BS ISO 10830:2011

BSI Standards Publication

Space systems — Non-destructive testing — Automatic ultrasonic inspection method of graphite ingot for solid rocket motors

National foreword

This British Standard is the UK implementation of ISO 10830:2011.

The UK participation in its preparation was entrusted to Technical Committee ACE/68/-/8, Space systems and operations - Materials and processes.

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.

ISBN 978 0 580 66378 9

ICS 19.100; 49.140

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 August 2011.

Amendments issued since publication

Date	Text affected

BS ISO 10830:2011

INTERNATIONAL STANDARD

ISO 10830

First edition
2011-07-15

Space systems — Non-destructive testing — Automatic ultrasonic inspection method of graphite ingot for solid rocket motors

Systèmes spatiaux — Essais non destructifs — Méthode par injection ultrasonique du bloc graphite pour les moteurs de fusée à combustible solide

Reference number
ISO 10830:2011(E)

Contents

Page

Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 10830 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

In February 2000, the Institute of Space and Astronautical Science (now Japan Aerospace Exploration Agency) launched an M-V-4 rocket that experienced an unexpected failure. An intensive post-flight study was carried out. It was finally concluded that the failure originated from the fracture of a nozzle throat insert made of graphite[1]. Then, a study of non-destructive inspection was initiated, and the ultrasonic inspection method specified in this International Standard was developed for use on the throat inserts of solid rocket motors.

Graphite materials have been utilized without quantitative non-destructive inspection in many applications, except for one example of the core structure of the High Temperature Engineering Test Reactor (HTTR) of the Japan Atomic Energy Research Institute[2]. There, planar flaws perpendicular to the top, bottom or side surfaces in a cylindrical ingot were targeted. However, for aerospace applications, it is necessary to detect internal planar flaws oriented in various directions.

The method is based on a single-probe, pulse-echo and immersion technique utilizing normal and angle-beam techniques to detect internal planar flaws oriented in various directions. The wave velocity and the attenuation coefficient in the test object are measured before inspection to determine the differences in acoustic properties from ingot to ingot. Incident-angle scanning is adopted in addition to the common beam-axis scanning to detect flaws that can be oriented in various directions. This inspection technique is necessary for inspection of sintered materials in general, including ceramics, and not only for graphite used in solid rocket motors.

The method was first published as JIS Z 2356[3] in 2006 by the Japanese Industrial Standards Committee.

Space systems — Non-destructive testing — Automatic ultrasonic inspection method of graphite ingot for solid rocket motors

1 Scope

This International Standard is applicable to the inspection of isotropic graphite ingots for use in solid rocket motors, in order to detect planar flaws oriented in various directions, using immersion testing by means of a single-probe, pulse-echo ultrasonic method.

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 5577, *Non-destructive testing — Ultrasonic inspection — Vocabulary*

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel — General principles*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5577 and the following apply.

3.1
beam-index scanning
common scanning method in which a probe (beam index) traverses the test surface of the test block

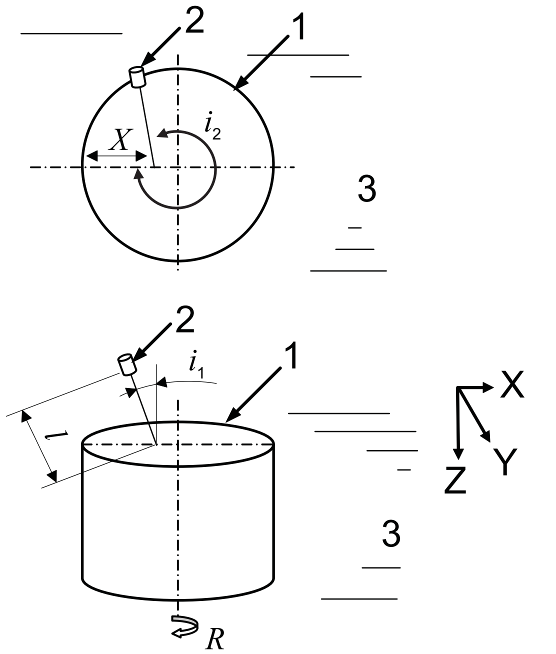
NOTE Either R-X scanning or R-Z scanning is conducted, depending on the test surface.

3.2
R-X scanning
beam-index scanning method that is executed on the top or bottom surface of the test block

NOTE It consists of the traverse translation of the probe in the diametrical direction of the test block and the axial rotation of the test block (see Figure 1).

3.3
R-Z scanning
beam-index scanning method that is executed on the side surface of the test block

NOTE It consists of the traverse translation of the probe in the longitudinal direction of the test block and the axial rotation of the test block (see Figure 2).



Key

1 test block

2 probe

3 water

i_1 incident angle

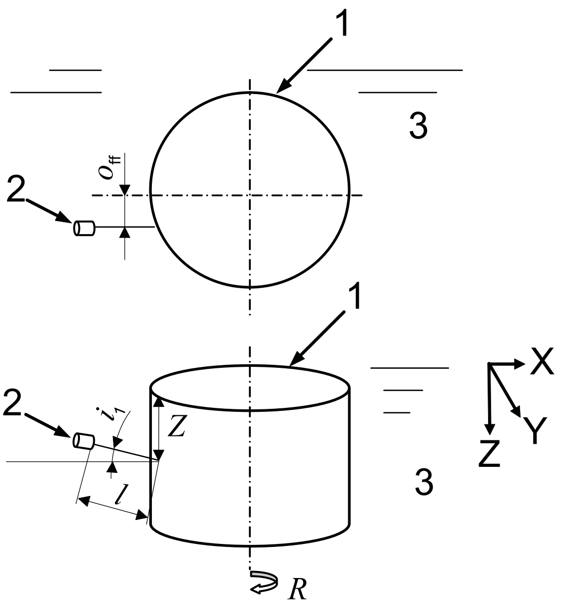
i_2 swivel

l water path

R rotation

X transverse

Figure 1 — Schematic diagram of R-X scanning



Key

1 test block

2 probe

3 water

i_1 incident angle

l water path

o_{ff} offset

R rotation

Z transverse

Figure 2 — Schematic diagram of R-Z scanning

3.4
incident-angle scanning
scanning method in which the two independent incident angles of a probe are changed sequentially

NOTE Either i_1-i_2 scanning or i_1-o_{ff} scanning is conducted following either an orthogonal scanning or staggered scanning method.

3.5
i_1-i_2 scanning
incident-angle scanning method that is executed on the top or bottom surface of the test block

NOTE It consists of changing the angle of incidence (inclining angle) i_1 and changing the swivel angle i_2 (see Figure 1). R-X scanning is conducted at each setting angle (data collection point).

3.6
i_1-o_{ff} scanning
incident-angle scanning method that is executed on the side surface of the test block

NOTE It consists of changing the longitudinal incident angle i_1 and changing the offset distance o_{ff} (corresponding to the horizontal incident angle, see Figure 2). R-Z scanning is conducted at each setting angle (data collection point).

