BRITISH STANDARD

BS 5996:1993

Specification for

Acceptance levels for internal imperfections in steel plate, strip and wide flats, based on ultrasonic testing

UDC 669.14-41:620.179.16

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Iron and Steel Standards Policy Committee (ISM/-) to Technical Committee ISM/73, upon which the following bodies were represented:

Associated Offices Technical Committee
BEAMA Ltd.
British Forging Industry Association
British Gas plc
British Steel Industry
Electricity Supply Industry in England and Wales
Engineering Equipment and Materials Users' Association
Lloyd's Register of Shipping
Power Generation Contractors' Association (BEAMA Ltd.)
Process Plant Association
Seamless Steel Tube Association
Welding Institute
Coopted members

The following body was also represented in the drafting of the standard, through subcommittees and panels:

National Association of Steel Stockholders

This British Standard, having been prepared under the direction of the Iron and Steel Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 August 1993

First published as DD 21, 1972
First published as BS 5996, October 1980
Second edition August 1993

The following BSI references relate to the work on this standard:
Committee reference ISM 73
Draft for comment 91 47792 DC

ISBN 0 580 21676 4

Amendments issued since publication

Amd. No.	Date	Comments

Contents

Foreword

This British Standard has been prepared under the direction of the Iron and Steel Standards Policy Committee. It supersedes BS 5996:1980 which is withdrawn.

Improvements in steelmaking technology resulting in cleaner steels, and the improvements in ultrasonic test techniques since the publication of BS 5996:1980 have resulted in technical changes being introduced in this edition. These include broadening the scope to permit the testing of material up to 200 mm thickness, the testing of austenitic stainless steels and the use of automatic ultrasonic testing. To reflect the increase in cleanliness of steels additional stringent acceptance levels have been introduced, particularly for edge testing.

This standard differs from BS 5996:1980 in that for any acceptance level only one test procedure is specified, the terms “discontinuity”, “lamination” and “inclusion cluster” have been replaced by “internal imperfections”, and the criteria for rejection have been simplified.

Assessed capability. Users of this British Standard are advised to consider the desirability of quality system assessment and registration against the appropriate Part of BS 5750 by a third party certification body.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 8, 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.

1 Scope

This British Standard specifies acceptance levels for internal imperfections in ferritic and austenitic steel plate, strip and wide flat material based on ultrasonic testing. Six acceptance levels (B1 to B6) are specified for the body of the material, and three acceptance levels (E1 to E3) are specified for the material edges. Two further acceptance levels, one for the body of the material (B7) and the other for the material edges (E4), are specified for austenitic steel plate.

This British Standard covers the inspection of material with a thickness in the range of 5 mm to 200 mm, using manual, assisted manual, semi-automatic or automatic testing methods.

This British Standard may be used to specify the requirements for the ultrasonic testing of steel plate/strip used in the manufacture of welded tubes, for the detection of internal imperfections, to acceptance levels B1 to B4 and E1 to E3.

NOTE 1 Two further special acceptance levels, one for the body of the material and the other for the material edges (BX and EX respectively) may be specified by the purchaser when the material is intended for critical applications, and also for certain grades of austenitic steels. When these acceptance levels are specified, the test sensitivity and the reference standard to be adopted, together with acceptance criteria for imperfection size and population density, should be agreed between the purchaser and the manufacturer.

NOTE 2 The supply of material in accordance with this British Standard can be to any acceptance level for the material body or for the material edges or for any acceptance level combination for both material body and edges, e.g. B3, E2, B3E3, B3E2.

NOTE 3 For thicknesses less than 5 mm and greater than 200 mm (or less in the case of austenitic plate dependent on chemical composition), difficulties can be experienced in achieving an adequate ultrasonic test for the detection of internal imperfections. In such instances agreement between purchaser and manufacturer is required to determine any deviation from the requirements of this British Standard.

2 Normative references

This British Standard incorporates, by reference, provisions from specific editions of other publications. These normative references are cited at the appropriate points in the text and the publications are listed on the inside back cover. Subsequent amendments to, or revisions of, any of these publications apply to this British Standard only when incorporated in it by amendment or revision.

