BS EN ISO 16827:2014

BSI Standards Publication

Non-destructive testing — Ultrasonic testing — Characterization and sizing of discontinuities (ISO 16827:2012)

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National foreword

This British Standard is the UK implementation of EN ISO 16827:2014. It is identical to ISO 16827:2012. It supersedes BS EN 583-5:2001 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee WEE/46, Non-destructive testing.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Zerstörungsfreie Prüfung - Ultraschallprüfung - Beschreibung und Größenbestimmung von Inhomogenitäten (ISO 16827:2012)

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Foreword

The text of ISO 16827:2012 has been prepared by Technical Committee ISO/TC 135 “Non-destructive testing” of the International Organization for Standardization (ISO) and has been taken over as EN ISO 16827:2014 by Technical Committee CEN/TC 138 “Non-destructive testing” the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2014, and conflicting national standards shall be withdrawn at the latest by September 2014.

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Endorsement notice

The text of ISO 16827:2012 has been approved by CEN as EN ISO 16827:2014 without any modification.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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ISO 16827 was prepared by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 3, *Ultrasonic testing*.

Introduction

This International Standard is based on EN 583-5:2000+A1:2003, *Non-destructive testing — Ultrasonic examination — Part 5: Characterization and sizing of discontinuities*.

The following International Standards are linked.

ISO 16810, *Non-destructive testing — Ultrasonic testing — General principles*

ISO 16811, *Non-destructive testing — Ultrasonic testing — Sensitivity and range setting*

ISO 16823, *Non-destructive testing — Ultrasonic testing — Transmission technique*

ISO 16826, *Non-destructive testing — Ultrasonic testing — Examination for discontinuities perpendicular to the surface*

ISO 16827, *Non-destructive testing — Ultrasonic testing — Characterization and sizing of discontinuities*

ISO 16828, *Non-destructive testing — Ultrasonic testing — Time-of-flight diffraction technique as a method for detection and sizing of discontinuities*

Non-destructive testing — Ultrasonic testing — Characterization and sizing of discontinuities

1 Scope

This document specifies the general principles and techniques for the characterization and sizing of previously detected discontinuities in order to ensure their evaluation against applicable acceptance criteria. It is applicable, in general terms, to discontinuities in those materials and applications covered by ISO 16810.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16810:2012, *Non-destructive testing — Ultrasonic testing — General principles*

ISO 16811, *Non-destructive testing — Ultrasonic testing — Sensitivity and range setting*

ISO 16823, *Non-destructive testing — Ultrasonic testing — Transmission technique*

ISO 16828, *Non-destructive testing — Ultrasonic testing — Time-of-flight diffraction technique as a method for detection and sizing of discontinuities*

ISO 23279, *Non-destructive testing of welds — Ultrasonic testing — Characterization of indications in welds*

3 Principles of characterization of discontinuities

3.1 General

Characterization of a discontinuity involves the determination of those features which are necessary for its evaluation with respect to known acceptance criteria.

Characterization of a discontinuity may include:

a) determination of basic ultrasonic parameters (echo height, time of flight);

b) determination of its basic shape and orientation;

c) sizing, which may take the form of either:

   i) the measurement of one or more dimensions (or area/volume), within the limitations of the methods; or

   ii) the measurement of some agreed parameter e.g. echo height, where this is taken as representative of its physical size;

d) location e.g. the proximity to the surface or to other discontinuities;

e) determination of any other parameters or characteristics that may be necessary for complete evaluation;

f) assessment of probable nature, e.g. crack or inclusion, where adequate knowledge of the test object and its manufacturing history makes this feasible.

Where the examination of a test object in accordance with the principles of ISO 16810 yields sufficient data on the discontinuity for its evaluation against the applicable acceptance criteria, no further characterization is necessary.

The techniques used for characterization shall be specified in conjunction with the applicable acceptance criteria.

3.2 Requirements for surface condition

The surface finish and profile shall be such that it permits sizing of discontinuities with the desired accuracy. In general the smoother and flatter the surface the more accurate the results will be.

For most practical purposes a surface finish of Ra = 6,3 μm for machined surfaces and 12,5 μm for shotblasted surfaces are recommended. The gap between the probe and the surface should not exceed 0,5 mm.

The above surface requirements should normally be limited to those areas from which sizing is to be carried out as, in general, they are unnecessary for discontinuity detection.

The method of surface preparation shall not produce a surface that gives rise to a high level of surface noise.

4 Pulse echo techniques

4.1 General

The principal ultrasonic characteristics/parameters of a discontinuity that are most commonly used for evaluation by the pulse echo techniques are described in 4.2 to 4.7 inclusive.

The characteristics/parameters to be determined shall be defined in the applicable standard or any relevant contractual document, and shall meet the requirements of 10.1 of ISO 16810:2012.

4.2 Location of discontinuity

The location of a discontinuity is defined as its position within a test object with respect to an agreed system of reference co-ordinates.

It shall be determined in relation to one or more datum points and with reference to the index point and beam angle of the probe, and measurement of the probe position and beam path length at which the maximum echo height is observed.

Depending on the geometry of the test object under examination, and the type of discontinuity, it may be necessary to confirm the location of the discontinuity from another direction, or with another probe angle, to ensure that the echo is not caused e.g. by a wave mode change at a geometrical feature of the test object.

4.3 Orientation of discontinuity

The orientation of a discontinuity is defined as the direction or plane along which the discontinuity has its major axis (axes) with respect to a datum reference on the test object.

The orientation can be determined by a geometrical reconstruction analogous to that described for location, with the difference that more beam angles and/or scanning directions are generally necessary than for simple location.

The orientation may also be determined from observation of the scanning direction at which the maximum echo height is obtained.

In several applications, the precise determination of the discontinuity orientation in space is not required, only the determination of the projection of the discontinuity onto one or more pre-established planes and/or sections within the test object.

4.4 Assessment of multiple indications

The method for distinguishing between single and multiple discontinuities may be based on either qualitative assessment or quantitative criteria.

The qualitative determination consists of ascertaining, through the observation of the variations of the ultrasonic indications, whether or not such indications correspond to one or more separate discontinuities. Figure 1 shows typical examples of signals from grouped discontinuities in a forging or casting.

Where acceptance criteria are expressed in terms of maximum allowable dimensions, preliminary quantitative measurements shall be made in order to determine whether separate discontinuities are to be evaluated individually or collectively according to pre-established rules governing the evaluation of the group.

Such rules may be based on the concentration of individual discontinuities within the group, expressed in terms of the total of their lengths, areas or volumes in relation to the overall length, area or volume of the group. Alternatively, the rules may specify the minimum distance between individual discontinuities, often as a ratio of the dimensions of the adjacent discontinuities.

Where a more accurate characterization of a group of indications is required, an attempt may be made to determine whether the echoes arise from a series of closely spaced but separate discontinuities, or from a single continuous discontinuity having a number of separate reflecting facets, using the techniques described in Annex A.

4.5 Shape of discontinuity

4.5.1 Simple classification

There are a limited number of basic reflector shapes that may be identified by ultrasonic testing. In many cases evaluation against the applicable acceptance criteria only requires a relatively simple classification, described in B.1. According to this, the discontinuity is classified as either:

1) point, i.e. having no significant extent in any direction;

2) elongated, i.e. having a significant extent in one direction only;

3) complex, i.e. having a significant extent in more than one direction.

   When required, this classification may be sub-divided into:

   a) planar, i.e. having a significant extent in 2 directions only, and

   b) volumetric, i.e., having a significant extent in 3 directions.

Depending upon the requirements of the acceptance standard, either:

a) separate acceptance criteria may apply to each of the above classifications, or

b) the discontinuity, independently of its point, elongated or complex configuration, is projected on one or more pre-established sections, and each projection is conservatively treated as a crack-like planar discontinuity.

Simple classification will normally be limited to the use of those probes and techniques specified in the examination procedure. Additional probes or techniques shall only be used where agreed.

4.5.2 Detailed classification of shape

In order to correctly identify the discontinuity types specified in the acceptance criteria, or to make a correct fitness-for-purpose evaluation, it may be necessary to make a more detailed assessment of the shape of the discontinuity.

Guidance on the methods that may be used for a more detailed classification is contained in B.2. It can require the use of additional probes and scanning directions to those specified in the examination procedure for the detection of discontinuities, and can also be aided by the use of the special techniques in Annexes E, F and G.

Classification of discontinuity shape will be limited to the determination of those discontinuity shapes which are necessary for the correct evaluation of a discontinuity against the acceptance criteria or other requirements. The validity of such a classification should be proven for the specific application, e.g. materials and configuration of the examination object, examination procedure, type of instrumentation and probes.

4.6 Maximum echo height of indication

The maximum echo height from a discontinuity is related to its size, shape and orientation. It is measured by comparison with a given reference level according to the methods described in ISO 16811.

Depending on the application and acceptance criteria the maximum echo height can be:

a) compared directly with a reference level that constitutes the acceptance standard;

b) used to determine the equivalent size of a discontinuity by comparison with the echo from a reference reflector at the same sound path range in the material under examination, or in a reference block having the same acoustic properties, as described in 4.7.2;

c) used in probe movement sizing techniques based on a specified echo drop (e.g. 6 dB) below the maximum, as described in 4.7.3.

4.7 Size of discontinuity

4.7.1 General

The sizing of a discontinuity consists in determining one or more projected dimensions/areas of the discontinuity onto pre-established directions and/or sections.

A short description of these techniques is found in Annex F and further details are given in ISO 16811.

4.7.2 Maximum echo height techniques

These techniques are based on a comparison of the maximum echo height from a discontinuity with the echo height from a reference reflector at the same sound path range.

They are only meaningful if:

a) the shape and orientation of the discontinuity are favourable for reflection, hence the need to take echo height measurements from several directions or angles, unless the shape and orientation are already known; and

b) the dimensions of the discontinuity, perpendicular to the beam axis, are less than the beam width in either one or both directions;

c) the basic shape and orientation of the reference target are similar to those of the discontinuity to be evaluated.

The reference target may be either a disk-shaped reflector, e.g. flat-bottomed hole or an elongated reflector, e.g. a side drilled hole or notch.

Discontinuities subject to sizing may be classified as follows:

i) discontinuities whose reflective area has dimensions less than the beam width in all directions;

ii) discontinuities whose reflective area shows a narrow, elongated form, i.e. having a length greater than the beam width and a transverse dimension less than the beam width.

For discontinuities corresponding to i) above, the area of the discontinuity, projected onto a section normal to the ultrasonic beam axis, is assumed to be equivalent to the area of a disk-shaped reflector, perpendicular to the beam axis, producing a maximum echo of the same height at the same sound path range.

For discontinuities corresponding to ii) above, the reference reflectors are generally of elongated form, transverse to the ultrasonic beam axis, and having a specified transverse profile. Such reflectors may be notches with rectangular, U- or V-shaped profile, or cylindrical holes, etc.

4.7.3 Probe movement sizing techniques

When using an angle beam probe, the dimensions generally determined are:

i) dimension, l, parallel to the lateral scanning direction, determined by lateral movement of the probe (see Figure 2);

ii) dimension, h, normal to the transverse scanning direction, determined by transverse movement of the probe (see Figure 2).

When using a straight beam probe the dimensions generally determined are l_1 and l_2, in directions parallel to the scanning surface, by probe movement in two mutually perpendicular directions (see Figure 3).

The techniques are classified into three categories, as follows:

1) fixed amplitude level techniques where the ends of a discontinuity are taken to correspond to the plotted positions at which the echo height falls below an agreed assessment level;

2) techniques where the edges of the discontinuity are taken to correspond to the plotted positions at which the maximum echo height at any position along the discontinuity has fallen by an agreed number of dB. The edges of the discontinuity may be plotted along the beam axis or along a pre-determined beam edge;

3) techniques which aim to position the individual echoes from the tips of the discontinuity, or from reflecting facets immediately adjacent to the edges.

The principal probe movement sizing techniques are described in Annex D.

4.7.4 Selection of sizing techniques

The selection of sizing technique(s) depends upon the specific application and product type, and on the size and nature of the discontinuity.

The following general rules apply:

a) maximum echo height techniques (see 4.7.2) may be applied only if the dimension to be measured is less than the 6 dB beam width of the probe;

b) fixed amplitude level techniques (see 4.7.3 (1)) may be applied to discontinuities of any dimension, but since the measured size is an arbitrary value dependent on the particular amplitude level selected, these techniques should only be used when specifically called for in the acceptance standard;

c) techniques based on probe movement at a specified dB drop below the maximum echo height from the particular discontinuity (see 4.7.3 (2)) may be applied only where the measured dimension is greater than the beam width at the same dB drop. If this condition is not fulfilled the dimension of the discontinuity shall be assumed to be equal to the applicable beam width;

d) techniques based on positioning the individual edges of a discontinuity (see 4.7.3 (3)) can only be applied when the ultrasonic indication from the discontinuity shows two or more resolvable echo maxima;

e) if the dimension to be determined is measured by more than one technique of 4.7.3 above, that value measured by the technique whose reliability and accuracy can be demonstrated to be the highest shall be assumed to be correct.

Alternatively, the highest measured value shall be assumed.

4.7.5 Sizing techniques with focusing ultrasonic probes

If focusing probes are used for sizing, the techniques described in 4.7.2 and 4.7.3 can also be used, provided that the discontinuity falls within the focal zone of the beam. In general the rules given under 4.7.4 also apply to focusing probes.

Where a higher accuracy of sizing is requested, an alternative technique can be used that is based on the construction of a series of C-scan images of the discontinuity.

These are plotted through an iterative process of 6 dB drop steps, starting from an initial plot corresponding to the 6 dB drop from the maximum echo of discontinuity, down to the step where the evolution of the plot corresponding to a 6 dB drop step is equal to, or less than, the 6 dB half-width of the ultrasonic beam.

In principle, this iterative technique can be used with both focused and unfocused ultrasonic beams, but where high accuracy is required, it is particularly suitable for use with focused beams. Annex E illustrates this technique in detail.

4.7.6 Use of mathematical algorithms for sizing

The main purpose of the sizing techniques illustrated in 4.7.2 and 4.7.3 is to compare the measured discontinuity size with acceptance levels expressed in terms of maximum allowable dimensions (or areas/volumes). Where a higher accuracy is required in order to better estimate the actual size of a discontinuity, but only data from the techniques described in 4.7.2 and 4.7.3 are available, mathematical algorithms may be of help.

Annex F illustrates in detail algorithms that can be used for the estimation of the actual size of discontinuities that are either larger or smaller than the diameter of the ultrasonic beam.

4.7.7 Special sizing techniques

Special sizing techniques are additional to those described in 4.7.2 to 4.7.6 and may be used in particular applications where higher levels of reliability and accuracy are called for.

When required, the reliability and accuracy of a special technique, applied to meet specified acceptance criteria, shall be demonstrated on the same configuration and type of material using the same examination procedure and type of instrumentation and probes.

The following list of special techniques is not comprehensive due to the large number available and their continuous development. Those described are the most commonly applied and their use is sufficiently well established.

a) Tip diffraction techniques

These techniques can be used for the confirmation of the planar nature of a discontinuity (if this is the case) and for sizing the transverse dimension ("h" of Figure 2) of a planar discontinuity. They are based on the detection and location of the echoes diffracted by discontinuity edges;

b) mode conversion techniques

Where applicable these techniques can be used for detection and characterization of planar discontinuities. They make use of mode conversion to generate an additional ultrasonic beam at a different reflected angle and velocity when the plane of the discontinuity is oriented at the appropriate angle to the incident beam. In certain cases these techniques can also be used for sizing, but require the use of special reference blocks representative of the test object to be examined, and containing planar reflectors of different sizes;

c) other special techniques

Other examples of ultrasonic techniques for the sizing of volumetric and planar discontinuities are:

acoustical holography;

acoustical tomography;

techniques using beams of variable angle;

synthetic aperture focusing techniques (SAFT); and

reconstruction of sectorial B-scan images.