3.7
orthogonal scanning
scanning method used in incident-angle scanning in which setting angles (data collection points) form a square lattice

3.8
staggered scanning
scanning method used in incident-angle scanning in which setting angles (data collection points) form a hexagonal lattice such that the number of scanning points is less than in the case of orthogonal scanning

NOTE Here, the scanning points are placed in a zigzag position with respect to one another (see Figure 3).

3.9
primary inspection
first of two inspection stages in which scanning is conducted using a relatively large scanning pitch, which corresponds to relatively large apparent widths of beam spread, and at a relatively high level of sensitivity

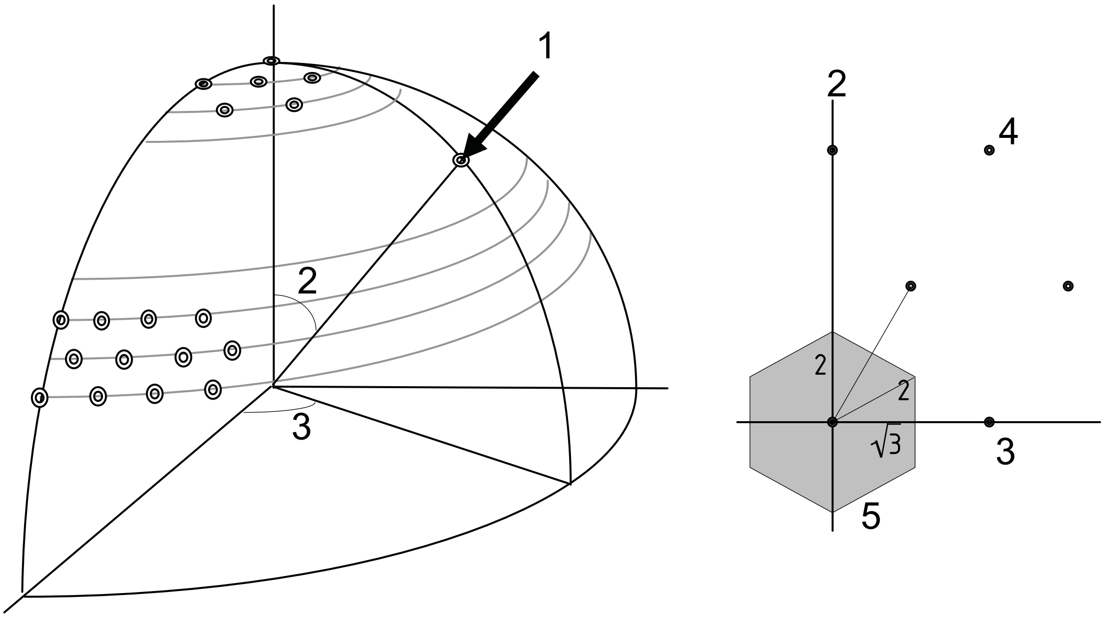
NOTE This stage identifies suspicious spots to be inspected in the secondary inspection.

3.10
secondary inspection
second of two inspection stages in which scanning is carried out on the spots identified in the primary inspection using a relatively small scanning pitch, which corresponds to relatively small apparent widths of beam spread, but at a relatively low level of sensitivity (lower by the beam-edge compensation than that of the primary inspection), in order to qualify the tested block

3.11
two-axis swivel scanning
swivel scanning in two incident-angle axes to obtain the maximum echo height, compensating for the wave-front fluctuation induced by the uneven ultrasonic propagation characteristics of graphite

NOTE Two-axis swivel scanning is conducted in the survey of echo height of a flat-bottomed hole to set the specified sensitivity.

3.12
planar width of beam spread
transversal range of a beam in which the echo of a flat-bottomed hole equivalent to the flaw to be detected appears at a height above the specified echo level in beam-index scanning



Key

1 ultrasonic beam

2 angle of refraction corresponding to i_1

3 angle of refraction corresponding to i_2 or o_{ff}

4 beam index

5 effective beam area of an incidence point

Figure 3 — Schematic diagram of staggered scanning in incident-angle scanning

3.13
angular width of beam spread
angular range of a beam in which the echo of a flat-bottomed hole equivalent to the flaw to be detected appears at a height above the specified echo level in incident-angle scanning

3.14
apparent attenuation-compensation rate
compensation for residual difference in echo height between the reference block and the test block

NOTE The apparent attenuation-compensation rate is applied after compensation of wave-front fluctuation by two-axis swivel scanning in the calibration of detection sensitivity. The difference is understood as the difference in properties between graphite ingot lots.

4 General

4.1 Requirements

Test blocks are cylindrical in form with a diameter/height ratio of approximately one and a diameter and a height no greater than 225 mm. Prior to inspection, the size, position and direction of the permissible flaw shall be evaluated in the design procedure. The minimum equivalent flaw diameter to be detected shall be greater than 3 mm.

NOTE 1 Isotropic graphite to be inspected by this method is produced by isostatic pressing.

NOTE 2 A larger test block might be inspected in accordance with this International Standard; however, the procedure has not been validated at diameters and heights greater than 225 mm.

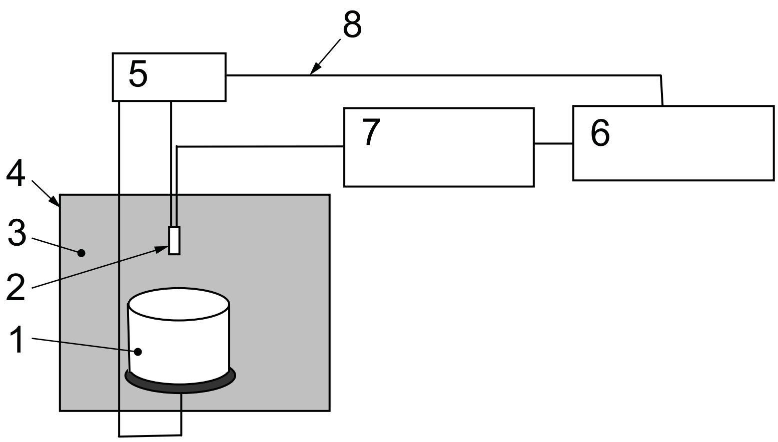
4.2 Test conductor

Persons who conduct this ultrasonic inspection of a graphite ingot for solid rocket motors shall be qualified to ultrasonic testing (UT) Level 2 in accordance with ISO 9712, or its equivalent, they shall have sufficient knowledge of graphite material and inspection methods, and they shall be trained in the operation of ultrasonic inspection equipment.

5 Composition of ultrasonic test equipment

5.1 Basic composition of equipment

Equipment adopted for this method comprises an ultrasonic test instrument, a probe and its associated scanning equipment, and displaying and recording equipment. Figure 4 shows the composition of the equipment.