3 Definitions

For the purposes of this British Standard, the definitions given in BS 3683-4:1985 apply, together with the following.

3.1
internal imperfection

any imperfection lying within the thickness of the material, e.g planar or laminar imperfections, single-plane or multi-plane inclusion bands or clusters

3.2
defects

unacceptable internal imperfections, i.e. exceeding the specified maximum size or population density limits

3.3
population density

the number of individual internal imperfections of a size greater than a specified minimum size and less than a specified maximum size per specified area of body or length of edge zone

3.4
manual and assisted manual testing

testing by an operator applying an ultrasonic transducer, or transducers, to the material surface, manually executing the appropriate scanning pattern on the material surface and visually assessing ultrasonic signal indications on the electronic equipment screen either by direct viewing or by built-in signal amplitude alarm devices

3.5
automatic and semi-automatic testing

testing using a mechanized means of applying the ultrasonic transducer or transducers to, and executing the appropriate scanning pattern on, the material surface, together with ultrasonic signal indication evaluation by electronic means. Such testing can be either fully automatic with no operator involvement, or semi-automatic when the operator performs basic equipment operation functions

4 Acceptance levels

4.1 Criteria for material body acceptance levels B1 to B7 shall be as given in Table 1 (see also Figure 1). When tested in accordance with annex A, material shall be deemed to conform to a particular acceptance level if it meets the following requirements.

a) The material shall contain no internal imperfections larger than the maximum individual imperfection size B_{max} given in Table 1.

b) The population density of imperfections smaller than the maximum imperfection size but larger than the minimum imperfection size shall be not greater than that specified in Table 1.

NOTE For an imperfection to be larger than the minimum imperfection size, the minimum area, minimum length and minimum width given in Table 1 all have to be exceeded.

4.2 Criteria for material edge acceptance levels E1 to E4 shall be as given in Table 2 (see also Figure 1). When tested in accordance with annex A, material shall be deemed to conform to a particular acceptance level if it meets the following requirements.

a) The material shall contain no internal imperfections larger than the maximum individual imperfection area E_{max} given in Table 2.

b) The material shall contain no imperfections longer than the maximum imperfection length L_{max} given in Table 2.

c) The population density of imperfections shorter than the maximum imperfection length but longer than the minimum imperfection length shall be not greater than that specified in Table 2.

4.3 If the material does not conform to a particular acceptance level, one of the following actions shall be taken.

a) The suspect area shall be removed and the remaining area shall be deemed to be acceptable providing that the edge conforms to the appropriate acceptance level.

b) The material shall be rejected for that grade.

Table 1 — Acceptance criteria for material body examination

Acceptance level	Maximum individual imperfection area B_{max}	Minimum imperfection size considered (see notes 1 and 2)			Maximum population density of imperfections smaller than B_{max} and larger than the minimum imperfection size		Maximum scan line separation S
		Area	Length	Width	No. of imperfections per 1 m × 1 m square	No. of imperfections per 500 mm × 500 mm square	
	mm^2	mm^2	mm	mm			mm
B1	10 000	2 500	100	20	5	—	100
B2	5 000	1 250	75	15	5	—	75
B3	2 500	750	60	12	5	—	60
B4	1 000	300	35	8	10	—	35
B5	500	150	15	8	—	10	15
B6	100	30	5	5	—	5	15[a]
B7[b]	50	25	5	5	—[c]	—[c]	15[a]

NOTE 1 For an imperfection to be larger than the minimum imperfection size, the minimum area, minimum length and minimum width given in Table 1 all have to be exceeded. The length is the dimension at right-angles to the scan track and the width is the dimension parallel to the scan track (see Figure 1).

NOTE 2 For the purpose of determining the extent of suspect area, adjacent suspect areas separated by less than the smaller of two minor axes of the imperfections shall be considered as one imperfection.

NOTE 3 Acceptance level BX may also be used for material body examination. Acceptance criteria for this level should be agreed between the purchaser and the manufacturer.