G.2 describes the principle and main characteristics of the SAFT.

5 Transmission technique

5.1 General

The general principles and requirements of the transmission technique are given in ISO 16823.

The following clauses describe some of the ultrasonic parameters and characteristics of the transmitted signals that may be used, either alone or in combination, to evaluate a discontinuity by this technique.

5.2 Location of discontinuity

When using normal beam probes, the location of a discontinuity is defined as the position on the surface of the test object, with respect to a two-dimensional co-ordinate system, at which the maximum reduction in transmitted signal amplitude is observed.

If it is practicable to direct ultrasonic beams through the area under investigation in two different directions, for example by the use of pairs of angle probes as illustrated in Figure 4, the three-directional location of the discontinuity may be determined.

5.3 Evaluation of multiple discontinuities

Whether a discontinuity is continuous or intermittent should first be determined qualitatively by observing variations in signal amplitude as the probe is scanned over the discontinuity.

If the signal amplitude remains relatively constant the discontinuity can be classified as continuous and evaluated as such against the acceptance criteria.

Conversely, if the signal amplitude shows marked maxima and minima the discontinuity may be classified as intermittent. In this case, it is necessary to determine quantitatively whether the concentration of discrete discontinuities within the affected area is sufficiently high to apply the size/area limitations imposed by the acceptance criteria.

The concentration of discontinuities within the affected area may be expressed, for example, in terms of the ratio between:

a) the dimensions (or area) of individual discontinuities and the distance between them;

b) the total length of discontinuities and a given overall length; and

c) the total area of individual discontinuities and a given overall area.

5.4 Reduction of signal amplitude

This parameter is taken into account whenever the signal amplitude falls below the specified evaluation level.

If the signal is lost completely, the limits of the zone on the scanning surface over which this occurs should be determined.

If there is only partial loss of the signal, the position on the scanning surface corresponding to the maximum amplitude reduction should be determined, together with the dB value of the reduction compared to the signal obtained in a zone free from discontinuities.

If the area on the scanning surface, affected by the signal reduction, is less than the cross-sectional area of the ultrasonic beam, the size of the discontinuity normal to the beam may be estimated by matching the reduction in amplitude with that due to a known reference reflector, e.g. a flat-bottomed hole, in a representative sample of discontinuity-free material [see 5.5 (a)].

Where a relatively constant partial reduction in signal amplitude is observed over a zone significantly greater than the area of the ultrasonic beam, it is probable that the discontinuity may take the form of, for example, a band of numerous small inclusions, an area of abnormal grain structure, a layer of ultrasonically semi-transparent material, or a large discontinuity under high compressive stress.

5.5 Sizing of discontinuity

The sizing of a discontinuity consists in determining one or more dimensions (or the area) of the projection of the discontinuity onto the scanning surface. In particular, the dimensions (or areas) so determined are compared with the applicable acceptance standards, whenever these standards are expressed in terms of maximum allowable dimensions (or areas), in order to assess the acceptability or unacceptability of the discontinuity.

Sizing techniques may be classified essentially in the following 2 categories:

a) techniques based on the comparison of the maximum amplitude reduction of the signal with respect to the maximum amplitude reduction of an equivalent reflector. Adoption of these techniques for the sizing is limited to the case where the dimension (or area) of the zone on the scanning surface corresponding to the signal amplitude reduction below the evaluation level is less than the probe dimension (or area) projected on the scanning surface.

   In this case, the maximum amplitude reduction of the signal with respect to the signal amplitude in a zone free of discontinuities is determined, together with the reflector, generally a flat-bottomed hole perpendicular to the beam axis located at a given depth (e.g. half thickness), producing the same maximum reduction in the transmitted signal amplitude.

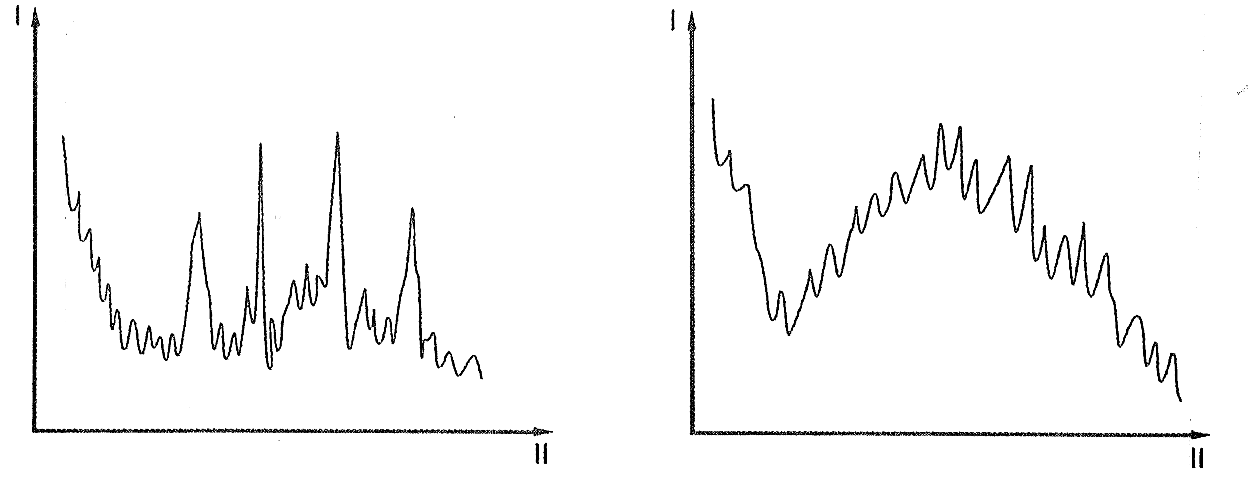
   The dimension (or area) of the discontinuity, projected on a plane perpendicular to the beam axis, is assumed to be the same as the dimension (or area) of the flat-bottomed hole;

b) techniques based on the amplitude reduction of the signal in conjunction with probe movement. These techniques consist of determining the zone on the scanning surface corresponding either to the loss of the signal or to its amplitude reduction in comparison to a given value (most frequently 6 dB) with respect to the signal amplitude from a zone free of discontinuities.

   Values other than 6 dB may be used when specified by the referencing documents, particularly when evaluating discontinuities which are partially transparent to ultrasound.

   The extent of the zone so determined is assumed to be the extent of the discontinuity projection on the scanning surface.

Since the transmission technique is most frequently used for detecting comparatively large discontinuities, where the required sizing accuracy is relatively low, the techniques described under b) above are adequate for most of applications. In this context, the data collected by the techniques described under a) above constitute a reference that may be used to ensure the reproducibility of the examination, rather than the basis for the direct sizing of discontinuities.



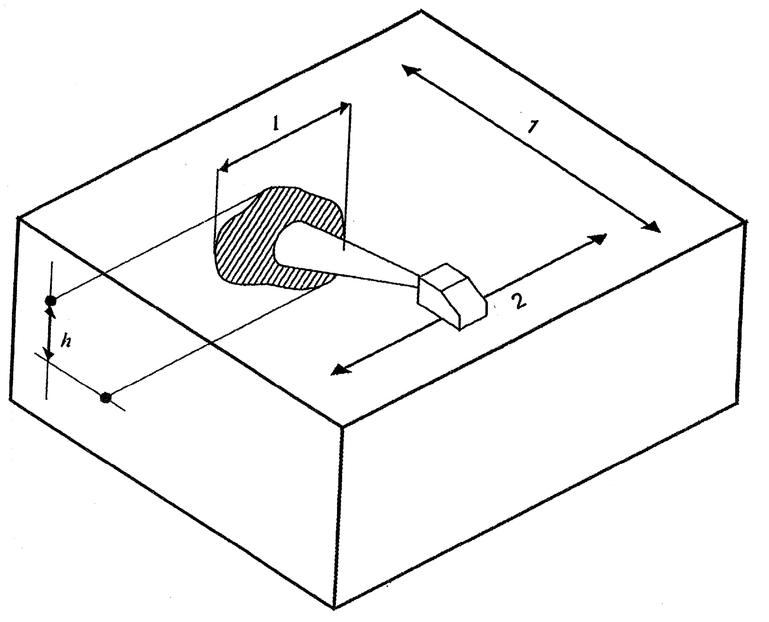
Key

I Signal height

II Time of flight

a) Resolvable grouped discontinuities **b) Unresolvable grouped discontinuities**

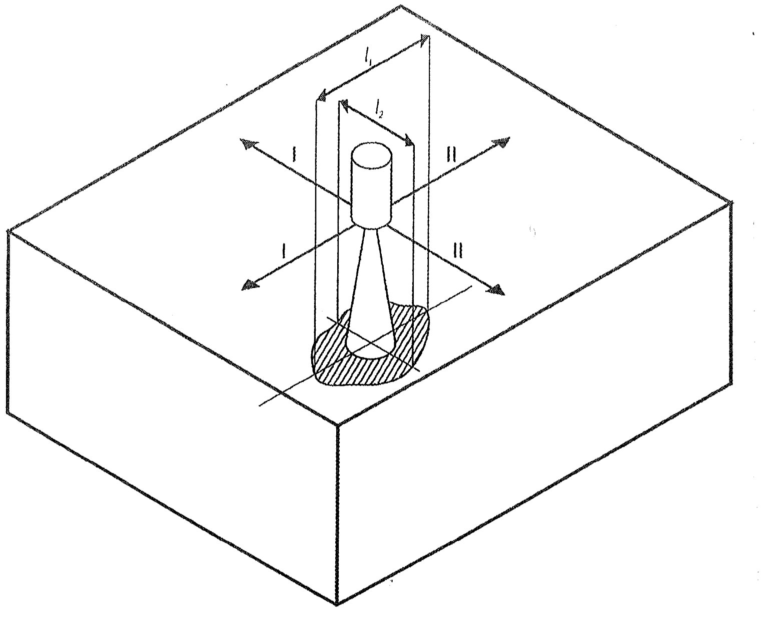
Figure 1 — Examples of A-scan signals from grouped discontinuities in a forging or casting



Key

1 Transverse movement
2 Lateral movement

Figure 2 — Projected parameters *l* and *h* for the conventional sizing of a discontinuity by an angle beam probe



Key

I Probe movement
II Probe movement

Figure 3 — Parameters l_1 and l_2 for the conventional sizing of discontinuity by a straight beam probe

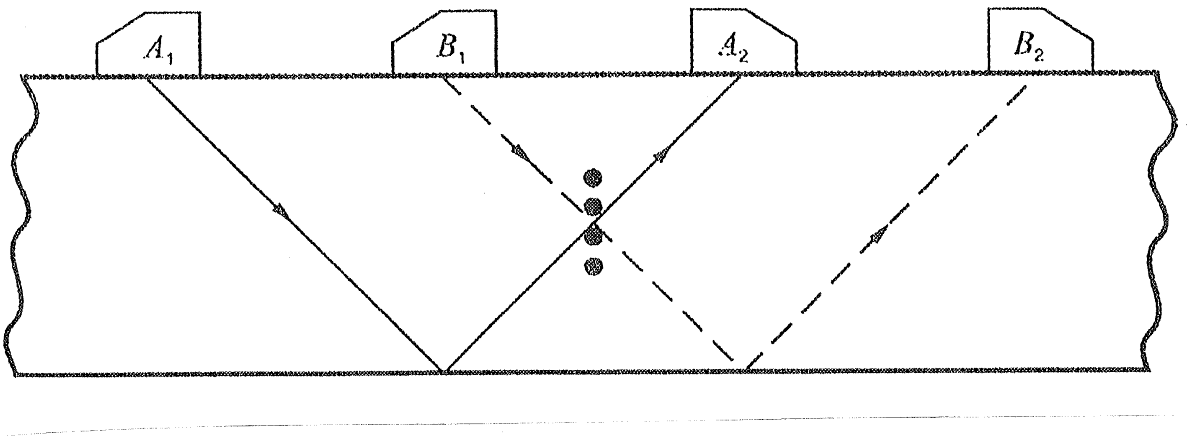


Figure 4 — Location of discontinuities by transmission technique using angle probes

The discontinuity lies at the intersection of the two beam paths A_1A_2 and B_1B_2, at which the maximum reduction in transmitted signal amplitude is observed.

Annex A
(normative)

Analysis of multiple indications

Some of the techniques which may be used to distinguish between intermittent and continuous discontinuities are described below.

Techniques A.1 and A.2 are particularly applicable to welds but may be adapted for other applications where angle probe examination is practicable. Technique A.3 is of wider application but limited with respect to the minimum area of discontinuities that can be evaluated.

A.1 Lateral characterization

For discontinuities showing a single, sharp, A-scan indication, the scanning direction, beam angle, size and frequency of the probe should be selected to give the narrowest practical beam width at the distance of the discontinuity, and a careful lateral scan should be carried out under uniform coupling conditions.

Marked dips in the echo height envelope along its length suggest that the discontinuity is intermittent. This should 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 due to a change in lateral orientation.

A.2 Transverse (Through-thickness) characterization

Careful transverse scans should be carried out across the discontinuity, from at least two directions at short sound path ranges, and the form of the echo envelope shall be noted.

Significant dips, or complete breaks, in the echo envelope suggest that the discontinuity may be intermittent.

Where access permits, it is recommended that a composite through-thickness picture of the discontinuity be built up by plotting all the echoes observed from a number of different directions and angles. Smooth flat scanning surfaces on either side of the discontinuity, and high plotting accuracy, are necessary if this technique is to be of value.