Key

1 test block
2 probe
3 water
4 water tank
5 scanner
6 controller
7 ultrasonic pulser/receiver
8 six axes (X, Y, Z, i_1, i_2, R)

Figure 4 — Composition of automatic ultrasonic test equipment

5.2 Ultrasonic test instrument

In addition to its basic function as an ultrasonic pulser/receiver that transmits spike pulses, the ultrasonic test instrument has an echo-recording gate, a distance-amplitude correction function (DAC circuit) and a data output/memory function, as specified in a) to c) below:

a) Echo-recording gate: At least one recording gate is provided.

b) Distance-amplitude compensation (DAC): A DAC curve is drawn by plotting echo heights at six or more points in the beam path. The DAC circuit has a compensation capability of at least 30 dB.

c) Data output/memory function: The ultrasonic test instrument displays the echo with the maximum echo height of the recorded echoes, together with its beam path, held in the echo recording gate. The corresponding A-scope is stored to memory simultaneously.

5.3 Probe

A normal-incidence immersion probe is used. A non-focusing probe with a nominal frequency range of 1 MHz to 2 MHz and with a nominal diameter of approximately 25 mm is recommended in order to obtain good signal-to-noise ratios of flaws with an equivalent diameter of 3 mm versus the background noise of the graphite matrix, even for a long beam path.

5.4 Scanning equipment

5.4.1 General

To detect flaws in all directions, the scanning equipment shall allow X-, Y- and Z-axis traverses, test-block rotation, and probe inclinations in two axes, in order to perform normal-beam and angled-beam techniques. It shall be installed in an adequate water pool, which shall be kept clean and free from algae. The water in the pool shall be left for a day before inspection.

5.4.2 Required functionality for the scanning equipment

The scanning equipment shall have functions for performing the following scanning, either automatically or manually:

a) X-axis: manual traverse and automatic scanning with variable pitch and speed;

b) Y-axis: manual traverse and automatic scanning with variable pitch and speed;

c) Z-axis: manual traverse and automatic scanning with variable pitch and speed;

d) probe incident angle i_1: manual change;

e) probe swivel angle i_2: manual change;

f) test-block rotation R: manual and automatic rotation with variable pitch and speed.

5.4.3 Required capabilities of the scanning equipment

The scanning equipment shall have the following capabilities and accuracy at each data measurement point:

a) X-, Y- and Z-axis scanning: resolution and minimum pitch are 0,5 mm or finer;

b) probe incident-angle scanning: scanning range of –90° to +90° and a resolution of 0,1° or finer;

c) probe swivel-angle scanning: scanning range of 0° to 360° and a resolution of 0,1° or finer;

d) test block rotation: scanning range of 0° to 360° and a resolution and minimum pitch of 0,2° or finer.

5.5 Display and recording equipment

5.5.1 General

The display instrument shall be capable of showing a C-scope of the top/bottom- and side-surface scanning of a cylindrical test block. The recording instrument shall be capable of recording the echo height of the highest echo in the echo recording gate and the scanning data for each scanning position.

5.5.2 Required functionality for the display/recording equipment

The display/recording equipment shall have the following functions:

a) C-scope display of top/bottom-surface incidence on the test block;

b) C-scope display of side-surface incidence on the test block;

c) recording of the echo height and beam path of the highest echo in the gate range;

d) recording of position (X, Y, Z), angle (i_1, i_2) of incidence and test-block rotation (R) of the highest echo in the gate range;

e) transfer of the recorded data to storage media.

5.5.3 Required capabilities of the display and recording equipment

The display and recording equipment shall have the following capabilities:

a) the lower display limit of the echo height or tone level can be adjusted to an arbitrary height or level before or after testing;

b) the C-scope display is capable of locating and presenting indications in 3 mm resolution or finer in three coordinate axes;

c) all indications are presented in plural tones or colours that are clearly distinguishable for each echo height or tone level.

6 Preparation of automatic ultrasonic inspection

6.1 Reference blocks

6.1.1 Surface treatment of the reference blocks

The reference blocks shall be machined to a surface roughness (average roughness along the centre-line) of Ra 3,2 or finer and shall be dried sufficiently. Then the surface of the blocks shall be thinly coated with a low-permeability epoxy resin for waterproofing.

6.1.2 Calibration of the test instrument

Calibration of the test instrument for this method shall be carried out using the reference blocks.

6.1.3 Reference blocks

Reference blocks shall be provided to make the adjustments specified in a) to d) below. Dimensions and shape of the reference blocks and the method of calibration shall be in accordance with Annex A. Attenuation compensation shall be carried out on the test block itself and not on the reference blocks, in accordance with 6.9 c) and B.3.

a) Distance-amplitude correction shall be carried out in accordance with 6.5 and A.2.2.

b) Determination of apparent beam-width shall be carried out in accordance with 6.6, A.2.3 and A.3.2.

c) Adjustment of the specified sensitivity shall be carried out in accordance with 8.1 a).

d) Calibration of detection sensitivity shall be carried out in accordance with 6.9.

6.2 Water path

The water path between the test block and the probe shall be adjusted so that surface echo S_2 travels outside the bottom echo B_1 beam path in the A-scope, under conditions that avoid turbulence in the distance-amplitude curve in the test region of the test block.

6.3 Setting for angle-beam incidence

6.3.1 Beam index

Beam index is the point of intersection of the extended geometric centre axis of the probe and the test block.

6.3.2 Geometric angle of refraction

The geometric angle of refraction, θ_g, in graphite (the angle between the normal line of the incidence plane and the direction of the refracted beam in graphite) at the top or bottom surface of the test block, is obtained using the following equation:

$$\sin\theta_g = \frac{v_g}{v_w} \sin\theta_i$$

where

v_w is the wave velocity in water;

v_g is the average wave velocity in graphite, in accordance with B.2.4 (here, a rough figure of two significant digits is used);

θ_i is the angle of incidence (formed by the normal line of incidence and the direction of the incidence beam).

The horizontal incident angle for the side-surface incidence of the test block is obtained using the following equation:

$$o_{ff} = \frac{D}{2} \sin\theta_i$$

where

o_{ff} is the offset distance;

D is the test-block diameter.

6.4 Scanning zone and gate range

6.4.1 General

Scanning shall be carried out on the top/bottom and side surfaces of the test block to detect flaws tilted up to about 70° from the test surface. Although, basically, the flaws tilted below 45° of each test surface shall be detected, detection of flaws tilted up to approximately 70° is necessary to eliminate undetected flaws located along the diagonals of the test block. The necessary scanning zone and corresponding gate range for this purpose are specified in 6.4.2 to 6.4.4.

6.4.2 Scanning zones for top/bottom-surface incidence

Scanning zones for top/bottom-surface incidence shall be as follows:

a) R-axis scanning zone: 0° to 360°;

b) X-axis scanning zone: from the centre to the side surface of the test block (the beam traverse distance is equal to the radius of the test block);

c) i_1-axis scanning zone: 0° to 70° in the geometric angle of refraction;

d) i_2-axis scanning zone: 0° to 360°.