[a] For acceptance levels B6 and B7, the maximum scan line separation given is based upon the use of a 25 mm diameter transducer. Where smaller transducers are used, the maximum scan line separation shall be 75 % of the transducer diameter.

[b] For austenitic plate only.

[c] Requirements for population density of imperfections for acceptance level B7 should be agreed between the purchaser and the manufacturer.

Table 2 — Acceptance criteria for material edge examination

Acceptance level	Maximum individual imperfection size		Minimum imperfection length considered L_{min}	Maximum population density (number of imperfections smaller than the maximum imperfection size and longer than L_{min} per 1 m length)
	Length L_{max} mm	Area E_{max} mm^2	mm	
E1	50	1 000	30	5
E2	30	500	20	4
E3	20	100	10	3
E4[d]	10	50	8	2

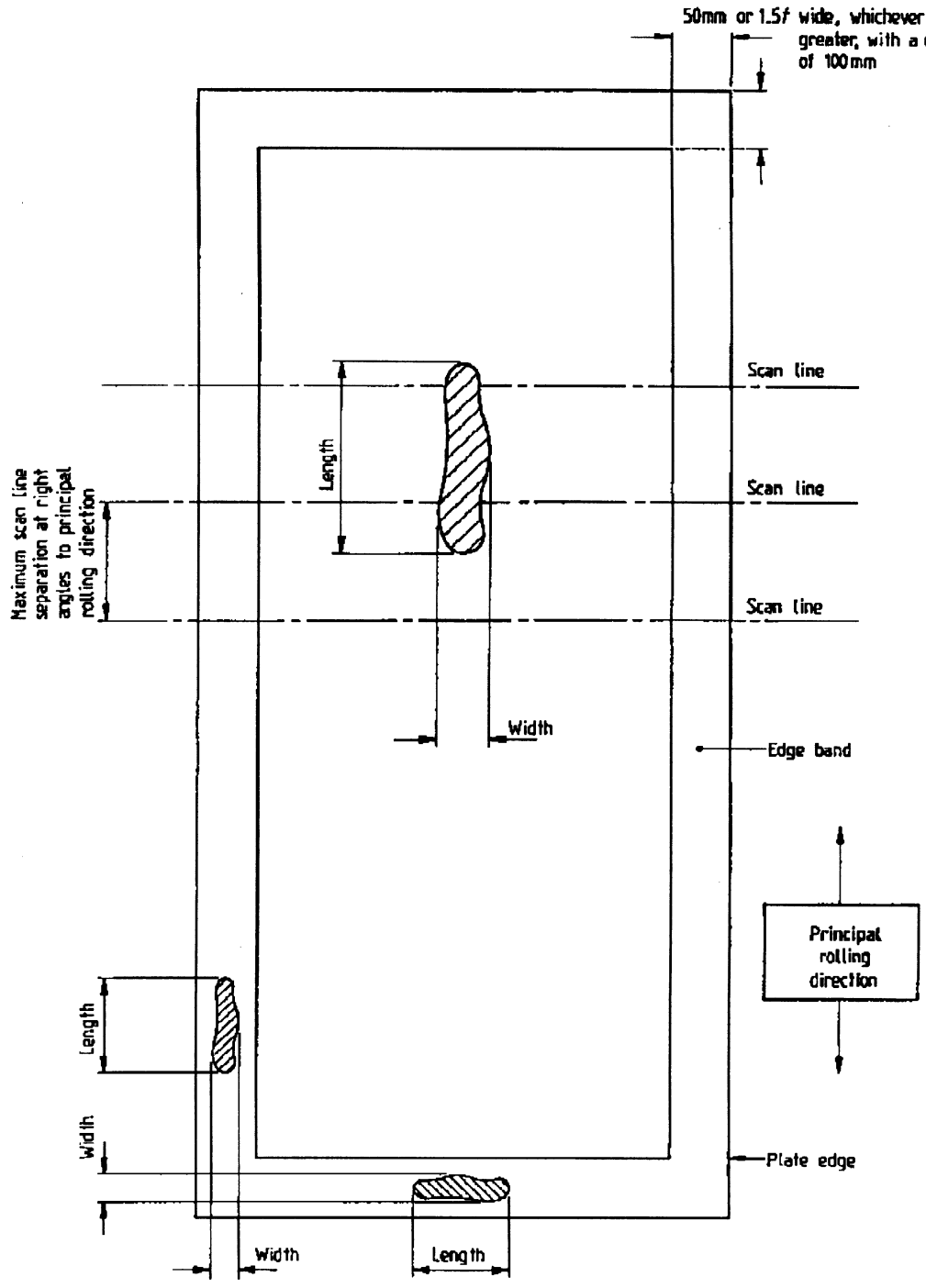
NOTE 1 E_{max} is the product of the longitudinal dimension L_{max} and the transverse dimension. An imperfection is considered to be larger than the maximum imperfection size if either E_{max} or L_{max} is exceeded.