A.3 Shadow technique

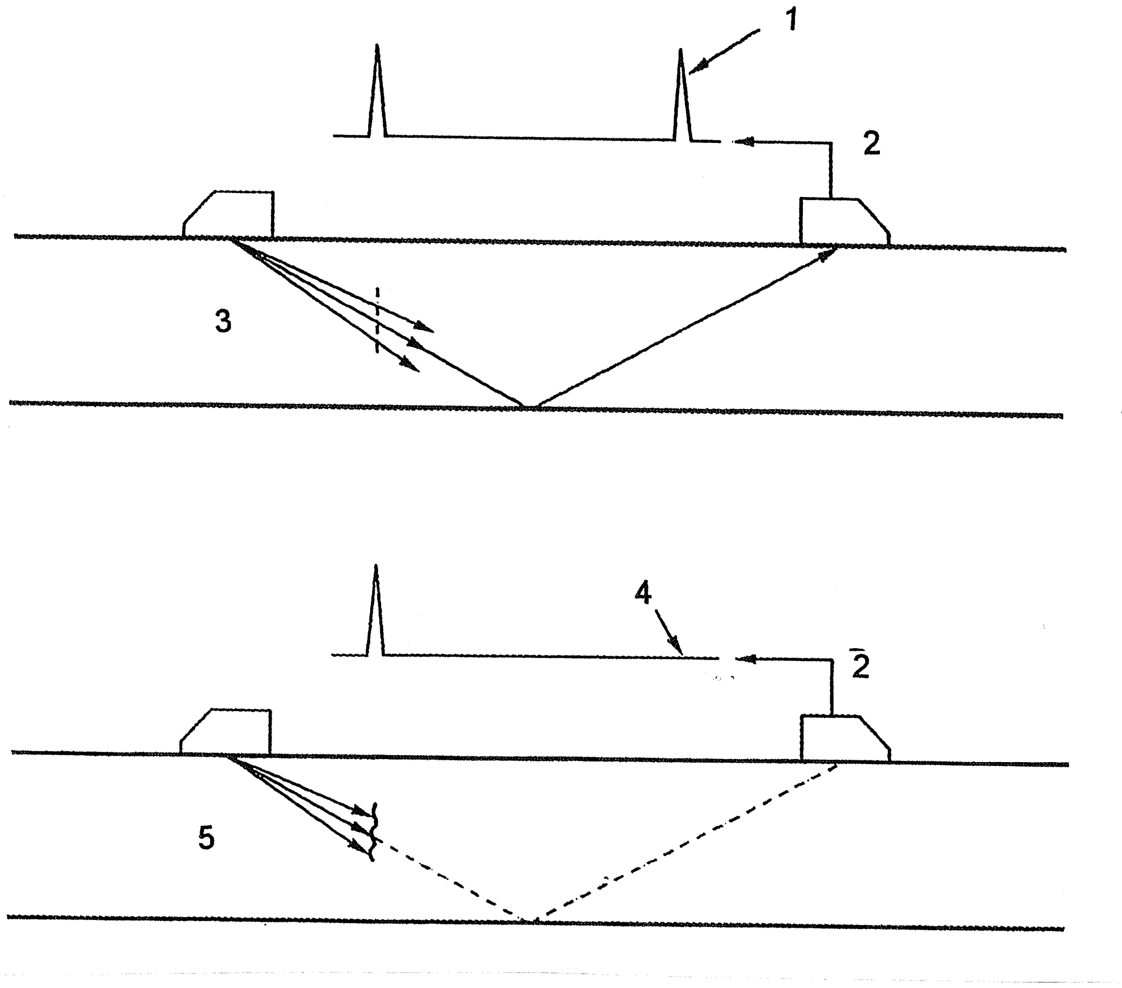
This technique is useful when the dimensions of the discontinuity, or group of discontinuities, are approximately equal to the beam width.

It is illustrated for angle probes in Figure A.1, but is equally applicable to normal beam probes, either using separate transmitting and receiving probes, or monitoring variations in the back wall echo height.

A strong transmitted signal through the affected area is positive proof of the absence of a major discontinuity. The amplitude of the transmitted signal is linked to the ratio of the discontinuity area to the beam area.

The resolution of all the above techniques may be improved by the use of focusing probes having a focal length close to the sound path range of the discontinuity.

Since the through-thickness dimension of a discontinuity is generally of critical importance, it should be assumed to be continuous unless there is conclusive evidence that it is intermittent in this direction.



Key

1 Transmission signal

2 A-scan

3 Intermittent discontinuity

4 No transmitted signal

5 Continuous discontinuity

Figure A.1 — Shadow technique for distinguishing between continuous and intermittent discontinuities

Annex B
(normative)

Techniques for the classification of discontinuity shape

B.1 Simple classification

B.1.1 General

The simple classification of discontinuity shape is based upon determining whether the discontinuity has a significant extent in any one or more direction(s). In the context of this International Standard, the term "significant extent" is defined as a dimension larger than the minimum measurable dimension, when taking into account the beam width, and resolution of the probe at the beam path range of the discontinuity.

In the context of this International Standard the principal discontinuity shapes are defined as follows:

point: no significant extent in any direction;

elongated: significant extent in one direction only;

large: Significant extent in either 2 perpendicular directions (planar), or 3 perpendicular directions (volumetric).

Either of the following techniques (see clauses B.1.2 and B.1.3) may be used to assess whether the discontinuity has a significant extent. Both involve scanning the discontinuity from 2 scanning directions, one perpendicular to the other, and using 2 probe movements (perpendicular and parallel to the scanning direction) for each scanning direction (see Figure B.1). An example of a procedure for the characterization of imperfections in welds is found as a flow chart in ISO 23279.

B.1.2 Reconstruction technique

For each scanning movement, an image of the discontinuity is reconstructed by plotting a series of indications from the discontinuity over which the echo height exceeds the evaluation/recording level. The dimensions of those images are then compared with the minimum measurable dimension noted in B.1.1.

B.1.3 Echo envelope technique

For each scanning movement, the shape of the A-scan indication from the discontinuity, and its variation in echo height with probe movement, is observed. A discontinuity that shows a single sharp indication that rises smoothly to a maximum amplitude, before falling smoothly to the base line, is classified as having no significant extent.

All other types of indication, e.g. multiple peaks on the A-scan presentation, or irregular variation in echo height with probe movement, are considered to be characteristic of discontinuities with a significant extent.

B.2 Detailed classification

B.2.1 General

The techniques described below are applicable when a more accurate estimate of the shape and nature of discontinuity, with respect to B.1, is required.

In this type of evaluation it is important to construct a picture of the type and size of the discontinuity which is consistent with all the measurements obtained. Where significant discrepancies are found which cannot be resolved, the type of discontinuity having the most severe acceptance criteria, and the most pessimistic values of discontinuity size, should be reported.

The basic discontinuity types and shapes which possibly may be distinguished are as follows:

1 point	a) spherical;
	b) planar;
2 elongated	a) cylindrical;
	b) planar;
3 large	a) volumetric;
	b) smooth planar;
	c) rough planar;
4 multiple	a) spherical;
	b) planar.

This list should not be regarded as a list of discontinuities for acceptance purposes, but rather as a list of shapes, the identification of which may aid the correct classification of the discontinuity types specified in the discontinuity acceptance standard.

Three techniques may be used in combination to identify these shapes and determine their orientation. These are based on:

a) echodynamic patterns (see B.2.2);

b) directional reflectivity (see B.2.3);

c) additional parameters, e.g. location, orientation, multiple indications (see clauses 4.2, 4.3 and 4.4).

B.2.2 Echodynamic pattern technique

The echodynamic pattern of a discontinuity is the change in shape and amplitude of its echo when an ultrasonic beam is traversed across it.

The observed echodynamic pattern is a function of the shape and size of the discontinuity, the probe in use, and the scanning direction and angle.

Discontinuities should be scanned, with each probe, in two mutually perpendicular directions, i.e. both along and across the discontinuity, and the pattern in each direction should be noted. Scanning from additional directions and with other probes will give useful additional information.

Typical echo responses of the different types of discontinuities as listed in B.2.1 are shown in Figures B.2 to B.5.

Pattern 1

A typical response of a point discontinuity is shown in Figure B.2. At any probe position the A-scan shows a single sharp echo. As the probe is moved this rises in amplitude smoothly to a single maximum before falling smoothly to noise level.

In general, echo-dynamic pattern 1 is indicative of a single reflecting surface in the direction along which the ultrasonic beam is traversed. This surface may be curved (i.e. spherical or cylindrical) or, alternatively, it may be flat and either smooth or rough, but too small to produce either a pattern 2 response or a pattern 3 response.

Pattern 2

A typical response of an elongated smooth discontinuity is shown in Figure B.3. At any probe position the A-scan shows a single sharp echo. When the ultrasonic beam is moved over the discontinuity the echo rises smoothly to a plateau and is maintained, with minor variations in amplitude of up to 4 dB, until the beam moves off the discontinuity, when the echo will fall smoothly to noise level.

Pattern 2 is indicative of a larger reflecting surface, equal to or greater than the approximate 6 dB beam width, and lying approximately perpendicular to the beam axis in the direction being scanned. For example, a cylindrical reflector would show pattern 1 across its diameter, and pattern 2 along its length. As a second example a laminar plate discontinuity, examined with a normal beam probe, would show pattern 2 in both directions.

Pattern 3

Typical responses of a large rough discontinuity are shown in Figures B.4.a) and B.4.b). There are two variants of this pattern, depending upon the angle of incidence of the probe beam on the discontinuity.

When either by a normal beam or an inclined beam the discontinuity is been hit perpendicularly then Figure B.4.a) is valid. At any probe position the A-scan shows a single but ragged echo. As the probe is moved this may undergo large (>±6 dB) random fluctuations in amplitude. (The fluctuations are caused by reflection from different facets of the discontinuity, and by random interference of waves scattered from groups of facets).

When the discontinuity is been hit with oblique incidence, then the "travelling echo pattern" in Figure B.4.b) is valid. At any probe position the A-scan shows an extended train of signals ("subsidiary peaks") within a bell-shaped pulse envelope. As the probe is moved each subsidiary peak travels through the pulse envelope, rising to its own maximum towards the centre of the envelope, and then falling. The overall signal may show large (>± 6 dB) random fluctuations in amplitude.

Pattern 3 is indicative of a rough or irregularly shaped discontinuity which consists of a number of discrete reflecting facets. An example would be a large rough-surfaced crack. It is an important characteristic of pattern 3 that each individual peak within the overall echo reaches its maximum height in sequence, giving rise to a "rolling echo".

Pattern 4

A typical response of a multiple discontinuity with a normal beam and angle beam probe is shown in Figure B.5. At any probe position the A-scan shows a cluster of signals which may or may not be well resolved in range. As the probe is moved the signals rise and fall at random but the signal from each separate discontinuity element, if resolved, shows pattern 1 response.

Pattern 4 is indicative of a cluster of small, randomly distributed reflectors, and differs from pattern 3 in not showing the "rolling echo" effect.

The use of these echo dynamic patterns in combination, and in conjunction with the information on directional reflectivity and other parameters is considered in B.3.

B.2.3 Directional reflectivity

This term is used to describe the variation in echo amplitude from a discontinuity in relation to the angle at which the ultrasonic beam is incident upon it.

Discontinuities which show relatively constant echo heights over a wide range of incident angles are said to have a low directional reflectivity, and vice versa.

The echo height from a discontinuity depends upon its size, orientation and surface contour. By measuring the echo height from different directions and angles (taking into account the effects of range on echo height) it is possible to obtain information about these characteristics. For example, a flaw which shows a very low directional reflectivity is likely to be spherical. Conversely, a discontinuity which shows a very high directional reflectivity is likely to be a large smooth reflector lying perpendicular to the beam angle at which the maximum echo height was observed.

The directional reflectivity of very small flat reflectors is relatively low and increases with the size of the reflector until it approaches the ultrasonic beam width. This effect can be used to help estimate the size of a discontinuity. For example, when carrying out an orbital scan of a short weld inclusion, a qualitative estimate of its length can be made by noting the directional reflectivity in the length direction.

B.3 Combination of data

Metallurgical discontinuities can have complicated shapes and give rise to complicated echo behaviour as the beam is scanned over them. Nevertheless, it is possible in most cases to identify the basic shape from its echodynamic patterns and directional reflectivity supplemented, in the case of large discontinuities, by the accurate location of its individual facets or the extremities of its surface.

Table B.1 summarizes all features of the typical responses of all discontinuity types and shapes defined in B.2.1 to combine the results of the classification according to B.2.2 and B.2.3.

The orientation of small planar discontinuities is generally determined by noting the beam angle at which the maximum echo height is obtained, the orientation being perpendicular to the beam axis.

The greater the number of angles from which the discontinuity is examined the greater will be the accuracy. Discontinuities that lie perpendicular to the surface of test object, and either break the surface or are very close to it, generally show a maximum echo height from both directions when the incident angle is between 40° and 50°.

Table B.1 — Guide to detailed classification

Shape/Type	Echodynamic patterns		Directional reflectivity	Remarks
	Transverse movement	Lateral movement		
Point spherical	Pattern 1	Pattern 1	Very low	Point location
Point planar	Pattern 1	Pattern 1	Moderate	Point location only
Elongated cylindrical	Pattern 1	Pattern 2	Very low in transverse plane. High in lateral plane (see note)	Point location by transverse movement
Elongated planar	Pattern 1	Pattern 2	Moderate in transverse plane. High in lateral plane (see note)	Ends may be individually located by lateral movement

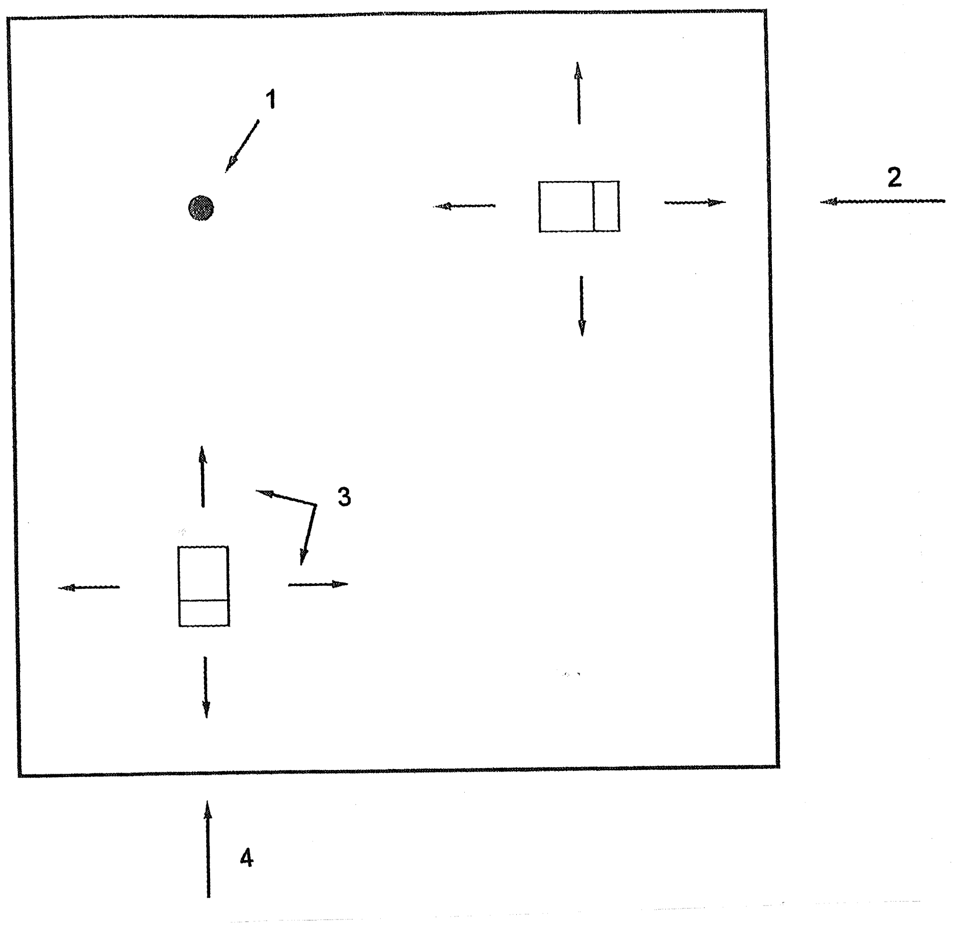
Table B.1 *(continued)*

Shape/Type	Echodynamic patterns		Directional reflectivity	Remarks
	Transverse movement	Lateral movement		
Large volumetric	Pattern 3	Pattern 2 or pattern 3	Moderate in transverse plane. Moderate in lateral plane (see note)	Approximate outline generally possible
Large smooth planar	Pattern 2	Pattern 2	Very high	Ends may be individually located
Large rough planar	Pattern 3	Pattern 3	Moderate	Location of individual facets and ends generally possible
Multiple spherical	Pattern 4	Pattern 4	Very low	Location of edges of cluster generally possible
Multiple planar	Pattern 4	Pattern 4	Moderate	

NOTE The transverse and lateral planes are defined as follows:

Transverse plane - perpendicular to the major axis of the discontinuity, or to a specified direction;

Lateral plane - parallel to the major axis of the discontinuity, or at right angles to the transverse plane.