6.4.3 Scanning zones for side-surface incidence

Scanning zones for side-surface incidence shall be as follows:

a) R-axis scanning zone: 0° to 360°;

b) Z-axis scanning zone: from the top surface to the bottom surface of the test block (the beam traverse distance is equal to the height of the test block);

c) i_1-axis scanning zone: 0° to 70° in the geometric angle of refraction;

d) o_{ff}-axis scanning zone: 0° to 70° in the geometric angle of refraction.

6.4.4 Gate range

A gate range under each scanning condition shall be decided on the basis of a diagram showing the respective beam-passing volumes in the test block for ultrasonic beams with geometrical refraction angles of 0°, 10°, 20°, 30° and 45° respectively. Confirm via the diagrams that, under all scanning conditions, undetected regions remain only in a 5 mm zone next to the outer edge or in an area 12 mm by 12 mm in the corners, as specified in 7.1.1. Finally, confirm the detection of reflectors on the border of the dead zone in the side-surface incidence on RB-H reference blocks (see A.1.3), as specified in A.5.

6.5 Distance-amplitude correction

The distance-amplitude correction is performed electronically by the DAC circuit, up to the required beam length of the test block for normal and angle incidence, in accordance with A.2.2. The maximum compensation value shall be 30 dB.

6.6 Determination of apparent widths of beam spread

In both beam-index-traverse and incident-angle-incline directions, apparent beam profiles are measured for both top/bottom- and side-surface incidence in accordance with A.2.3 and A.3.2. Then, the planar and angular widths of beam spread are determined on the basis of the respective intensity drops at the beam edge for primary and secondary inspection, as indicated in Table 1. They are determined on the basis of the minimum equivalent flaw diameter to be detected. This measurement shall be carried out on all reference blocks below the necessary beam path for the required test block. The minimum value obtained for width from among the different beam paths shall be set as the apparent width for each condition (planar or angular, test surface and inspection stage).

Table 1 — Intensity drop at the beam edge for primary and secondary inspection

Minimum equivalent flaw diameter to be detected	Intensity drop at the beam edge	
	Primary inspection	Secondary inspection
≥3 mm but <5 mm in diameter	−3 dB	−1 dB
≥5 mm in diameter	−6 dB	−3 dB

6.7 Selection of scanning pitch in beam-index scanning

In beam-index scanning, i.e. R-X scanning and R-Z scanning, the scanning shall be performed with a scanning pitch (data collection interval) determined on the basis of the apparent planar width of beam spread as defined in 6.6 in order to eliminate any undetected region. In R-scanning, the angular pitch of rotation is adjusted such that the distance between incidence points is less than one-fifth of the planar width of beam spread. In X- and Z-axis scanning, the scanning pitch is the same as or smaller than the planar width of beam spread. Figures 1 and 2 show schematic diagrams of R-X scanning and R-Z scanning respectively.

6.8 Selection of data collection interval in incident-angle scanning

In incident-angle scanning, i.e. i_1-i_2 scanning and i_1-o_{ff} scanning, scanning shall be performed with a scanning pitch (data collection interval) determined on the basis of the apparent angular width of beam spread as defined in 6.6 in order to eliminate any undetected region, using either orthogonal scanning or staggered scanning (Figure 3). In i_1 scanning, the angular detection pitch is adjusted so that the pitch of the geometric refraction angle is within the angular width of beam spread. In i_2 and o_{ff} scanning, the detection pitch is set so that, if i_1 is near 90°, the data collection points expressed in the geometric angle of refraction form a square lattice (orthogonal scanning) or a hexagonal lattice (staggered scanning). When i_1 becomes smaller, the detection pitch of i_2 and o_{ff} may be increased; however, to simplify the scanning condition, it is desirable to set it to an integral multiple only when the pitch may be larger than that integral multiple. To correct decreases in beam-edge intensity and thereby eliminate undetected regions, a larger angular width, of $2/\sqrt{2}$ (= 1,42) times the angular width of beam spread defined in 6.6 for orthogonal scanning, or $2/\sqrt{3}$ (= 1,15) times that for staggered scanning, is necessary, along with a larger beam-edge compensation in accordance with 6.9 d).

6.9 Required compensation of detection sensitivity

Detection sensitivity, G_R (dB), as defined in 8.2, is based on the specified sensitivity, G_T, which is adjusted to a level whereby the echo height of a flat-bottomed hole (equivalent to the flaw to be detected) is shown as 80 % on the instrument display. In addition, G_T is adjusted by the following types of compensation:

a) Incident-plane compensation, ΔG_P: Compensation ΔG_P for side-surface incidence (curved-surface incidence) against top/bottom-surface incidence (flat-surface incidence), determined in accordance with A.4.1.

b) Incident-angle compensation, ΔG_θ: Compensation ΔG_θ for angle incidence against normal incidence, determined in accordance with A.4.2. A single compensation value is used for each angle through all necessary beam paths. However, if the compensation value is large due to a large angle of incidence, the beam path may be divided into sections and different compensation values allocated to each.

c) Attenuation compensation, $2\alpha W_{max}$: Maximum attenuation in test block $2\alpha W_{max}$ is calculated using the apparent attenuation-compensation rate, α, and the maximum beam path, W_{max}, in accordance with B.3. It is applied uniformly to all scanning surfaces to compensate for attenuation.

d) Beam-edge compensation, ΔG_S: The sum of beam-edge corrections for planar and angular widths of beam spread specified in 6.7 and 6.8 respectively.

e) Corner-incidence compensation, ΔG_C: Compensation ΔG_C for corner incidence against the regular plane-surface incidence, in accordance with A.4.3.

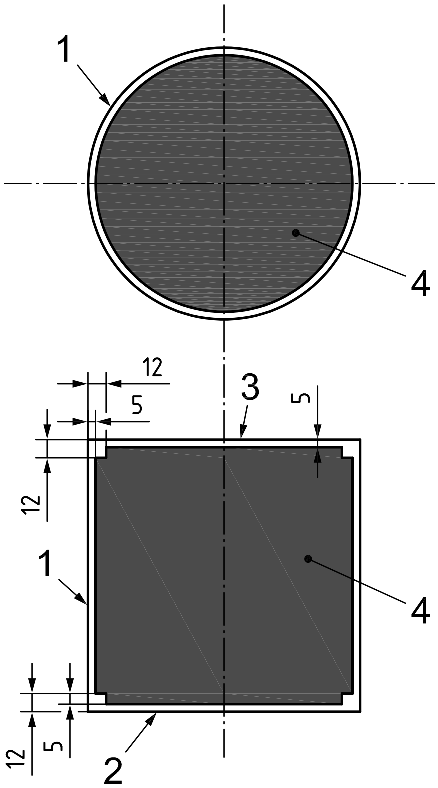
7 Procedure for automatic ultrasonic inspection

7.1 Test blocks

7.1.1 Detection region

The detection region shall be the entire volume of a cylindrical test block for which the diameter/height ratio is approximately one, excluding a 5 mm outer zone of each test surface and an area 12 mm by 12 mm in the corners of the top and bottom edges, as shown in Figure 5.