NOTE 2 The length is the dimension parallel to the material edge.

NOTE 3 For the purpose of determining the extent of suspect area, adjacent suspect area separated by less than the smaller of the two minor axes of the imperfections shall be considered as one imperfection.

NOTE 4 Acceptance level EX may also be used for material edge examination. Acceptance criteria for this level should be agreed between the purchaser and the manufacturer.

[d] For austenitic plate only.



t is the thickness of the material.

Figure 1 — Schematic representation of terms

Annex A (normative)
Method for ultrasonic testing of steel plate, strip and wide flats

A.1 General

A.1.1 *Stage of testing*

Ultrasonic testing shall be performed on the as-supplied material in the as-rolled condition or after heat treatment operations.

A.1.2 *Personnel*

The testing shall be carried out by personnel nominated by the manufacturer and qualified in accordance with a recognized certification scheme.

NOTE The certification scheme should be agreed between the manufacturer and the purchaser.

A.1.3 *Surface condition*

The material shall be sufficiently flat to ensure the validity of the test. The surfaces shall be free from scale, dirt, grease, paint and other foreign matter that would interfere with the validity of the test.

A.2 Apparatus

A.2.1 *General*

A.2.1.1 The ultrasonic equipment used for manual and assisted manual testing shall be of the pulse-echo type and shall be subject to performance and calibration checks in accordance with BS 4331-1:1978 and Part 3: 1974.

A.2.1.2 The ultrasonic equipment used for automatic and semi-automatic testing shall be capable of differentiating between acceptable and suspect material by means of automatic trigger/alarm levels.

NOTE 1 This differentiation may be combined with evaluation of areas of internal imperfection in terms of maximum allowable size and population density, coupled with marking and/or sorting systems, where appropriate.

NOTE 2 Prior to ultrasonic testing, the performance of automatic and semi-automatic equipment should be demonstrated by the manufacturer to the satisfaction of the purchaser that it is capable of detecting the minimum imperfection sizes required.

A.2.1.3 A liquid couplant (e.g. water or oil), capable of conducting ultrasound between the ultrasonic transducer(s) and the surface of the material to be tested, shall be used. The couplant shall not be detrimental to the material or its surface finish.

A.2.2 *Transducers*

A.2.2.1 Ultrasonic compression wave transducers with a nominal angle of 0° shall be used.

The ultrasonic transducer(s) for automatic and semi-automatic testing shall be of the single or double type.

For manual and assisted manual testing, the type of ultrasonic transducer shall be as specified in Table A.1.

Table A.1 — Types of ultrasonic transducer for manual and assisted manual testing

Thickness of the material t mm	Type of transducer
$5 \leq t \leq 20$	Double
$20 < t \leq 100$	Single[a] or double
$100 < t \leq 200$	Single[a]

[a] When a single transducer is used, one of the following shall apply.

a) Where practical, the near surface dead zone shall not exceed 15 % of the specified material thickness or 15 mm, whichever is the smaller.

b) Where the near surface dead zone specified in a) is not practical, testing shall be executed between the first and second backwall echoes (see **A.4.3**), or the material shall be tested from both sides.