Key

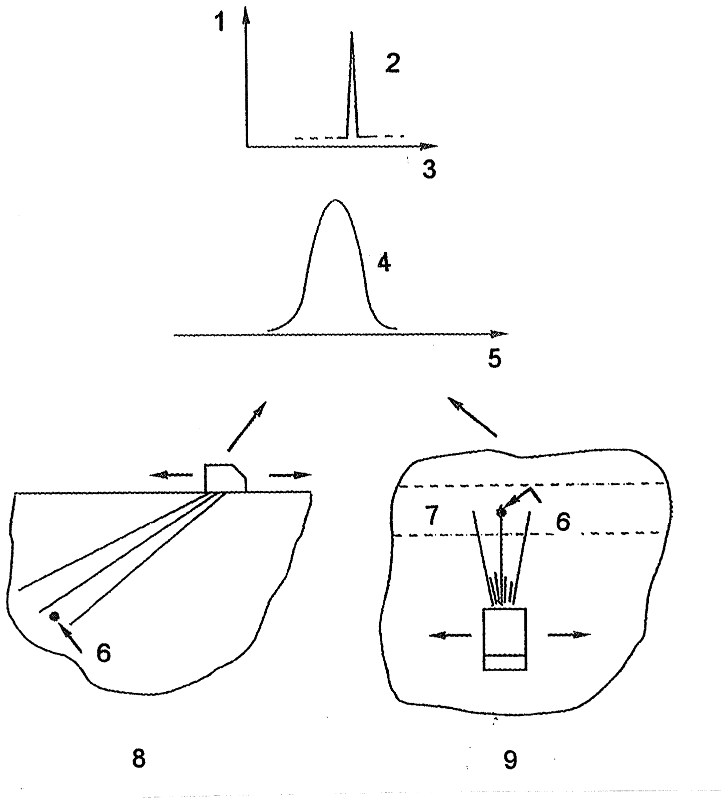
1 Discontinuity

2 Scanning direction 1

3 Probe movements

4 Scanning direction 2

Figure B.1 — Probe movements and scanning directions for simple classification of discontinuity shape when using angle probes



Key

1 Amplitude

2 A-scan

3 Range

4 Variation in peak signal amplitude

5 Probe position

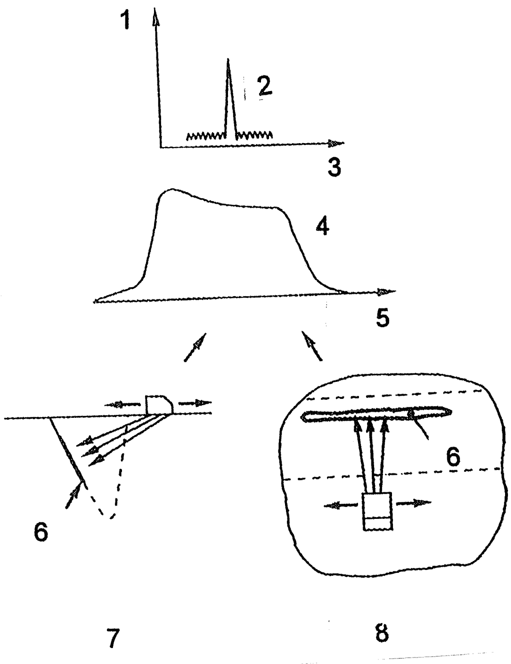
6 Reflector

7 Weld

8 Typical occurrence in through-thickness direction

9 Typical occurrence in lateral (length) direction

Figure B.2 — Pattern 1 ultrasonic response



Key

1 Amplitude

2 A-scan

3 Range

4 Variation in peak signal amplitude

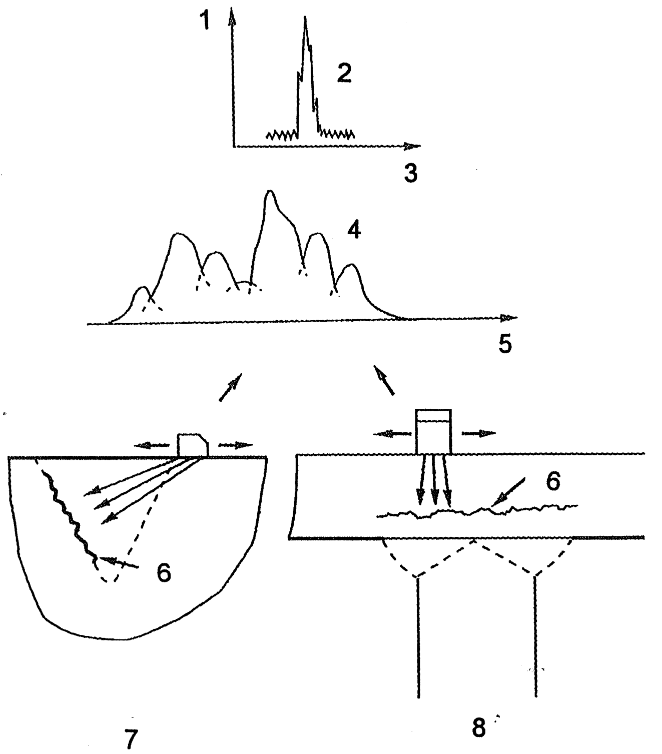
5 Probe position

6 Reflector

7 Typical occurrence in through-thickness direction

8 Typical occurrence in lateral (length) direction

Figure B.3 — Pattern 2 ultrasonic response



Key

1 Amplitude

2 A-scan

3 Range

4 Variation in peak signal amplitude

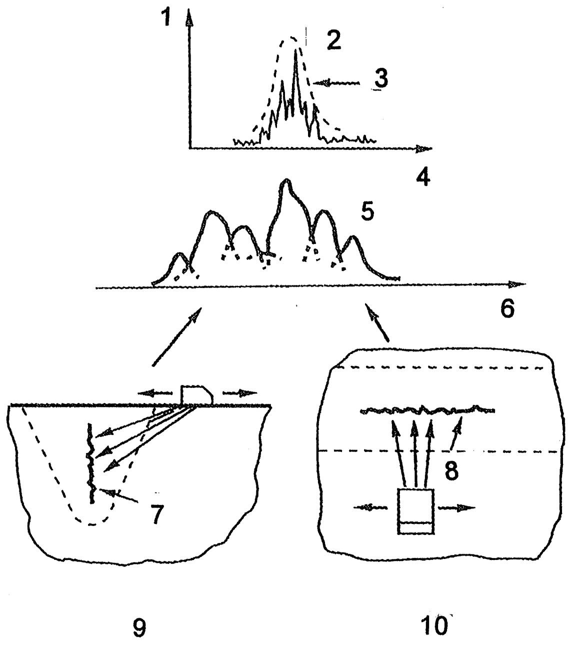
5 Probe position

6 Reflector

7 Typical occurrence in through-thickness direction

8 Typical occurrence in lateral (length) direction

a) Pattern 3b ultrasonic response
Normal incidence to discontinuity

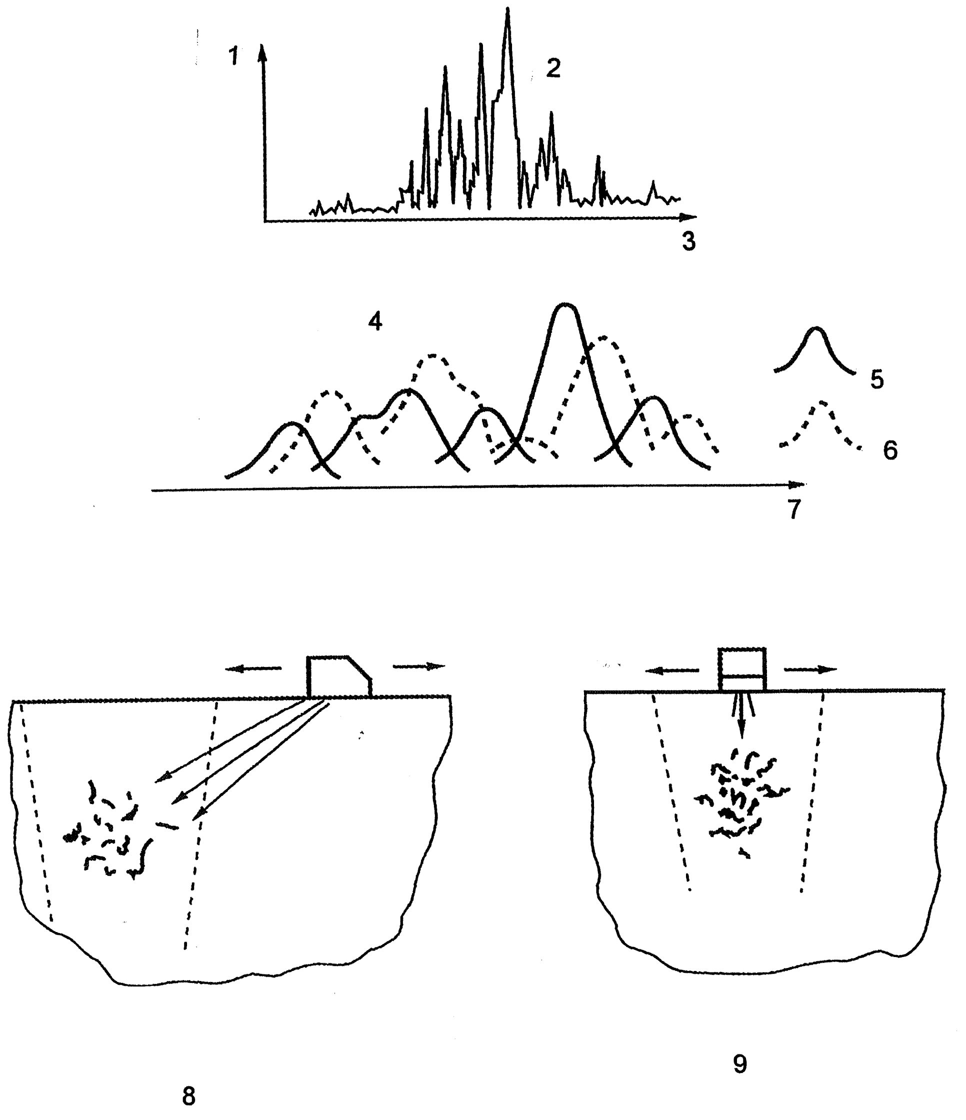


Key

1 Amplitude
2 A-scan
3 Pulse envelope
4 Range
5 Variation in peak signal amplitude
6 Probe position
7 Reflector
8 Reflector with through-thickness extent
9 Typical occurrence in through-thickness direction
10 Typical occurrence in lateral (length) direction

b) Pattern 3b ultrasonic response
Oblique incidence to discontinuity

Figure B.4 — Patterns 3a and 3b ultrasonic response



Key

1 Amplitude

2 A-scan

3 Range

4 Variation in peak signal amplitude

5 Short range echoes

6 Long range echoes

7 Probe position

8 Typical occurrence in through-thickness direction

9 Typical occurrence in lateral (length) direction

Figure B.5 — Pattern 4 ultrasonic response

Annex C
(informative)

Maximum echo height sizing technique

C.1 Distance-gain-size (DGS) technique

C.1.1 Principle

In this technique the maximum echo height from a discontinuity is expressed in terms of the equivalent diameter of a disk reflector perpendicular to the beam axis and at the same sound path range as the discontinuity being measured. DGS curves showing the relationship between echo height, range and reflector diameter are generally determined theoretically for a particular probe type, transducer diameter, and ultrasonic frequency.

When applying a DGS diagram, an allowance has to be made for the effects on echo height of differences in attenuation and transfer loss between the test object under examination and the calibration block. Details of how the technique is applied are contained in ISO 16811.

C.1.2 Applications and limitations

1) The smaller and smoother the discontinuity, and the more nearly perpendicular it is to the beam axis, the more accurate the measured equivalent size will be;

2) when testing at long ranges, the technique has the advantage over the DAC technique that large calibration blocks are not required;

3) its range of application extends from the end of the near field as far in the material as the discontinuity signals can be distinguished from the noise level. The following conditions shall be met:

    the signal from the discontinuity shall be maximized;

    the indications utilized for the sizing shall be distinguishable from the noise level;

    the indication from the discontinuity shall not be subject to interference effects from other echoes, e.g. reflections from the sides of the test object under examination;

4) the geometry of the test object under examination, or of a suitably representative sample of material, should provide a back wall echo which can be used to determine material attenuation and transfer loss;

5) since the echo height from a reflector is frequency dependent, only narrow band width probes should be used.

C.2 Distance-amplitude-correction (DAC) curve technique

C.2.1 Principle

The technique is based on expressing the maximum echo height from a discontinuity in terms of the number of dB it is above or below the echo from a reference target at the same range. The reference targets may be side-drilled holes, flat-bottomed holes, or other shapes, e.g. square or V-shaped notches, when specified.

A DAC curve, showing the relationship between echo height and range, is determined experimentally for the actual probe to be used for evaluation. It is plotted on a series of targets, either in a machined low attenuation calibration block, or in a representative sample of the material to be examined. If the former is used, allowance should be made when applying the technique for differences in attenuation and transfer loss between the test object under examination and the calibration block.

When used as a direct sizing technique, the maximum echo height from the discontinuity is expressed in terms of the same width, diameter, or other relevant dimension, as that of the reference target giving the same maximum echo height at the same range. Further details of the technique are contained in ISO 16811.

C.2.2 Applications and limitations

1) The range over which the technique may be applied depends upon the type of reference target. When using flat-bottomed holes or other small reflectors, the technique can only be used outside the near zone. However, when using elongated targets, e.g. side-drilled holes, the technique can also be used within the near zone;

2) the echo from the discontinuity to be sized shall be maximized;

3) the DAC curve shall be plotted for the probe to be used;

4) when using a calibration block, as distinct from a representative sample of material, the geometry of the test object under examination should provide a back-wall echo for the determination of attenuation and transfer loss.

Annex D
(normative)

Probe movement sizing techniques

D.1 Fixed amplitude level techniques

D.1.1 Principle

The technique measures the dimensions of a discontinuity over which the echo is equal to or greater than an agreed amplitude assessment level. The amplitude level may be related to a DGS curve or may be at some dB level in relation to a DAC curve.

To make a measurement the beam is scanned over the discontinuity and the probe position and beam path range, at which the echo has fallen to the assessment level, is noted. The position of the edge of the discontinuity is then determined by plotting the indicated range along the beam axis. In the example shown in Figure D.3 a level of 6 dB below a calibration DAC curve has been used.

Alternatively, the position of the edge of the discontinuity may be plotted along the 12 dB or 20 dB beam edge, as illustrated in Figure D.2.

Whichever procedure is used it shall be repeated to position the opposite edge of the flaw.

D.1.2 Application and limitations

1) The measured size depends on the amplitude assessment level;

2) the technique is simple to apply and gives highly reproducible values;

3) the technique may be applied to large or small discontinuities but, in the latter case, the measured length is more closely related to the beam width than to the actual discontinuity size;

4) the assessment level must be set equal to or below the amplitude level at which a discontinuity of infinite length is acceptable.

D.2 6 dB drop from maximum technique

D.2.1 Principle

The amplitude assessment level in this technique is 6 dB below the maximum echo height observed at any position along the flaw, rather than at a constant, predetermined level as used in the previous technique (D.1).