Dimensions in millimetres



Key

1 side surface

2 bottom surface

3 top surface

4 detected zone

Figure 5 — Test region in the test block

7.1.2 Surface treatment

The test block surface shall be machined to a roughness (average roughness along the centre-line) of Ra 3,2 or finer and shall be dried sufficiently. The entire surface shall then be thinly coated with a low-permeability epoxy resin for water proofing.

7.2 Test sequence

7.2.1 General

Inspection is divided into two processes: a propagation-characteristic test and automatic ultrasonic inspection. The propagation-characteristic test is further subdivided into a bottom-echo monitoring test and an attenuation-compensation test. The sequence of the three tests on a test block is as specified in 7.2.2 to 7.2.4. See also Figure 6.

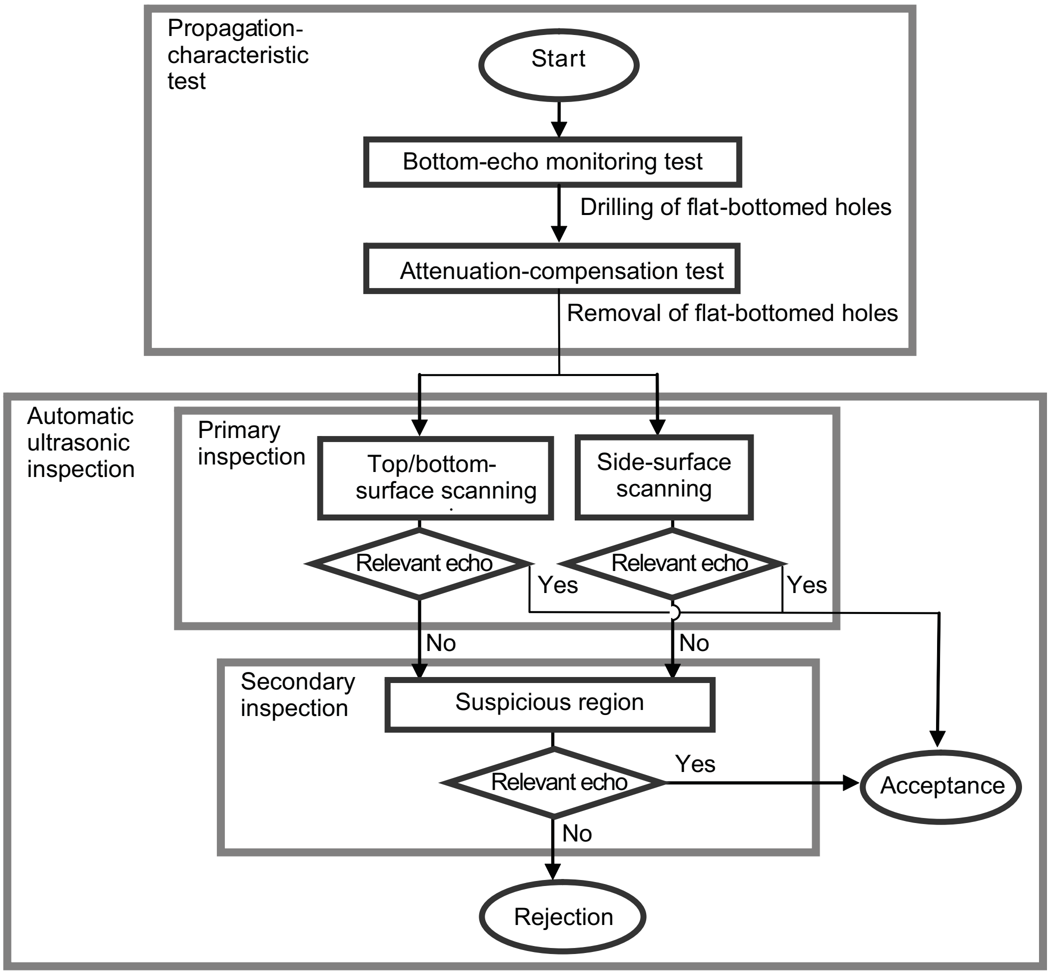


Figure 6 — Test sequence for inspection

7.2.2 Bottom-echo monitoring test

This is the first test to examine ultrasonic wave propagation characteristics in order to determine the locations in which to drill flat-bottomed reference reflectors, in the lowest attenuation region and the highest attenuation region, as described in detail in B.2. In addition, the average velocity in the test block is determined from the bottom-echo travelling time for 36 test points.

7.2.3 Attenuation-compensation test

This propagation-characteristic test is performed after drilling flat-bottomed holes after the bottom-echo monitoring test, in order to calibrate the specified sensitivity, as described in detail in B.3. Echo heights of flat-bottomed holes located in multiple positions are determined by two-axis swivel scanning. The coefficient of attenuation compensation, α, is obtained from the minimum value of maximum echo height and the path of the associated beam.

7.2.4 Automatic ultrasonic inspection

This is the flaw-detection test conducted after removal by milling of the flat-bottomed holes used in the attenuation-compensation test. It comprises two stages: primary inspection and secondary inspection. First-stage scanning is conducted using a relatively large scanning pitch, which corresponds to relatively large apparent widths of beam spread, and at a relatively high level of sensitivity, in order to identify spots to be inspected in the secondary stage. Second-stage scanning is conducted on those spots identified in the primary inspection, using a relatively small scanning pitch, which corresponds to relatively small apparent widths of beam spread, and at a lower level of sensitivity (lower by the beam-edge compensation than that of the first stage), in order to qualify the tested block.

8 Automatic ultrasonic inspection

8.1 Preparation for testing

The following adjustments shall be made on each day of testing:

a) Specified sensitivity calibration: Using the flat-bottomed hole of the maximum path equivalent to the flaw to be detected in the RB-F reference block (see A.1.1), specified sensitivity, G_{T}, is adjusted to a level such that echo height in the two-axis swivel scanning is shown as 80 % on the instrument display. At this point, the testing equipment is ready to conduct surface scanning, during which the actual A-scope displays and C-scope displays shall be recorded.

b) Axis alignment of the test block: The test-block rotation axis is adjusted using the surface echo of the test-block side surface.

c) Beam-axis alignment: Alignment of the beam axis to the probe index is carried out using the surface echo of each scanning surface of the test block.

d) Water-path adjustment: The water path is adjusted using the surface echo of each scanning surface of the test block.