A.2.2.2 Unless the material exhibits high ultrasonic attentuation characteristics due to the material structure (e.g. some grades of austenitic steels or on thick sections), the minimum ultrasonic test frequency shall be 2 MHz.

NOTE If the material exhibits high ultrasonic attenuation characteristics, a lower test frequency may be used.

The manufacturer shall inform the purchaser if it is intended to use a lower test frequency for material exhibiting high ultrasonic attenuation characteristics.

For manual and assisted manual testing, the maximum ultrasonic test frequency shall be 5 MHz. For automatic or semi-automatic testing, the maximum ultrasonic test frequency shall be 10 MHz.

A.2.2.3 Unless the material exhibits high ultrasonic attenuation characteristics due to the material structure (e.g. some grades of austenitic steels or on thick sections), the maximum dimension of the ultrasonic transducer shall be 25 mm.

NOTE If the material exhibits high ultrasonic attenuation characteristics, a larger ultrasonic transducer may be used.

The manufacturer shall inform the purchaser if it is intended to use a larger ultrasonic transducer for material exhibiting high ultrasonic attenuation characteristics.

A.3 Procedure

A.3.1 *General*

Use one of the following test methods.

a) Test the material from one surface only, using an ultrasonic pulse echo technique for the detection of internal imperfections, with ultrasound transmitted normally in the direction nominally perpendicular to the test surface.

b) If the material exhibits high ultrasonic attenuation characteristics due to the material structure (e.g. some grades of austenitic steels or on thick sections), test the material from both sides using the ultrasonic pulse echo technique described in a). In this instance the manufacturer shall be able to demonstrate that more than 50 % of the material thickness is examined from each side.

c) If required in Table A.1, test the material from both sides using the ultrasonic pulse echo technique described in a).

d) Test the material using an automatic ultrasonic through-transmission technique that can be shown to give equivalent results to the ultrasonic pulse echo technique described in a).

A.3.2 *Testing of the material body*

A.3.2.1 During manual and assisted manual testing of the material body, move the material and the transducer assembly relative to each other, at a speed not exceeding 150 mm/s, so that the material surface is scanned, along parallel equispaced scan lines at right-angles to the principal rolling direction, to ensure the detection of the relevant minimum imperfection size with the limiting length and width dimensions (see Table 1).

The maximum scan line separation shall be as given in Table 1.

A.3.2.2 During automatic and semi-automatic testing of the material body, move the material and the transducer assembly relative to each other so that the material surface is scanned along equispaced scan lines to ensure the detection of the relevant minimum imperfection size, with the limiting length and width dimensions together (see Table 7).

The pulse repetition frequency of each transducer in relation to the relative movement along each scan line shall be sufficient to ensure detections of the relevant minimum imperfection length and width dimension (see Table 1).

A.3.3 *Testing of the material edges*

During testing of the material edges, move the material and the transducer assembly relative to each other so that the material surface is 100 % scanned over a band referenced from the final cut edge. In order to detect the relevant minimum imperfection length L_{min} (see Table 2), the band width shall be as given in Table A.2.

NOTE The longitudinal edges are those parallel to the principal rolling direction, and the transverse edges are those at right-angles to the principal rolling direction.

Table A.2 — Band width for material edge testing

Thickness of the material t mm	Band width mm
$5 \leq t \leq 33.3$	50
$33.3 < t \leq 66.6$	$1.5t$
$66.6 < t \leq 200$	100

A.4 Test sensitivity

A.4.1 Adjust the ultrasonic equipment and transducer combination statically to establish the test sensitivity as follows:

a) for acceptance levels B1 to B4 and E1 and E2 only, adjust the equipment sensitivity such that the first back wall echo from a satisfactory area of material is set at full screen height; or

b) for acceptance levels B5 and above and E3 and above, establish the equipment sensitivity using the relevant distance amplitude correction (DAC) curve reference block in accordance with annex B; or

c) for automatic and semi-automatic testing equipment, ensure that at the test sensitivity the equipment will detect, under static conditions, the appropriate reference target in the reference test piece(s).