To make a measurement the maximum echo height is first measured and then the beam is scanned over the discontinuity until the echo has fallen by 6 dB below this maximum. The position of the probe and the sound path range are noted, and the edge of the discontinuity is plotted along the beam axis. The procedure is repeated at the opposite edge of the discontinuity. The technique is illustrated in Figure D.3.

D.2.2 Application and limitations

1) Where the discontinuity is perpendicular to the beam axis, where its surface is smooth, and where its cross- section is equal to or greater than the beam, such that it gives a relatively constant echo height along the direction to be measured, the technique can be used to measure its size with a relatively high degree of accuracy.

If, however, the discontinuity is irregular or of varying cross-section, significant sizing errors may occur;

2) the technique is only applicable where the dimension of the discontinuity to be measured is at least equal to the 6 dB beam width at the relevant sound path range.

D.3 12 dB or 20 dB drop from maximum technique

D.3.1 Principle

The amplitude assessment level is set at either 12 dB or 20 dB below the maximum echo height observed at any position along the discontinuity. It also differs from the 6 dB drop from maximum technique in that the edge of the discontinuity is positioned along the beam edge instead of the beam axis. To apply the technique the maximum echo height from any position along the discontinuity is noted and the beam scanned over it until the echo height falls by either 12 dB or 20 dB. The position of the probe and beam path range are then noted and the edge of the discontinuity is positioned along the 12 dB or 20 dB edge of the beam, as appropriate (see Figure D.4). The procedure is repeated to position the opposite edge.

D.3.2 Application and limitations

1) If the discontinuity is perpendicular to the beam axis and shows a uniform echo height along the direction to be measured, the technique can be used to determine its absolute dimensions. However, it is important that the edges of the beam have been previously plotted using a smooth reference target larger than the beam width. If these conditions do not apply the technique will give inaccurate results and is not recommended;

2) the technique is potentially more accurate than the 6 dB drop technique but the need to plot accurately the beam edges before taking any measurements can introduce another source of possible sizing error;

3) the technique is only applicable where the dimension of the discontinuity to be measured is at least equal to the –12 dB or -20 dB beam width at the discontinuity distance.

D.4 Drop to noise level technique

D.4.1 Principle

This technique measures the dimensions of a discontinuity over which the echo can be observed above the background noise level.

To apply the technique, the ultrasonic beam is scanned over the discontinuity and the probe position and beam path range noted at which the indication is only just discernable above the noise level. The edge of the discontinuity is then plotted along the beam axis, as illustrated in Figure D.5.

The procedure is repeated to determine the position of the opposite edge of the discontinuity.

D.4.2 Application and limitations

1) The technique is not very reproducible, as the measured size will decrease with an increasing noise level, and vice versa. However, it is useful for determining the overall size of a discontinuity, or group of discontinuities, especially when the noise level is high in relation to the echoes from the discontinuity;

2) the technique gives a conservative size measurement, especially where other techniques may carry the risk of undersizing a particular discontinuity;

3) the technique is relatively simple to apply and does not require a particular amplitude level to be set.

D.5 6 dB drop tip location technique

D.5.1 Principle

This technique differs from the 6 dB drop technique in that the echo height local to each end of the discontinuity is taken as the reference value on which the 6 dB drop is based.

To apply the technique the beam is scanned over the discontinuity and note is made of the echo height just prior to its rapid fall as the beam passes over the edge of the discontinuity.

The position of the probe and the beam path range are then recorded at the point where the echo height has fallen by 6 dB below the noted value. The position of the line of the discontinuity is then plotted along the beam axis. The procedure is repeated at the opposite edge, working from the maximum echo height immediately adjacent to this edge. The technique is illustrated in Figure D.6.

D.5.2 Application and limitations

1) The technique is only applicable to relatively smooth surfaced discontinuities, perpendicular to the beam axis, which do not show rapid changes in echo height along the direction to be measured. Under these conditions it can measure discontinuity size to relatively high degree of accuracy;

2) the technique is better able to accommodate variations in echo height along the direction to be measured than the 6 dB drop from maximum. However, it is more subjective in its application as it is not always easy for the operator to decide the echo height level on which the 6 dB drop should be based;

3) the technique is only applicable where the dimensions to be measured are at least equal to the 6 dB beam width at the range of the discontinuity.

D.6 Beam axis tip location technique

D.6.1 Principle

The technique is based on the principle than when an individual peak, within the overall echo from a discontinuity, is at maximum amplitude, the facet of the discontinuity giving rise to that peak will lie on the beam axis. The procedure is repeated to position the opposite edge.

The technique is illustrated in Figure D.7.

D.6.2 Application and limitations

1) The technique is capable of determining the actual discontinuity dimensions to a relatively high degree of accuracy;

2) it is only applicable to discontinuities having dimensions above the range resolution of the probe, and showing two or more amplitude peaks either on the A-scan presentation or along the echo envelope (i.e. echo-dynamic patterns 3 or 4. See B.3);

3) the application of the technique requires experience and judgement in choosing the most suitable angle of incidence and in identifying the correct peaks from the edges of the discontinuity. The accuracy of the technique may be reduced if access for scanning from the optimum directions is restricted.

D.7 20 dB drop tip location technique

D.7.1 Principle

The technique is basically similar to the beam axis tip location technique except that the 20 dB beam edge is used to position the edge of the discontinuity.

To apply the technique the individual peak, within the overall echo, from the tip of the discontinuity or the last reflecting facet adjacent to its edge, is first identified. This peak is then maximized and probe movement continued away from the edge until its echo height has fallen by 20 dB below its maximum value. The position of the edge is then plotted out along the 20 dB edge of the beam that has been previously determined.

The technique is illustrated in Figure D.8.

D.7.2 Application and limitations

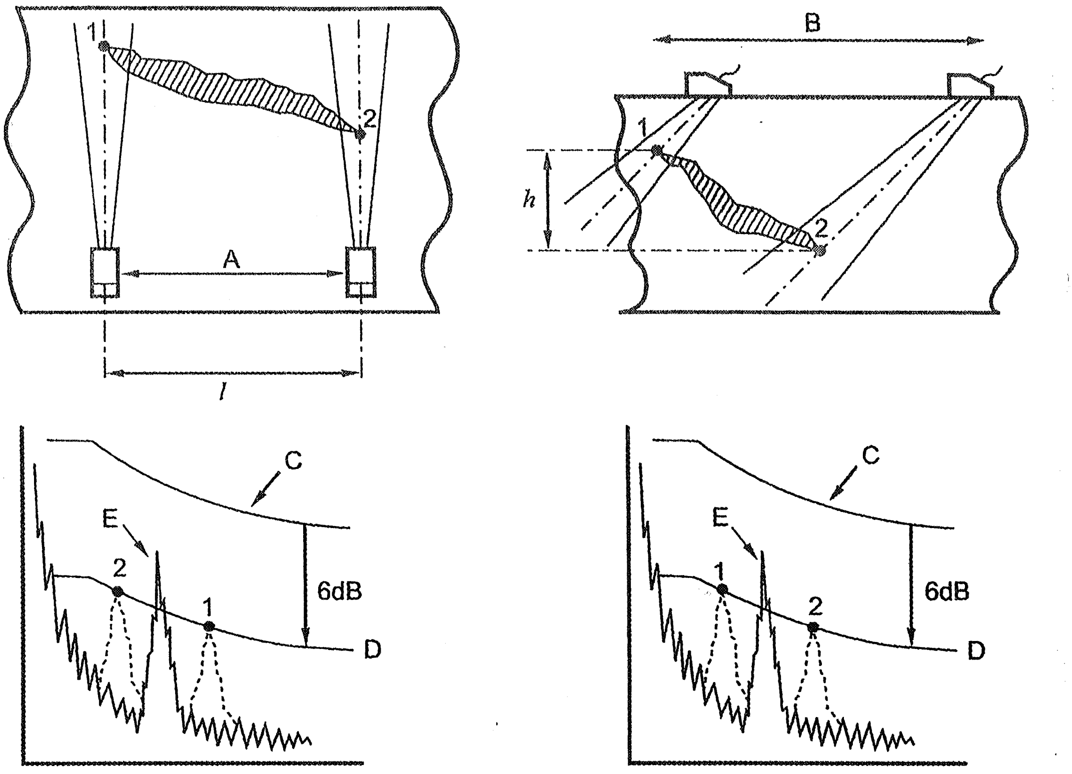
1) The technique is capable of determining the actual discontinuity dimensions to a relatively high degree of accuracy;

2) it is applicable to all discontinuities above the range resolution of the probe, and showing two or more amplitude peaks, either on the A-scope presentation, or along the echo envelope (i.e. echodynamic patterns 3 or 4. See B.3);

3) the 20 dB beam edge shall be plotted using a series of small circular reflectors, such as 1,5 mm or 3 mm diameter side-drilled holes;

4) this is potentially the most accurate technique for sizing multi-faceted discontinuities, but the need to accurately plot the beam edge before taking any measurement is an additional possible source of error compared to the beam axis tip location technique;

5) the application of the technique requires experience and judgement in choosing the most suitable angle of incidence and in identifying the individual peaks from the edges of the discontinuity.



Key

A Lateral movement

B Transverse movement

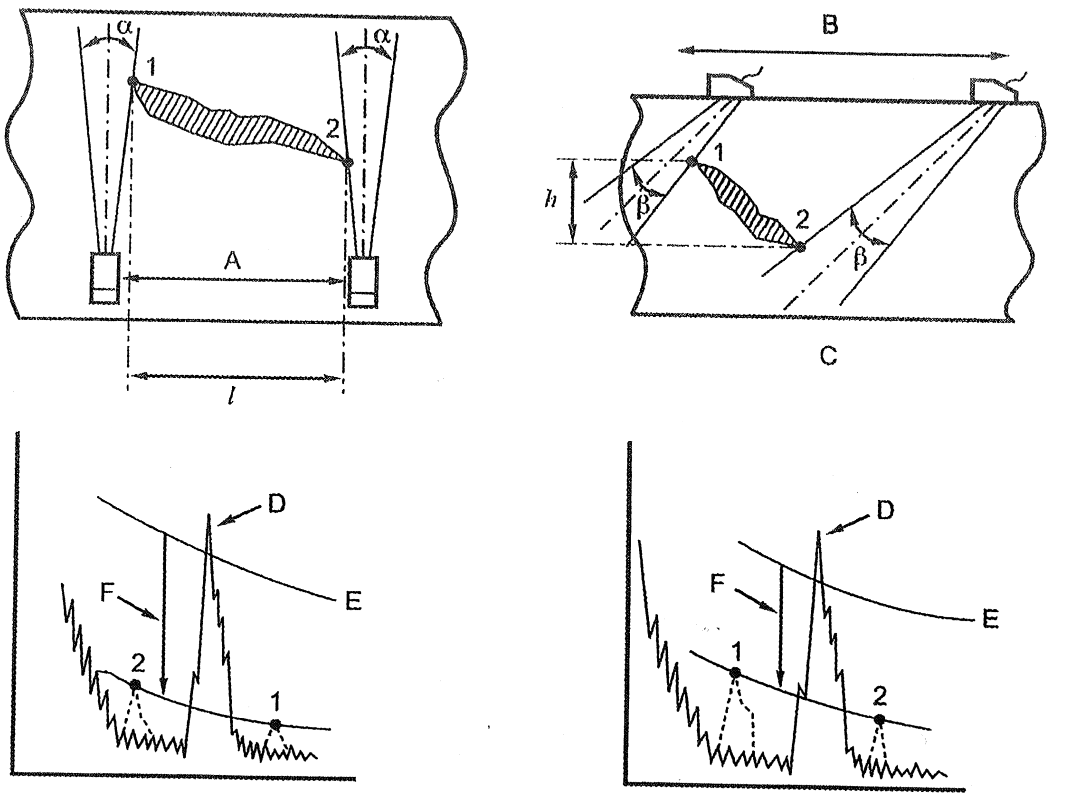
C Calibration curve

D Assessment level

E Max echo

1, 2 Positions and respective echo amplitudes of dB drop

Figure D.1 — Fixed amplitude level technique using the beam axis



Key

A Lateral movement

B Transverse movement

C α, β = 12 dB beam width (for 12 dB drop)
or 20 dB beam width (for 20 dB drop)