8.2 Primary inspection

Primary inspection scanning shall be conducted on the basis of the apparent width of beam spread determined as specified in 6.6. The detection sensitivity, G_{R}, shall be determined using the following equation:

$$G_{\mathrm{R}} = G_{\mathrm{T}} + \Delta G_{\mathrm{P}} + \Delta G_{\theta} + 2\alpha W_{\mathrm{max}} + \Delta G_{\mathrm{S}} + \Delta G_{\mathrm{C}}$$

where

G_{T} is the specified sensitivity adjusted to a level such that the echo height of the flat-bottomed hole equivalent to the flaw to be detected is 80 % on the instrument display, as specified in 8.1 a);

ΔG_{P} is the incident-plane compensation estimated in accordance with 6.9 a);

ΔG_{θ} is the incident-angle compensation estimated in accordance with 6.9 b);

$2\alpha W_{\mathrm{max}}$ is the attenuation compensation estimated in accordance with 6.9 c);

ΔG_{S} is the beam-edge compensation estimated in accordance with 6.9 d);

ΔG_{C} is the corner-incidence compensation estimated in accordance with 6.9 e).

Usually, detecting sensitivity is determined for each incidence prior to testing. However, a maximum value of detecting sensitivity may be applied to any arbitrary detection to simplify the testing. Areas for which echo heights are found to be 80 % or more on the instrument display, which is equivalent to a flat-bottomed hole echo, shall be subject to secondary inspection as specified in 8.3.

8.3 Secondary inspection

Secondary inspection shall be carried out on the areas identified in the primary inspection. Secondary inspection scanning shall be conducted on the basis of the apparent width of beam spread determined as specified in 6.6. Detection sensitivity, G_R, shall be determined in accordance with 8.2. Compensation for detection sensitivity may be made by subtracting the corresponding value from the echo height equivalent to the acceptance criteria as specified in Clause 9.

9 Acceptance criteria

If any area is found on the test block that shows 80 % echo height or more of a flat-bottomed hole equivalent to the acceptance criteria, that tested block shall be neither accepted nor qualified.

10 Reporting and recording

10.1 General

Report the items listed in 10.2 to 10.5.

10.2 Report of test result

Report the following data:

a) date of testing;

b) name of the person who carried out the testing;

c) identification number of the test block;

d) material and dimensions of the test block;

e) model number of the automatic ultrasonic test instrument;

f) model number of the probe;

g) qualification result of the test block.

10.3 Scanning details and corresponding gate range

Record the following data for each incidence condition:

a) test surface;

b) incident angle, i_1;

c) swivel angle, i_2 (for top/bottom-surface incidence), or offset, o_{ff} (for side-surface incidence);

d) gate range.

10.4 Inspection condition data

Report the following data:

a) identification number or shape of the reference blocks;

b) A-scope and C-scope displays of the reference blocks;

c) average velocity of the test block;

d) distance-amplitude compensation data;

e) sensitivity compensation values.

10.5 Secondary inspection details

Record the following data for each area on which secondary inspection was executed:

a) test surface;

b) incident angle, i_1;

c) swivel angle, i_2 (for top/bottom-surface incidence), or offset, o_{ff} (for side-surface incidence);

d) position of beam index;

e) beam path;

f) echo height.

Annex A
(normative)

Reference blocks and test method for ultrasonic characteristic determination of graphite ingot

A.1 Reference blocks

A.1.1 RB-F blocks

RB-F blocks are the reference blocks used to determine distance-amplitude correction, specified sensitivity and apparent width of beam spread in normal incidence on top/bottom surfaces (flat surfaces). The blocks shall be cuboidal and made of isotropic graphite, as shown in Figure A.1. They shall have dimensions, reflectors and beam paths as specified in Table A.1. A block of sufficient beam path and shorter ones shall be provided for the test. There shall be two or more reflectors in each block; the one that gives the weakest echo shall be the reference reflector.

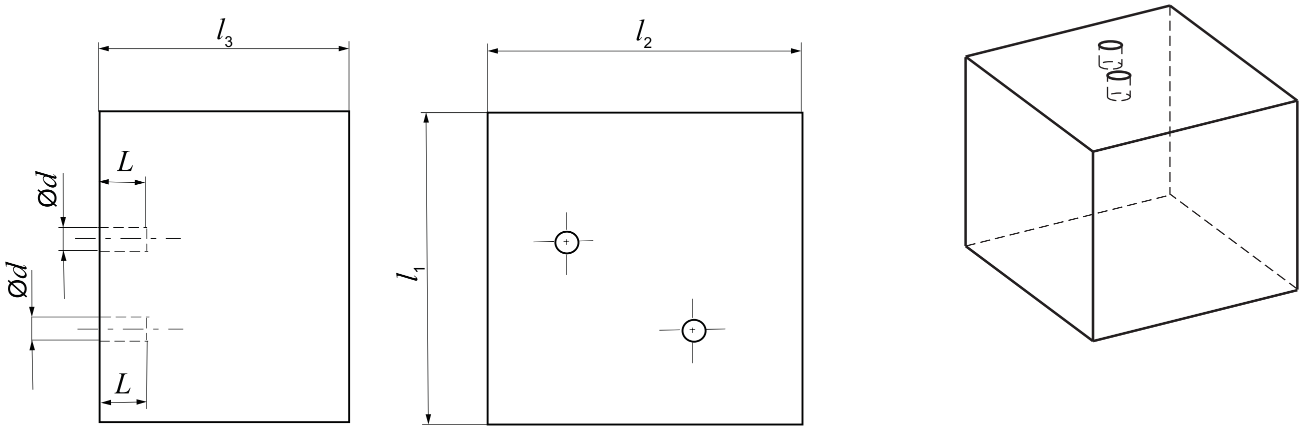


Figure A.1 — Shape and dimensions of RB-F reference block

Table A.1 — Dimensions, reflectors and beam paths of RB-F blocks

Reference block	Dimensions			Reflector: flat-bottomed hole of the flaw diameter to be detected			Beam path mm
	l_1 mm	l_2 mm	l_3 mm	$\varnothing d$	L mm	Number of holes	
RB-F1	≥100	≥100	≥20	Flaw diameter	≥10	≥2	10 ± 5
RB-F2	≥100	≥100	≥40	Flaw diameter	≥10	≥2	30 ± 5
RB-F3	≥100	≥100	≥70	Flaw diameter	≥10	≥2	60 ± 5
RB-F4	≥100	≥100	≥110	Flaw diameter	≥10	≥2	100 ± 10
RB-F5	≥100	≥100	≥160	Flaw diameter	≥10	≥2	150 ± 10
RB-F6	≥100	≥100	≥230	Flaw diameter	≥10	≥2	220 ± 10

A.1.2 RB-G block

An RB-G block is the reference block used to compensate detection sensitivity for different surfaces and to determine the apparent width of beam spread in normal incidence on side surfaces (curved surfaces). The block shall be cylindrical and made of isotropic graphite, as shown in Figure A.2, and have, in principle, the same diameter as the test block. The block shall have dimensions, reflectors and beam path as specified in Table A.2. There shall be two or more reflectors in the block; the one that gives the weakest echo shall be the reference reflector.