A.4.2 For acceptance levels B5 to B7, E3 and E4 use a 5 mm diameter flat bottomed hole as the reference target.

NOTE For acceptance levels BX and EX the diameter of the reference target should be agreed between the purchaser and the manufacturer.

A.4.3 Unless otherwise specified in Table A.1, adjust the ultrasonic equipment such that the ultrasonic through-thickness scan is executed between the entry surface and the back wall, in order that clearly identifiable signal responses from internal imperfections can be obtained within this time period.

A.4.4 When using DAC curves, adjust the test sensitivity, as established during the preparation of the DAC curves, by the difference in attenuation between the reference block and the material under test, taking into account the test material thickness.

A.4.5 Check the test sensitivity of the equipment at regular intervals during the production testing of material of the same thickness and grade. The frequency of checking the equipment test sensitivity shall be at least once every 8 h.

A.4.6 Readjust the equipment test sensitivity following any system alterations or whenever the specified nominal material thickness or grade of steel is changed.

A.4.7 If, on checking during production testing, the test sensitivity requirements are not satisfied, even after increasing the sensitivity by 2 dB to allow for system drift, then all material tested since the previous check shall be retested after the equipment test sensitivity has been readjusted, unless recorded data from individually identifiable material are available which permit accurate classification into suspect and acceptable categories.

A.5 Imperfection criteria

A.5.1 *Levels B1 to B4 and E1 and E2*

The presence of an internal imperfection is indicated by:

a) a 50 % reduction in the signal amplitude of the back wall echo, with or without the presence of an imperfection echo;

b) the presence of an imperfection echo which equals or exceeds 50 % of the amplitude of the reduced back wall echo.

A.5.2 *Levels B5 and above and E3 and above*

The presence of an internal imperfection is indicated by:

a) a 50 % reduction in the signal amplitude of the back wall echo, with or without the presence of an imperfection echo;

b) the presence of an imperfection echo that equals or exceeds the response from a reference target at the same depth, i.e. equals or exceeds the DAC curve.

NOTE On material where the required test sensitivity is high, the first back wall echo signal may be in saturation. Under these circumstances it may be necessary to carry out an additional scan using reduced sensitivity to test for the presence of the imperfection described in a).

A.5.3 *Evaluation of imperfections*

If any imperfections are detected, evaluate each area of imperfection either:

a) by manual techniques in accordance with annex C to establish the imperfection size and population within that area; or

b) using an automatic system that can be demonstrated to delineate the imperfections accurately.

A.6 Test report

When requested, the manufacturer shall submit to the purchaser a test report that includes, as a minimum, the following information:

a) material identity and size;

b) material condition (e.g. as rolled, normalized);

c) transducer type, dimension and frequency;

d) test equipment type and model;

e) couplant used;

f) scanning pattern;

g) statement of conformity to the relevant acceptance level of this British Standard;

h) operator identity and certification.

Annex B (normative) Technique for establishing a distance amplitude correction (DAC) curve

B.1 Principle

In this technique, the energy returned from an internal imperfection is compared with the energy returned from a reference target at the same material depth beneath the sound entry surface.

By the selection of a suitable reference target size a threshold signal response curve is established at which the internal imperfection becomes significant and will initiate subsequent specified action.

The reference target is normally a flat bottomed hole, but the use of rectangular recesses is permitted provided the length and width of the recess is chosen to provide an ultrasonic signal response essentially equivalent to that obtained from the stipulated flat bottomed hole using the same equipment/transducer type combination.

The technique requires the provision of a specially prepared reference block approximating to the thickness of the material being tested containing a series of flat bottomed hole targets of the same diameter at increasing material depths.

B.2 Reference block

NOTE Where practical, the reference block should have acoustic properties essentially similar to the material being tested.

The entry surface shall be flat and the interior free from naturally occurring internal imperfections which give recognizable ultrasonic responses. If the attenuation coefficient of the reference block is significantly different from that of the material being tested, sensitivity compensation shall be applied (see **A.4.4**).