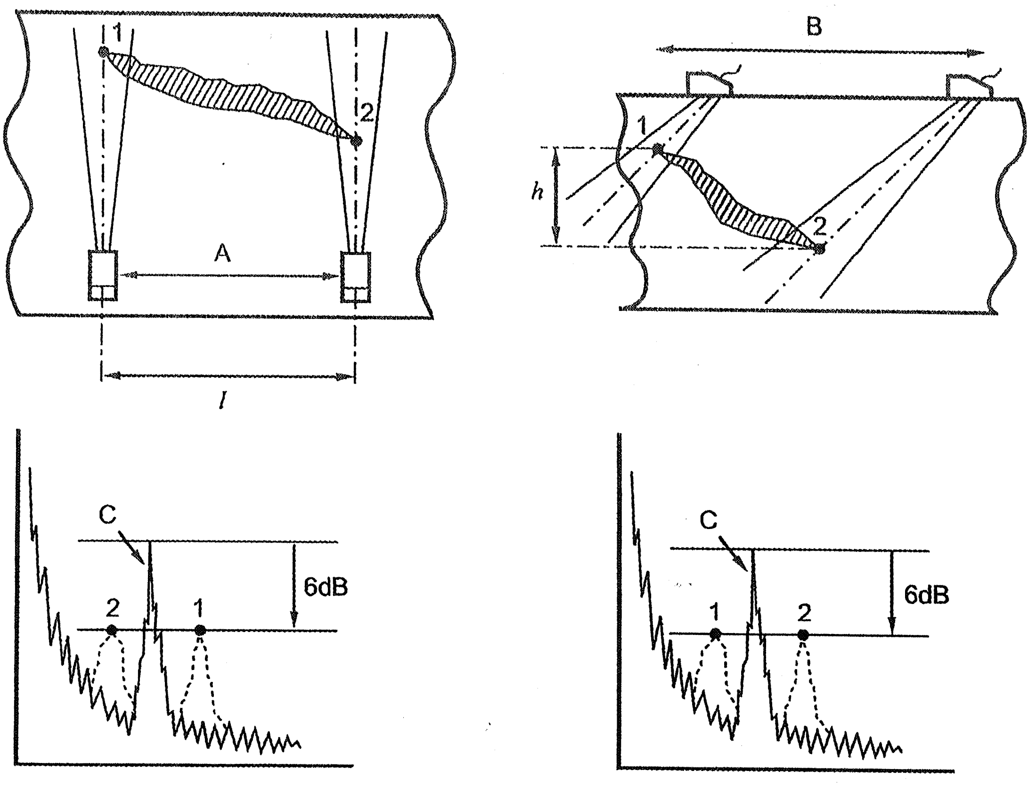
D Max echo

E Calibration curve

F 12 (or 20) dB

1, 2 Positions and respective echo amplitudes of dB drop

Figure D.2 — Fixed amplitude level technique using the beam edges



Key

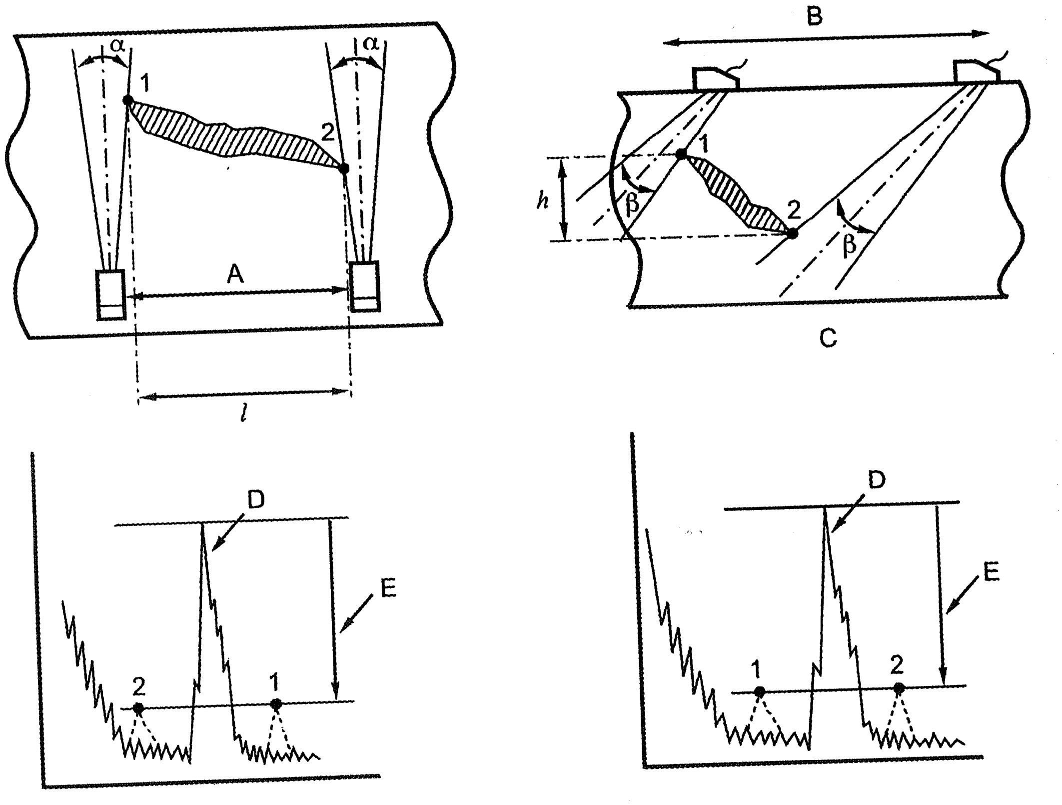
A Lateral movement

B Transverse movement

C Max echo

1,2 Positions and respective echo amplitudes of dB drop

Figure D.3 — 6 dB drop from maximum technique



Key

A Lateral movement

B Transverse movement

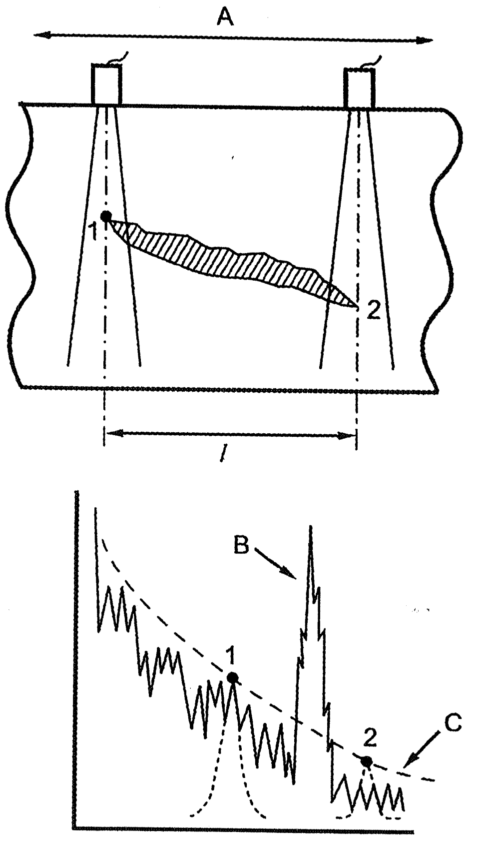
C α, β = 12 dB beam width (for 12 dB drop)
or 20 dB beam width (for 20 dB drop)

D Max echo

E 12 (or 20) dB

1, 2 Positions and respective echo amplitudes of dB drop

Figure D.4 — 12 dB or 20 dB drop from maximum technique



Key

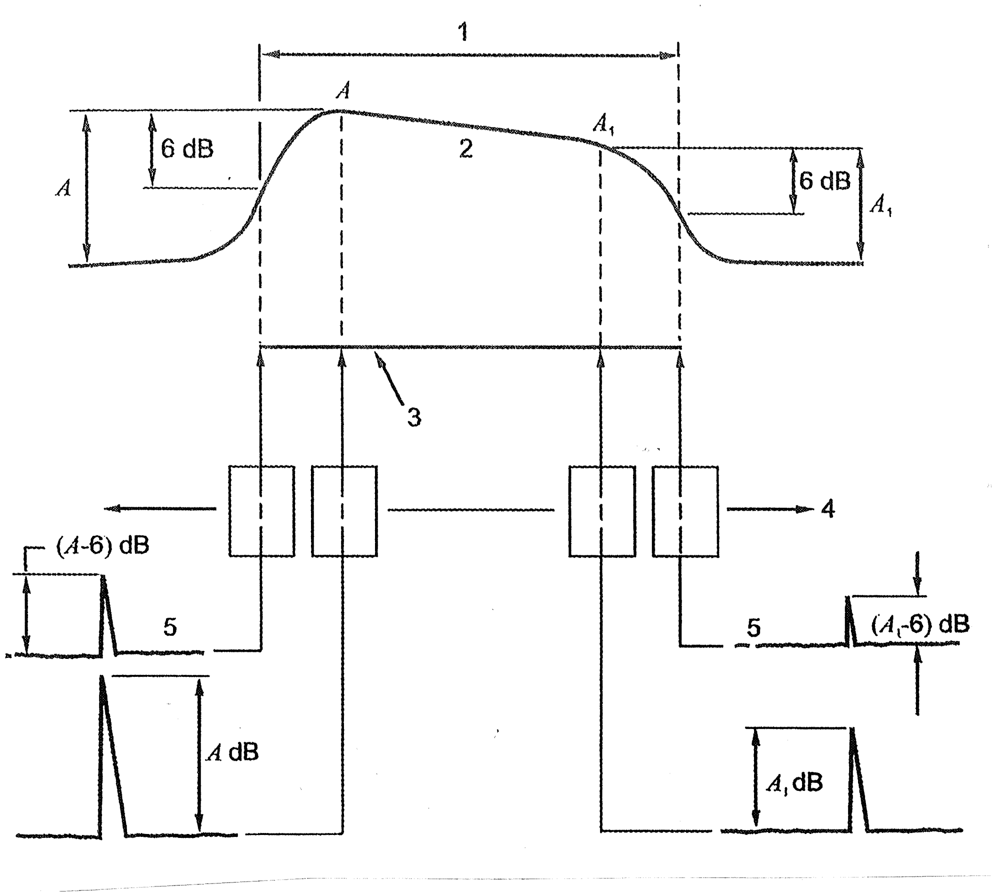
A Probe movement

B Max echo

C Noise level

1, 2 Positions and respective echo amplitudes of dB drop

Figure D.5 — Drop technique to noise level (illustrated for a straight beam probe)



Key

1 Measured reflector length

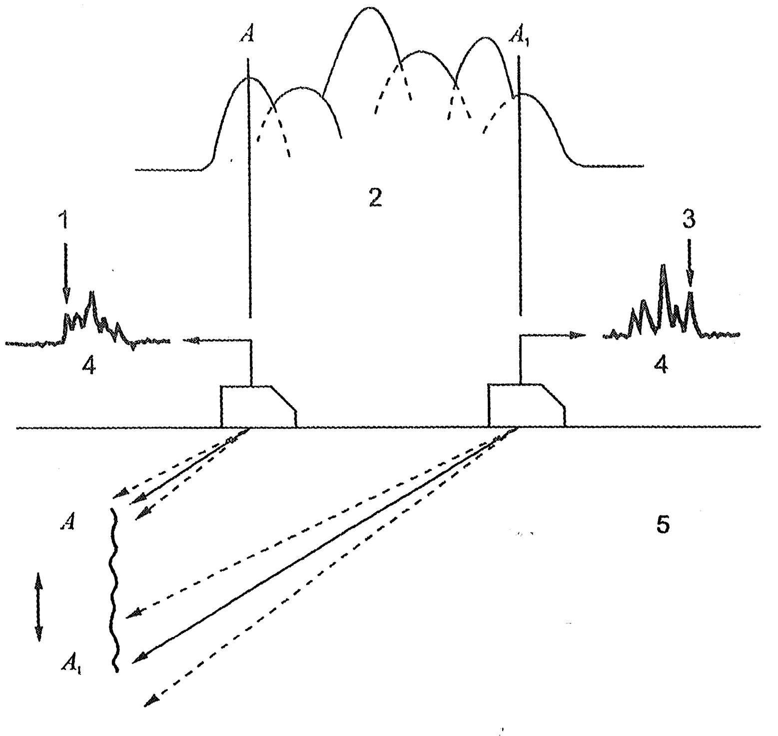
2 Variation in peak signal amplitude

3 Reflector

4 Direction of probe movement

5 A-scan

Figure D.6 — 6 dB drop tip location technique



Key

1 Echo A at maximum height

2 Variation on peak signal amplitude

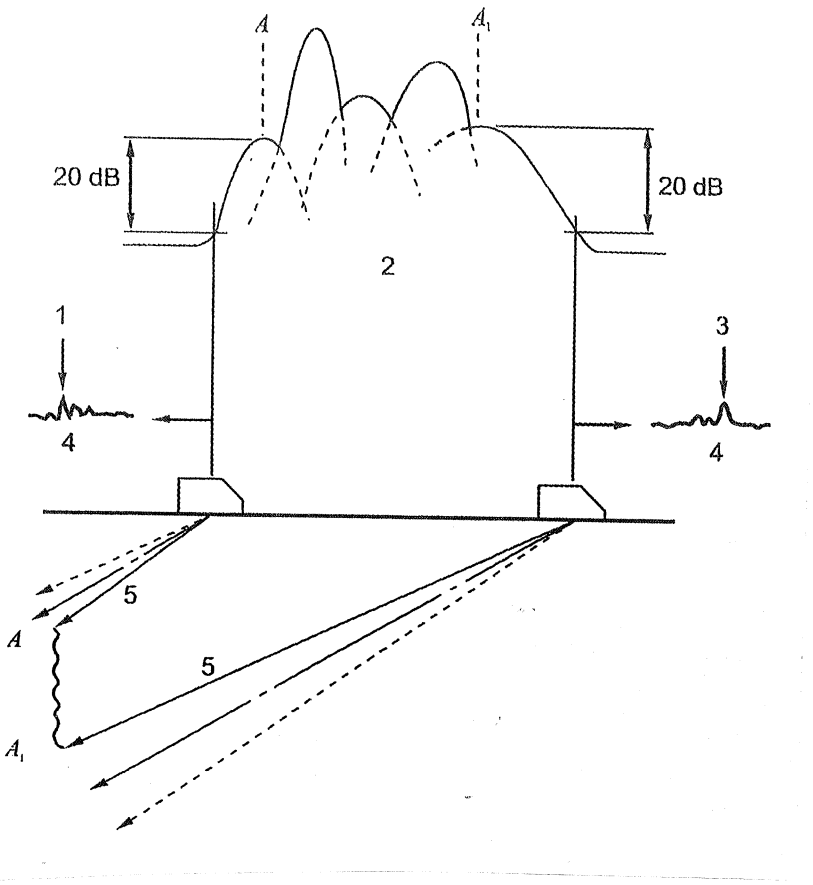
3 Echo A_1 at maximum height

4 A-scan

5 Echo A will be the first to appear when moving probe backwards.
Echo A_1 will be the first to appear when moving probe forwards.

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

Figure D.7 — Beam axis tip location technique



Key

1 Echo A at 20 dB below maximum height

2 Variation on peak signal amplitude

3 Echo A_1 at 20 dB below maximum height

4 A-scan

5 20 dB edge

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

Figure D.8 — 20 dB drop tip location technique

Annex E
(normative)

Iterative sizing technique

E.1 Scope

This annex describes a technique using a focusing probe for ultrasonically assessing the dimensions of a reflector to a relatively high degree of accuracy. It is applicable to tests made at normal incidence using a vertical beam probe, or at oblique incidence using an angle probe.

E.2 Normal incidence testing

E.2.1 Principle

The size and shape of the reflector are assessed from a series of C-scan type images plotted at threshold levels of –6 dB, –12 dB, –18 dB etc., in relation to the maximum echo height from the reflector.

The threshold levels may be set in various ways, for example by marking the different levels on the instrument screen or, as described below, by successive 6 dB increases in the gain of the instrument.

The scanning pitch and scanning speed shall be set in relation to the effective size of the ultrasonic beam, and the required accuracy of plotting.

E.2.2 Adjustment of gain

The instrument gain is initially set such that the maximum amplitude of the echo from the reflector to be measured reaches a reference level N, lying between 20 % and 80 % of full-screen height.

E.2.3 Procedure

One possible method of plotting the reflector is described below:

The gain is increased by 6 dB above the reference level N, up to a new value of N_1, and the full area of the reflector is scanned in the x- and y-directions. The results of the scans are plotted, either manually or automatically, by noting the positions of the transducer axis on a plane of rectangular co-ordinates when the echo height reaches reference level N_1. The plotting procedure is repeated after the gain has been increased by a further 6 dB up to value N_2. The plots at N_1 and N_2 are then assessed in relation to each other and the 6 dB beam profile of the probe. The following situations may then be observed:

Situation 1

At gain level N_1 the plot reproduces the 6 dB beam profile of the probe [see Figure E.1.a)]. In this case, either:

a) the reflector is smaller than, or equal to, the 6 dB beam profile of the probe; or

b) the reflective zone of the reflector at the given gain setting N_1, is smaller than the 6 dB beam profile.

The plot at gain setting N_2 allows these two possibilities to be resolved since, if the increase in size around the periphery of the plot between gain settings N_1 and N_2 is not greater than the 6 dB half-width of the beam, the hypothesis (a) above applies.

If the increase in size around the periphery, at gain setting N_2, in greater than the 6 dB half-beam width, it indicates that additional less reflective zones have been revealed, which have contributed to new images plotted. In this case, the reflector has to be considered under situation 2 (b) below.

Situation 2

At gain level N_1 the plotted size of the reflector exceeds the 6 dB beam profile of the probe. In this case either a) or b) below apply.

a) the increase in size around the periphery of the plot between gain settings N_1 and N_2 is not greater than the 6 dB half-beam width of the probe. In this case the size of the reflector in the plan concerned is assumed to be given by the plot at the N_1 level [see Figure E.1.b)];

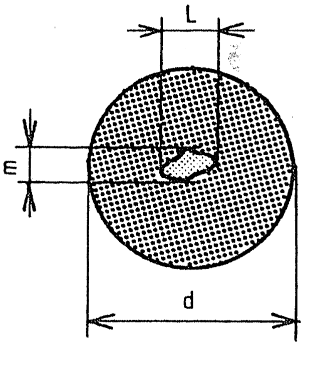
b) additional reflective zones appear when the plotting is carried out at gain level N_2. If this occurs further plots should be made after increasing the gain in 6 dB steps. The size of the reflector is then assumed to be given by the plotted image at the gain setting 6 dB lower than that at which the increase in size around the periphery of the image ceases to exceed the 6 dB half-beam width of the probe [see Figures E.1.b) and E.1.c)].

The whole operation may be represented by Figure E.3.