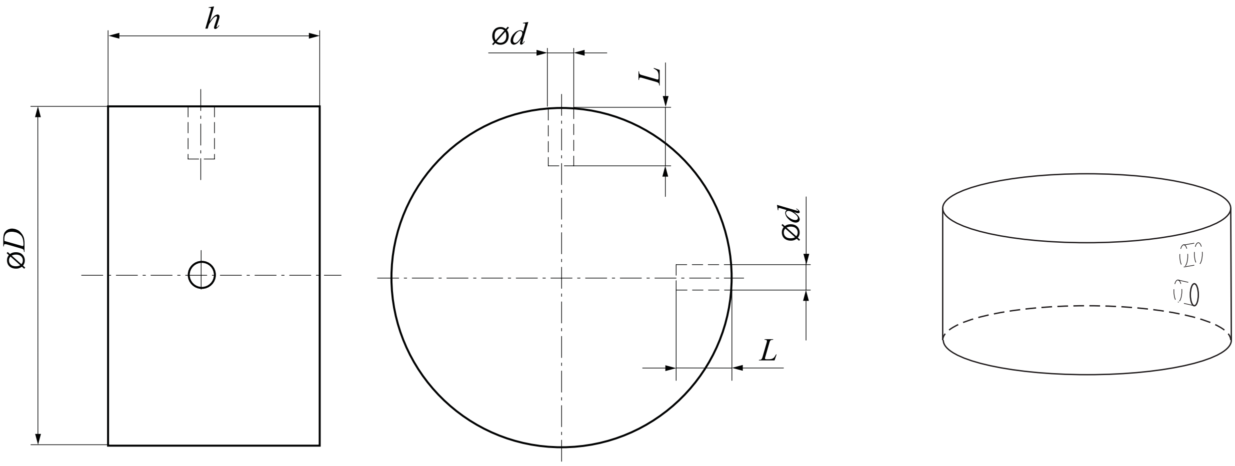


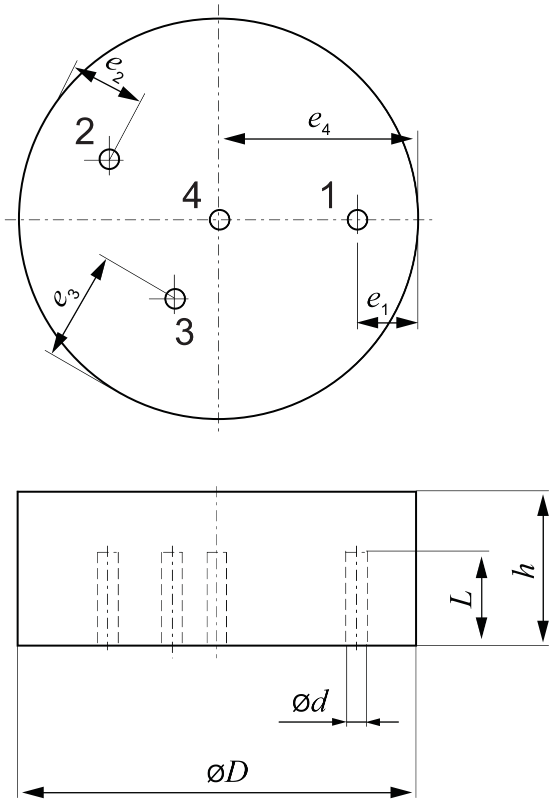
Figure A.2 — Shape and dimensions of RB-G reference block

Table A.2 — Dimensions, reflectors and beam paths of RB-G block

Reference block	Dimensions		Reflector: reference flat-bottomed hole of the flaw diameter to be detected			Beam path mm
	$\varnothing D$ mm	h mm	$\varnothing d$	L mm	**Number of holes**	
RB-G	Same diameter as test block, in principle	≥40	Flaw diameter	10	≥2	$\varnothing D$–10

A.1.3 RB-H blocks

RB-H blocks are the reference blocks used to determine incident-angle compensation in side-surface (curved-surface) incidence and to confirm full detection of tilted flaws in all directions. The block shall be cylindrical and made of isotropic graphite, as shown in Figure A.3, and have, in principle, the same diameter as the test block. The block shall have dimensions, reflectors and distances from the side surface as specified in Table A.3.



Key

1 to 4 holes as specified in Table A.3

Figure A.3 — Shape and dimensions of RB-H reference block

Table A.3 — Dimensions, reflectors and distance from side surface of RB-H blocks

Reference block	Dimensions		Reflector: side-drilled hole				
	$\varnothing D$ mm	h mm	Hole No. n	$\varnothing d$ mm	L mm	Number of holes	Distance from the side surface, e_n mm
RB-H1	Same diameter as test block, in principle	≥50	1	2	40	1	2,5
			2	2	40	1	7,5
			3	2	40	1	72,5 ± 10
			4	2	40	1	$\varnothing D/2$
RB-H2	Same diameter as test block, in principle	≥50	1	2	40	1	12,5
			2	2	40	1	22,5 ± 5
			3	2	40	1	37,5 ± 5
			4	2	40	1	$\varnothing D/2$

A.1.4 RB-L block

An RB-L block is the reference block used to compensate corner effects in normal and angle incidence on corners (corner-edge region). The blocks shall be cuboidal and made of isotropic graphite, as shown in Figure A.4. They shall have dimensions, reflectors and beam paths as specified in Table A.4. There shall be two or more reflectors in each block; the one that gives the weakest echo shall be the reference reflector.