The external dimensions, length and width of the reference block shall be selected by the manufacturer so that the reference targets are sufficiently separated from each other and from the extremities of the reference block to avoid mutual interference such that a clearly distinguishable signal indication is obtained from each reference target. The lower surface of the reference block may be stepped to facilitate the introduction of the reference targets.

For quality grades B5 to B7, and E3 and E4, the diameter of the flat bottomed hole reference targets shall be 5 mm.

NOTE For quality grades BX and EX, the diameter of the flat bottomed hole reference target should be agreed between the purchaser and supplier.

The tolerance on the diameter of the flat bottomed hole or width of the recess used shall be ± 5 %. The bottom of each reference target shall be nominally flat, parallel to the ultrasound entry surface (within 2 %) and free from pits or score marks that significantly degrade its ultrasonic reflectivity. The sides of the reference target shall be perpendicular to the ultrasound entry surface.

B.3 Construction of the DAC Curve

Make an initial assessment of the response of each reference target in the reference block to establish which reference target gives the largest response.

With the transducer optimized over the most responsive reference target, adjust the equipment gain/attenuator control to set the echo height at approximately 80 % of full screen height. Mark the position of the echo tip on the screen and record the gain/attenuator value.

This gain setting is the test sensitivity.

At the recorded gain/attenuator value, optimize the transducer over every other reference target in the reference block in turn and, for each target, mark the position of the echo tip on the screen.

Draw a curve on the screen of the flaw detector joining the marked points. This curve is the DAC curve and is exclusive to the reference block/imperfection detector/transducer combination used. Where other combinations are used, separate curves shall be established.

Annex C (normative) Determination of the size of internal imperfections by manual ultrasonic scanning

C.1 General

The procedure for manual ultrasonic pulse echo scanning of steel plate, strip and wide flats to determine the size of internal imperfections is described in **C.2**.

This procedure uses the technique known as the 6 dB drop method or half amplitude method, which is based on the fact that when half the sound beam strikes an internal imperfection the imperfection echo amplitude is reduced by 6 dB from the maximum imperfection echo amplitude.

The method is accurate for the delineation of the size of an internal imperfection equal to or greater than the transducer area. For smaller imperfection sizes the method has some degree of oversizing.

The method is suitable for the delineation of imperfection sizes for acceptance levels B1 to B5 in Table 1 and E1 to E3 in Table 2.

For acceptance levels B6, B7, BX, E4 and EX the method can be applied but inaccuracies in the form of oversizing may result. In these instances other sizing techniques as applicable are to be used.

C.2 Procedure

Optimize the transducer over the imperfection to obtain the maximum echo amplitude. Adjust the gain so that the signal amplitude lies between 40 % and 80 % of the full screen height. Note the actual height. Increase the gain by 6 dB and move the transducer over the edge of the imperfection until the imperfection echo falls to the noted screen height. The edge of the imperfection is then coincident with the axis of the transducer. Repeat this action in as many directions as is necessary to delineate the extent of the imperfection. When double-crystal transducers are used, the acoustic barrier separating the crystals shall be at right-angles to the boundary of the imperfections.

If the internal imperfection is badly orientated to the ultrasonic beam, its edge is considered to be coincident with the axis of the transducer at the point where the signal amplitude of the first backwall echo is reduced by 6 dB.

Having delineated the extent of the internal imperfection, determine its maximum dimensions parallel to and transverse to the rolling direction. The product of these dimensions is defined as the area of the imperfection.

List of references (see clause 2)

Normative references

BSI standards publications

BRITISH STANDARDS INSTITUTION, London

BS 3683, *Glossary of terms used in non-destructive testing.*
BS 3683-4:1985, *Ultrasonic flaw detection.*
BS 4331, *Methods for assessing the performance characteristics of ultrasonic flaw detection equipment.*
BS 4331-1:1978, *Overall performance: on-site methods.*
BS 4331-3:1974, *Guidance on the in-service monitoring of probes (excluding immersion probes).*

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