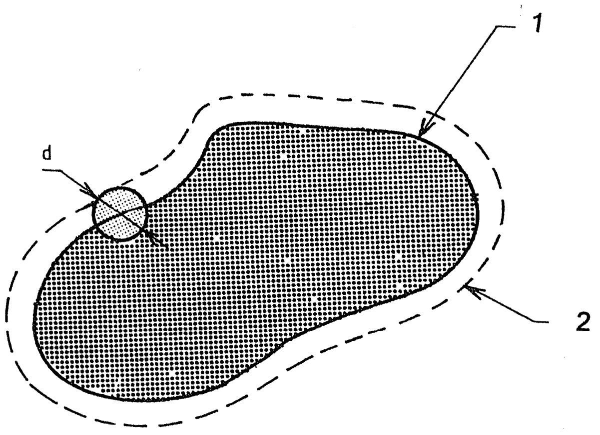
E.3 Oblique incidence testing

The basic procedure is similar to that described above. It differs from normal incidence testing in that whilst the transducer is scanned in only one plane (i.e. parallel to the surface of the test object under examination) the actual plotted image is that seen by the transducer (i.e. in a plane normal to the axis of the ultrasonic beam). Because of this the plotted image is distorted in one direction (that of the plane defined by the beam axis) and normal to the scanning surface.

The assessment of dimensions in oblique incidence testing thus follows the same rules as apply to normal incidence testing insofar as the plotting procedure is concerned. However, the relevant plotted dimension shall be multiplied by cos α, where α is the probe angle, in order to determine the size of the reflector perpendicular to the beam axis [see Figures E.2.a) and E.2.b)].



a) Flaw smaller than the cross-section d of the useful ultrasonic beam

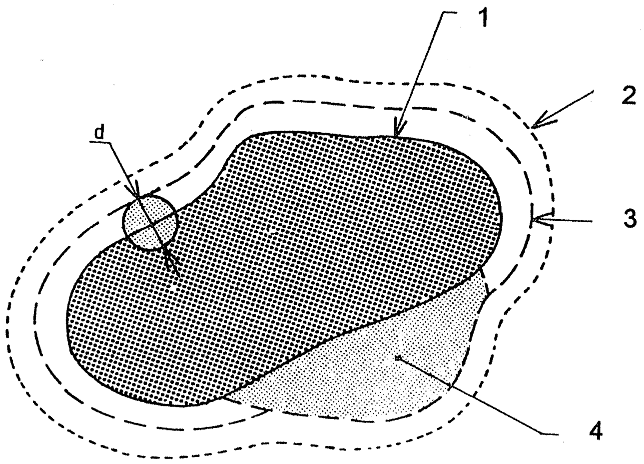


Key

1 Image at N_1 level

2 Image at N_2 level

b) Discontinuity greater than d



Key

1 Image at N_1 level

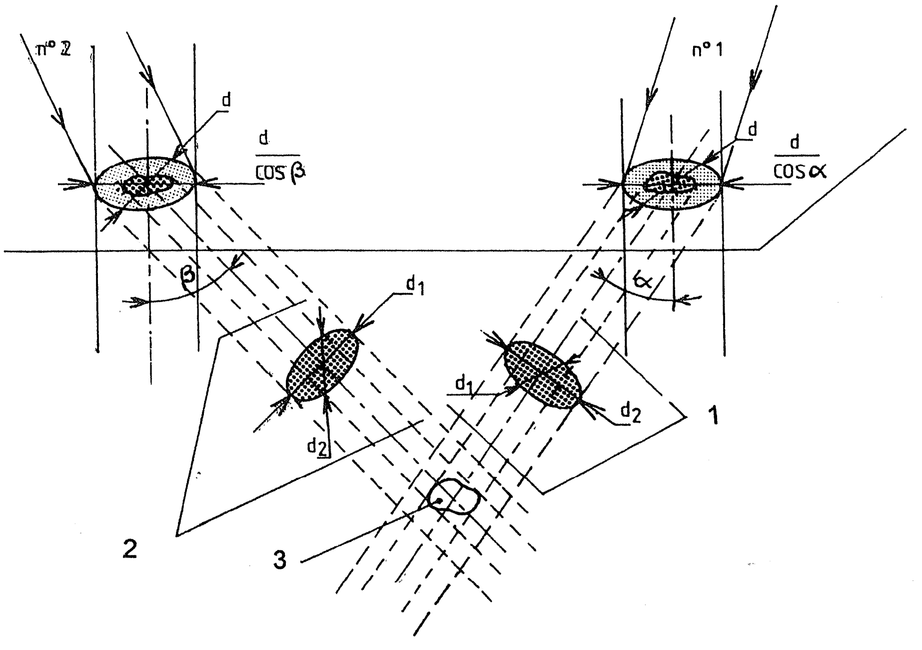
2 Image at N_2 level

3 Image at N_3 level

4 Fresh reflective zone

c) Appearance of a fresh reflective zone

Figure E.1 — Test by normal longitudinal waves



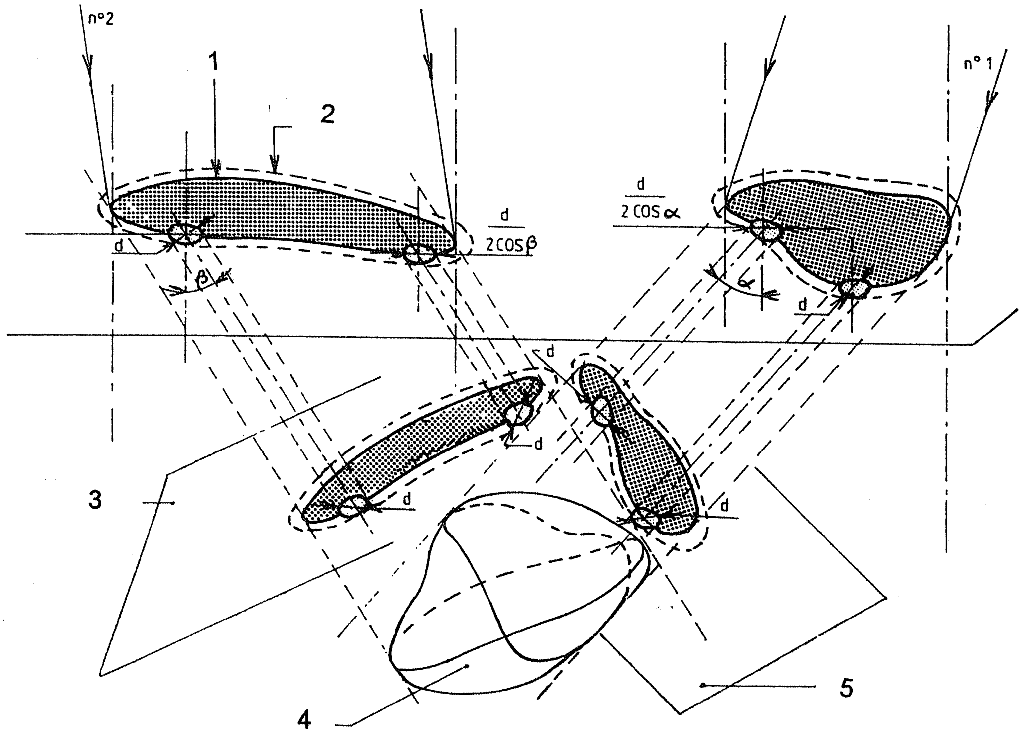
Key

1 Plane of cross section of 1st beam

2 Plane of cross section of 2nd beam

3 Discontinuity

a) Discontinuity smaller than d



Key

1 Level N_i

2 Level N_{i+1}

3 Plane of cross-section of 2nd beam

4 Discontinuity

5 Plane of cross-section of 1st beam

b) Discontinuity greater than d

Figure E.2 — Test by oblique shear waves or longitudinal waves

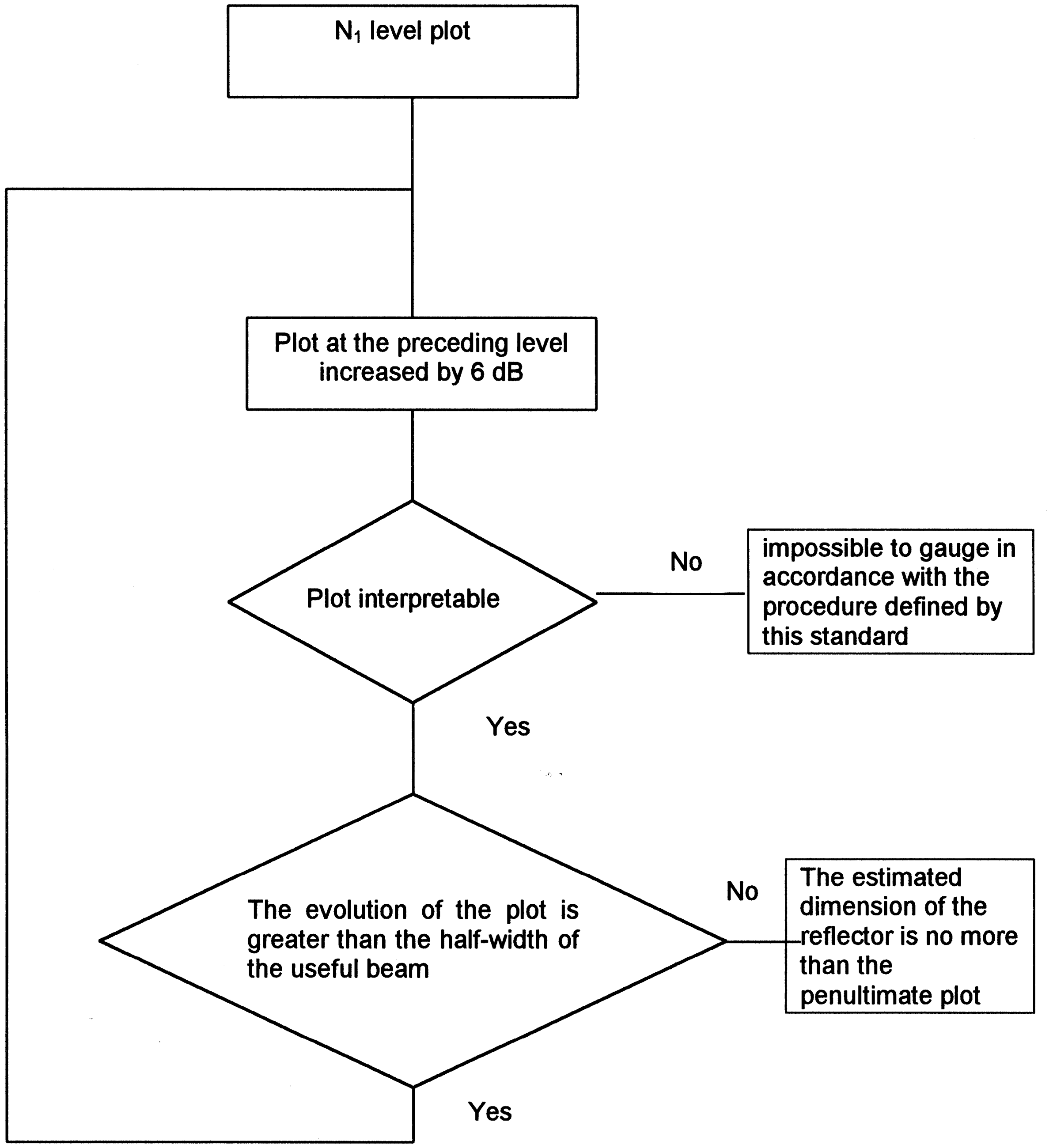


Figure E.3 — Flow chart of the evaluation operations

Annex F
(normative)

Mathematical algorithms for the estimation of the actual size of a discontinuity

F.1 Large planar discontinuities

The dimension of a discontinuity larger than the diameter of the sound beam and parallel to the scanning surface shall be determined by (see Figure F.1):

$$L = \Delta L \quad \text{(F.1)}$$

valid for

$s \geq N$; $L > D_F$

where

D is the transducer diameter in millimetres;

N = 0,25 D^2/λ near field length in millimetres;

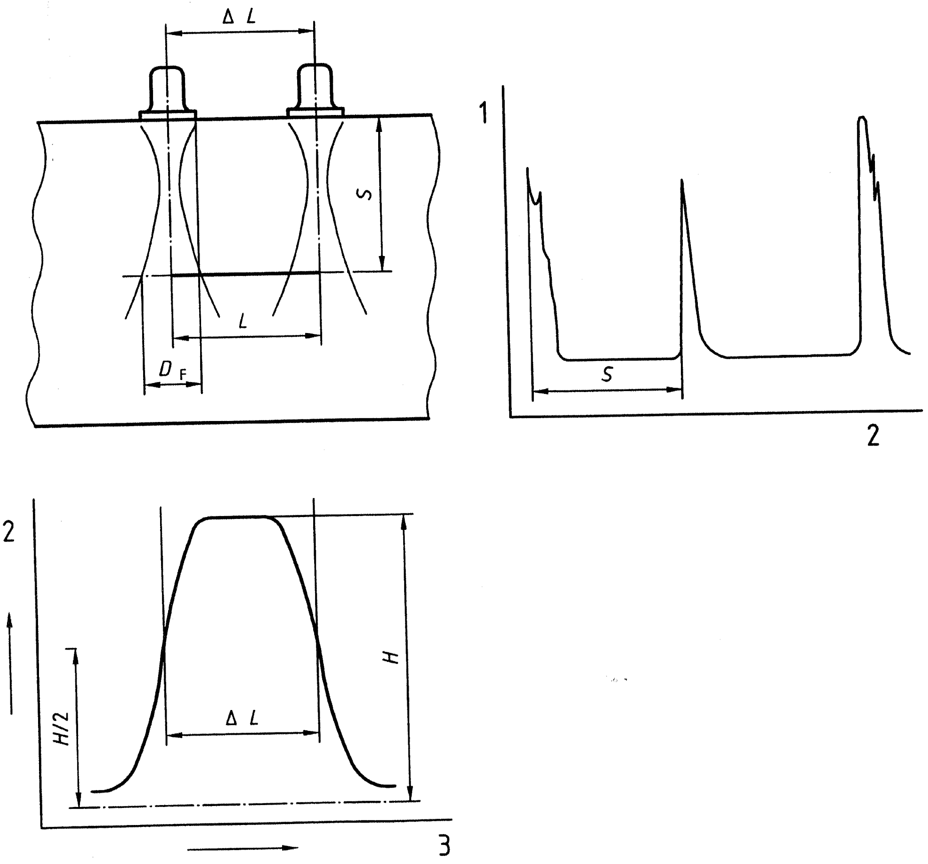
D_F = $\lambda\, s/D$ diameter of sound beam at distance s;

λ is the wavelength in millimetres;

s is the sound path in millimetres;

L is the actual discontinuity length;

ΔL = 6 dB drop – length.



