curve, provided the attenuation factor for the DAC block is measured and subtracted from that of the material under test. In general, the following methods are more useful when working with the DGS system.

Q.2 Attentuation measurement

Q.2.1 ***Normal probes: method 1***

The steps required are as follows.

a) Calibrate the time base.

b) Position the probe on the material to be measured and select two back wall echoes at a distance ratio of 2:1, the first echo being at least three near field lengths from the probe.

NOTE 1 If not known, the near field length *N* can be calculated from the following equation:

$$N - \frac{\text{crystal diameter}^2}{4 \times \text{wave length}}$$

c) Measure the echo height difference *S* (in dB) between the two selected echoes, and record their range difference *T* (in mm).

d) In the absence of attenuation, the back wall echo falls by 6 dB for every doubling of the range. The attenuation factor *A* (in dB) can therefore be calculated from the following:

$$A = \frac{(S - 6)}{2T}$$

NOTE 2 This method becomes increasingly inaccurate as the number of multiple echoes employed increases. This is due to the loss of 1 dB or more at the probe/material interface for each multiple reflection.

Q.2.2 ***Normal probes: method 2***

Provided a DGS diagram is available for the probe in use, the attenuation factor can be calculated as follows without the need to use numerous multiple back wall echoes.

a) Calibrate the time base.

b) Note the echo height difference S (in dB) between the first and second back wall echoes from the material being measured, and record their range difference T (in mm).

c) Refer to the DGS diagram and note the echo height difference U (in dB) along the back wall echo curve between the ranges of the echoes used in step a).

d) The attenuation factor A (in dB/mm) is given by the equation:

$$A = \frac{(S - U)}{2T}$$

Q.2.3 ***Angle probes: method 1***

This method requires the use of an identical pair of shear wave probes having a beam angle within the range 40° to 50°, and of the same frequency as the probe(s) to be used for the subsequent weld examination. The crystal size of the measuring probes should be such that the beam path range, X, in step b) exceeds approximately three near field lengths.

The steps required are as follows.

a) Calibrate the time base in the normal way using a single shear wave probe.

b) Position the two probes in V-formation for through-transmission on the material to be measured. Maximize and record the echo height V (in dB) and record the echo range X (in mm).

c) Reposition the probes in W-formation and again maximize and record the echo height W (in dB) and record the echo range Y (in mm).

d) The attenuation factor A (in dB/mm) is given by the equation:

$$A = \frac{(V - W) - 6}{2\ (Y - W)}$$

Q.2.4 ***Angle probes: method 2***

This method can be used where a DGS diagram is available for the probes used for making the attenuation measurement. It requires the same probes as for method 1, except that the restriction on near field length does not apply.

The steps required are as follows.

a) Calibrate the time base as for method 1.

b) Position the probes on the material to be measured in V-formation. Maximize and record the echo height V (in dB) and record the range X (in mm).

c) Reposition the probes in W-formation and maximize and record the echo height W (in dB) and record the range Y (in mm).

d) Refer to the DGS diagram and note the echo height difference U (in dB) along the back wall echo curve between ranges X and Y.

e) Calculate the attenuation factor A (in dB/mm) from the following equation:

$$A = \frac{(W - V) - U}{2\ (Y - X)}$$

Q.2.5 ***Angle probes: methods 1a and 2a***

These methods are basically similar to methods 1 and 2 (see **Q.2.3** and **Q.2.4** respectively), but can be used to measure the attenuation of a test block which is too short to allow the probes to be placed in the W-formation.

They differ from previous methods in that a single probe is used, and measurements are based on the half-skip and full-skip echoes from the corners of the test block.

The method of calculating the attenuation factor for methods 1a and 2a is the same as for methods 1 and 2, respectively.

Q.3 Transfer loss measurement

Q.3.1 ***General***

Both the methods described in **Q.3.2** and **Q.3.3** are based on the use of an appropriate DGS diagram, and require prior measurement of the attenuation in the material under test.

For practical purposes, the effect of attenuation within the A2 block can be ignored.

The probes used to make the measurements should be of the same type as those for the weld examination. For the angle probe measurements, two identical probes are required.

Q.3.2 ***Normal probes***

The steps required are as follows.

a) Calibrate the time base.

b) Measure the echo height difference E (in dB) between the first back wall echo from the A2 block (25 mm thickness) and that from the material under test.

c) Note the ranges R_1 and R_2 (in mm) for each echo, respectively.

d) Correct the echo height difference E (in dB) for attenuation A (in dB/mm) to give the corrected echo height E_C from the equation:

$$E_C = E + 2\ (R_2 \times A)$$

e) Refer to the DGS diagram, and note the echo height difference F (in dB) along the back wall echo curve between ranges R_1 and R_2.

f) Calculate transfer loss B (in dB) from the equation:

$$B = (E_C - F)$$

Q.3.3 ***Angle probes***

The steps required are as follows.

a) Calibrate the time base.

b) Measure the echo height difference E (in dB) between the through-transmission signal (V-formation) from the A2 block, and that from the material under test.

c) Note the range R_1 (in mm) in the A_2 block and the range R_2 (in mm) in the material.

d) Correct the echo height difference E (in dB) for attenuation A (in dB/mm) to give the corrected echo height E_C from the equation:

$$E_C = E + 2\ (R_2 \times A)$$

e) Refer to the DGS diagram, and note the echo height difference F (in dB) along the back wall echo curve between ranges R_1 and R_2.

Calculate transfer loss B (in dB) from the following equation:

$$B = (E_C - F)$$

blank

Publications referred to

BS 499, *Welding terms and symbols.*
BS 499-1, *Glossary for welding, brazing and thermal cutting.*
BS 1134, *Method for the assessment of surface texture.*
BS 2704, *Specification for calibration blocks for use in ultrasonic flaw detection.*
BS 3683, *Glossary of terms used in non-destructive testing.*
BS 3683-4, *Ultrasonic flaw detection.*
BS 4331, *Methods for assessing the performance characteristics of ultrasonic flaw detection equipment.*
BS 4331-1, *Overall performance: on-site methods.*
BS 4331-3, *Guidance on the in-service monitoring of probes (excluding immersion probes).*
BS 5750, *Quality systems*[1)].
BS 5996, *Methods for ultrasonic testing and specifying quality grades of ferritic steel plate.*

[1)] Referred to in the foreword only.

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Tel: 020 8996 9000. Fax: 020 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: 020 8996 9001. Fax: 020 8996 7001.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre. Tel: 020 8996 7111. Fax: 020 8996 7048.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration. Tel: 020 8996 7002. Fax: 020 8996 7001.

Copyright

BSI
389 Chiswick High Road
London
W4 4AL