Key

1 A-scan

2 Echo height

3 Probe position

Figure F.1 — Sizing of a large discontinuity parallel to the scanning surface

F.2 Small planar discontinuities

The dimension of a discontinuity smaller than the diameter of the sound beam and parallel to the scanning surface shall be determined by (see Figure F.2):

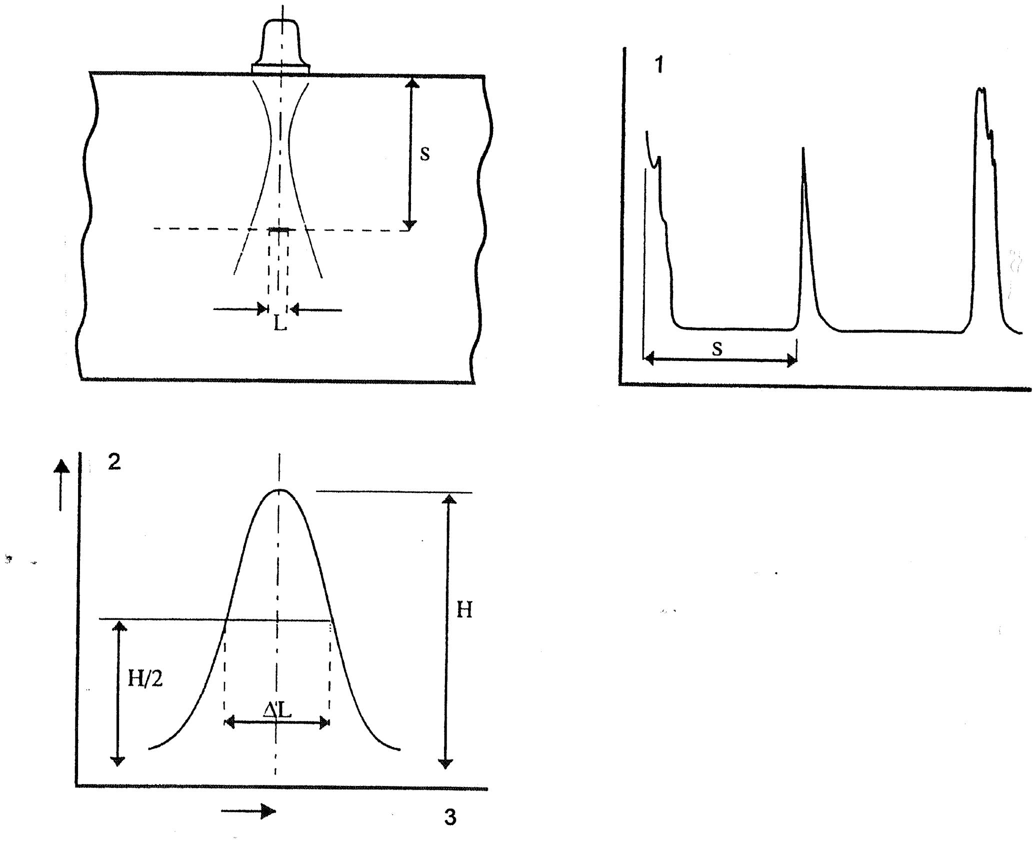
$$L = \sqrt{\left(\frac{1{,}03 \cdot s \cdot \lambda}{\Delta L \cdot D_{\text{eff}}}\right)^2 - 1 \; \frac{(D_{\text{eff}})^2}{2{,}13}} \qquad \text{(F.2)}$$

valid for:

$s \geq 4N$; $L \geq 2\lambda$

where

$$D_{\text{eff}} = 2\sqrt{\lambda_{\text{eff}} \cdot N_{\text{eff}}} \qquad \text{(F.3)}$$



Key

1 A-scan

2 Echo height

3 Probe position

Figure F.2 — Sizing of a small discontinuity parallel to the scanning surface

This measurement shall be performed with 2 probes with different near field lengths with a ratio of at least 2:1.

EXAMPLE 1 Probe 1 (f_1; D_1)

Probe 2.1 ($f_{2.1} = 2f_1$; $D_{2.1}=D_1$)

EXAMPLE 2 Probe 1 (f_1; D_1)

Probe 2.2 ($f_{2.2} = f_1$; $D_{2.2}= 1,5\ D_1$)

where

f is the frequency;

D is the probe diameter.

For the chosen pair of probes the following values have to be noted:

probe 1

ΔL_1 length measured using the 6 dB-drop technique;

L_1 calculated length from equation (F.2).

probe 2

ΔL_2 length measured using the 6 dB-drop technique;

L_2 calculated length from equation (F.2).

If 2 of these 4 values are equal, this value is considered as the actual discontinuity dimension.

If the actual dimension of discontinuity is smaller than 2 wavelengths, the reflector has to be considered as a pointlike, disk-shaped reflector, the diameter of which can be calculated from the echo height (for instance using the DGS technique).

F.3 Planar discontinuities in a cylindrical test object

In the case of planar discontinuities the actual dimensions (length and width) can be determined with the methods described in F.1 and F.2 (see Figure F.3).

If the actual length of a planar discontinuity is larger than the sound beam diameter, the discontinuity width (W), can be calculated from the equation:

$$W = \frac{I, II(d_{\text{DSR}})^2}{\sqrt{s \cdot \lambda}} \tag{F.4}$$

where

d_{DSR} is the diameter of the "disk-shaped reflector" corresponding to the echo height of the indication;

s is the sound path;

λ is the wavelength.

For short reflectors (in comparison to the diameter of the sound field) an approximate equation may be used:

$$W = \frac{(d_{\text{DSR}})^2}{L} \tag{F.5}$$

where

L is the axial length of the discontinuity determined with method F.1 or F.2.

NOTE Due to the roughness of real planar discontinuities the discontinuity-width calculated from the echo height may be smaller than the width determined on the basis of the echo-dynamic as described in F.2.

$$W = \frac{0{,}32\lambda}{\sin\left(\frac{\Delta W \cdot 180}{s \cdot \pi}\right)} \tag{F.6}$$

For the determination of the discontinuity dimension in axial direction one of the methods described in F.1 or F.2 can be used.

Equation (F.6) is valid if:

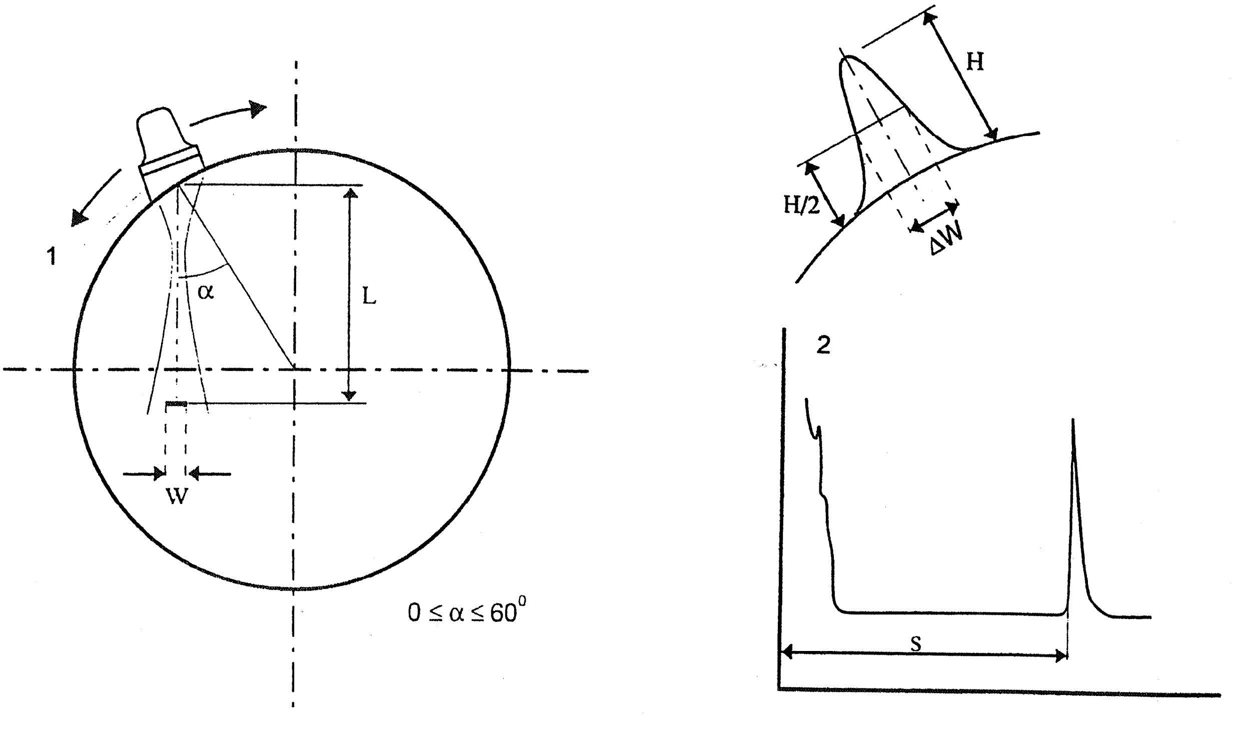
$s \geq 3N$

$W > \lambda$

where

W is the actual width of discontinuity;

ΔW = 6 dB drop width.



Key

1 Wedge

2 A-scan

Figure F.3 — Sizing of discontinuity from a cylindrical scanning surface

Annex G
(informative)

Examples of special sizing techniques

G.1 Tip diffraction techniques

a) Time of flight diffraction (TOFD) technique

The technique is illustrated in its simplest form in Figure G.1. For more details of this technique see ISO 16828. The probes used are generally angled compressive wave probes having a very wide beam spread. Since the distance (2s) between them is kept constant, two reference echoes, one due to direct transmission between the probes (lateral wave), and the other due to reflection from the back wall, will be obtained in addition to the diffracted echoes. In the simple case where the discontinuity lies mid-way between the probes, the depth of the upper tip can be calculated from:

$$T = \frac{2\sqrt{d^2 + s^2}}{v} \qquad \text{(G.1)}$$

where

T is the time taken for pulse to travel from transmitter to receiver via the crack tip;

$2s$ is the distance between probes;

d is the depth of tip below test surface;

v is the velocity of sound.

A similar calculation is used to determine the depth of the lower tip.

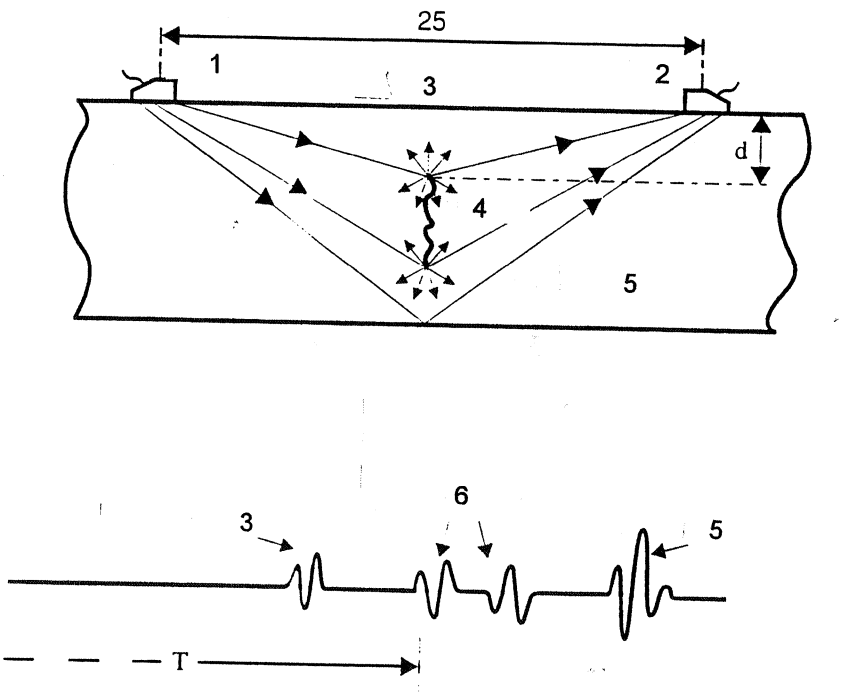
Since the time taken for the diffracted pulse to travel from one probe to the other can be measured accurately, much greater sizing accuracies are possible, particularly for larger discontinuities, than can be obtained using methods based on discontinuity echo amplitude. However, in order to interpret the TOFD data, it is desirable to display the observed signals as a B-scan.

b) Example of single probe tip diffraction technique

Figure G.2 shows the case of the sizing of cracks transverse to the beam axis, open to the surface opposite to the scanning surface.

In this case the calibration can be performed on blocks containing notches with rectangular cross sections of different height, placed transverse to the beam axis.

In an A-scan presentation, the dimension, h, of the crack is determined by comparing the mutual position of the 2 crack echoes with the mutual position of the analogous echoes produced by the notches in the calibration block.



Key

1 Transmitter

2 Receiver

3 Lateral wave

4 Crack

5 Back-wall echo

6 Diffracted waves

Figure G.1 — Probe arrangement and typical R.F. echo pattern for the TOFD technique

G.2 Synthetic aperture focusing technique (SAFT)

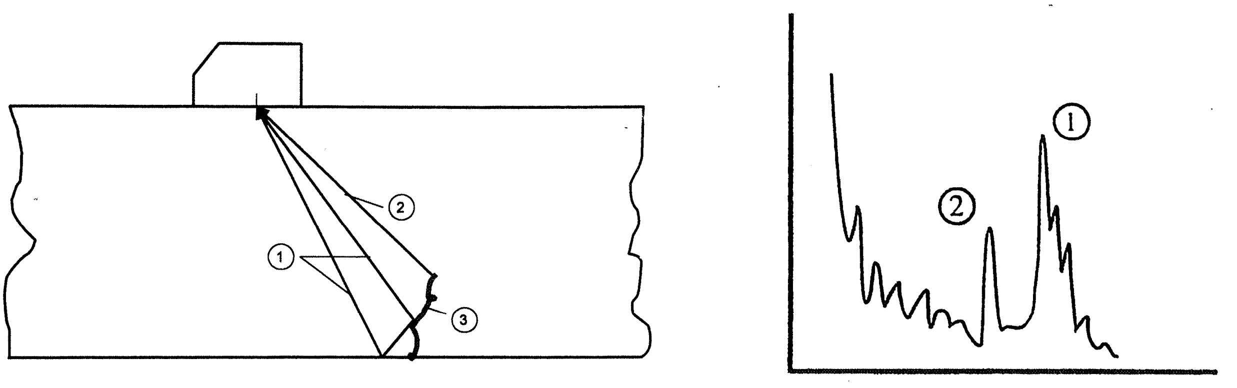
The SAFT is a method of simulating a large focusing probe by digitally processing all the range/amplitude information obtained from a scan over a discontinuity with an ordinary unfocused beam. It has the advantage over a conventionally focusing probe of having a variable focal length.

The basic principle of the technique is as follows:

As the ultrasonic beam is scanned over a discontinuity, a signal is first observed when the discontinuity intercepts the leading edge of the beam. On continuing the scan the signal increases in amplitude up to a maximum along the beam axis and then falls to zero at the trailing edge of the beam. In addition to these amplitude variations the sound path range also varies; in the case of a normal beam probe the sound path will be at a minimum when it lies along the beam axis. By electronically correcting for these variations in range across the width of the beam it is possible to mutually superimpose a large number of separate signals from the discontinuity. This process, which is carried out on the digitized signals using a suitable computer, greatly improves the signal/noise ratio, since the noise signals will be randomly superimposed, whilst the discontinuity signals will be preferentially superimposed.

Optimum superimposition of the signals will only occur if the corrections for sound path range are based on the true position of the discontinuity. Corrections based upon a false position will result in the sum of the superimposed signal being very much reduced. The technique is very sensitive to this effect and, therefore, by carrying out a number of summations, based on different assumed positions of the discontinuity, and by recording that at which the maximum superimposed signal amplitude is observed, a very accurate measurement of the position of the discontinuity is possible.

This technique is particularly valuable when used to locate the sources of the diffraction signals at the tips of a planar discontinuity, since these signals are often very small and may be lost in the general noise level when using conventional sizing techniques.



Key

1 Crack root echo

2 Crack tip diffraction

3 Crack

Figure G.2 — Tip diffraction technique
Examples of transverse crack open to the surface opposite to the scanning surface

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