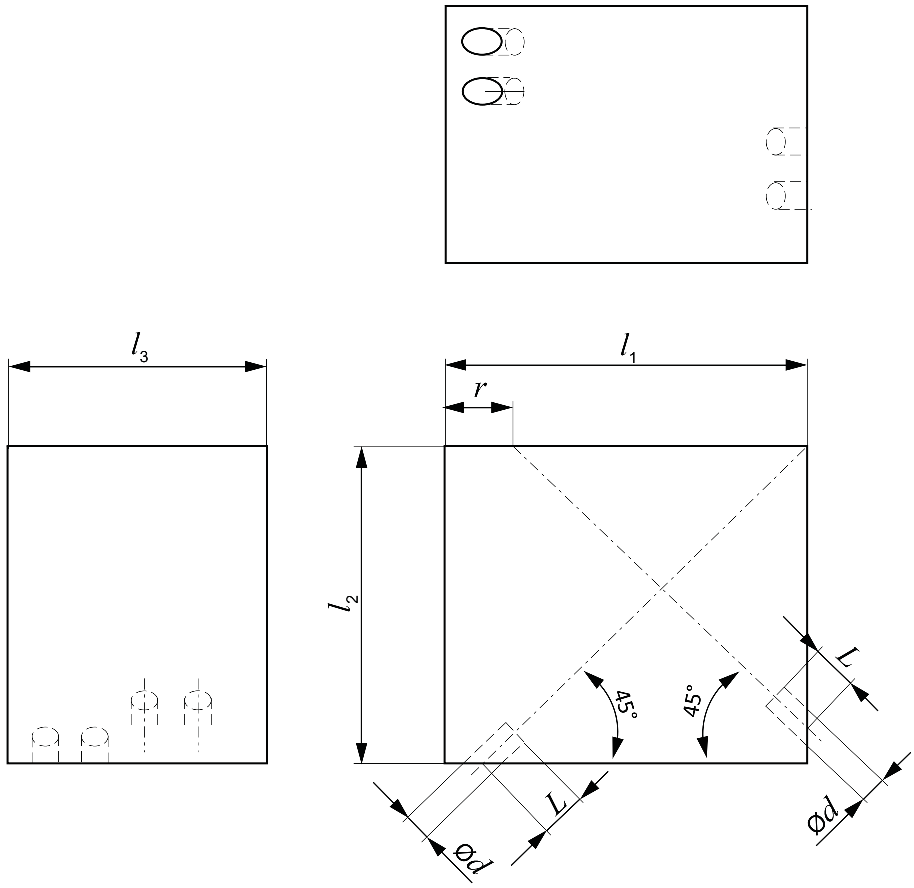


Figure A.4 — Shape and dimensions of RB-L reference block

Table A.4 — Dimensions, reflectors and beam paths of RB-L block

Reference block	**Dimensions**			**Reflector:** 45° **tilted flat-bottomed hole of the flaw diameter to be detected**			**Distance to corner**	**Beam path**
	l_1 mm	l_2 mm	l_3 mm	Ød	L mm	Number of holes	r mm	mm
RB-L	100	90	≥50	Flaw diameter	14	≥2	0	93
				Flaw diameter	14	≥2	20	107

A.2 Ultrasonic characteristic determination for top/bottom-surface incidence

A.2.1 Beam index

The beam index shall be the intersection of an extended line of the geometric centre axis of the probe and the reference block.

A.2.2 Distance-amplitude correction

For each RB-F reference block of different beam path, the respective maximum echo heights are obtained for multiple flat-bottomed holes using two-axis swivel scanning. Distance-amplitude compensation is performed by adjusting the gain so that, for each beam path, the lowest among the maximum echo heights becomes the specified echo height. This correction is applied for both top/bottom- and side-surface incidence. In the case of side-surface incidence, incident-plane compensation is applied later.

A.2.3 Determination of apparent widths of beam spread

A.2.3.1 Apparent planar width of beam spread

For each RB-F reference block of different beam path, the maximum echo height is obtained for a flat-bottomed hole using two-axis swivel scanning. Then, lateral scanning around the maximum echo height position is conducted to obtain the apparent planar beam profile for each beam path. The transverse distance is measured for each beam path between the points where the intensity drops from the maximum of the value given in Table 1. This measurement shall be carried out on all reference blocks below the necessary beam path for the required test block. The minimum traverse distance in all beam path blocks shall be the apparent planar width of beam spread in top/bottom-surface incidence.

A.2.3.2 Apparent angular width of beam spread

For each flat-bottomed hole on each RB-G reference block, the maximum echo height is obtained by plane scanning for the respective values of incident angle i_1. Then, the apparent angular beam profile is obtained for each beam path. The angular distance is measured for each beam path between the angles where the intensity drops from the maximum of the value given in Table 1. This measurement shall be carried out on all reference blocks below the necessary beam path for the required test block. The minimum angular distance in all beam path blocks shall be the apparent angular width of beam spread in top/bottom-surface incidence.

A.3 Ultrasonic characteristic determination for side-surface incidence

A.3.1 Beam index

The beam index shall be the intersection of an extended line of the geometric centre axis of the probe and the reference block.

A.3.2 Determination of apparent width of beam spread

A.3.2.1 Apparent planar width of beam spread

The apparent planar width obtained for the top/bottom-surface incidence as specified in A.2.3.1 shall be taken as the apparent planar width of beam spread in side-surface incidence.

A.3.2.2 Apparent angular width of beam spread

For each flat-bottomed hole on each RB-F reference block, the maximum echo height is obtained by R-Z scanning for the respective values of offset, o_{ff}. Then, the apparent angular beam profile is obtained for each beam path. The angular distance is measured for each beam path between the angles where the intensity drops from the maximum of the value given in Table 1. This measurement shall be carried out on all reference blocks below the necessary beam path for the required test block. The minimum angular distance in all beam path blocks shall be the apparent angular width of beam spread in side-surface incidence.

A.4 Compensation of detection sensitivity

A.4.1 Incident-plane compensation

Determine the sensitivity difference, ΔG_{P}, in normal incidence between a flat surface and a curved surface using the RB-F block with the longest beam path and the RB-G block.

A.4.2 Incident-angle compensation

Locate the maximum echo height position of the side-drilled holes in the RB-H reference block at a refraction angle that is converted geometrically to an incident angle, and carry out scanning in the hole-axis direction at this point to obtain the maximum echo height. Obtain the distance-amplitude characteristic at this angle of incidence from the echo height and beam path of the reflectors. Compare this DAC with the similarly obtained DAC of normal incidence to obtain the difference ΔG_{θ}, which is the incident-angle compensation of that angle. The value at this incident angle shall be applicable to all beam paths. However, if the compensation value is large because of a large incident angle, paths may be divided into groups to allocate individual compensation values.

A.4.3 Corner-incidence compensation

At 45° incidence to the RB-L reference block, determine the difference of sensitivity between the corner incidence and the inner-surface incidence to obtain the difference value ΔG_{C}, which represents the corner incidence compensation.

A.5 Confirmation of flaw detection in all directions

A.5.1 Angle of refraction

Confirm the detection of reflectors at the border of the dead zone in the side-surface incidence on RB-H reference blocks. Determine the maximum and the minimum angles of refraction to such reflectors and confirm that they are within the preset range of detection.

A.5.2 Beam path

Confirm the detection of reflectors at the border of the dead zone in the side-surface incidence on RB-H reference blocks. Determine the maximum and the minimum beam paths of such reflectors and confirm that they are within the preset range of detection.

A.5.3 Dead zone

Confirm the detection of reflectors at the border of the dead zone in the side-surface incidence on RB-H reference blocks.

Annex B
(normative)

Propagation-characteristic test of graphite ingot

B.1 Overview of propagation-characteristic test

B.1.1 Purpose

A graphite ingot has a particular distribution of ultrasonic propagation characteristics within a block. For this reason, it is necessary to examine each ingot to determine the attenuation characteristics and adjust the specific sensitivity to the level found in the reference blocks. This test shall be conducted before automatic ultrasonic inspection.

B.1.2 Test sequence

B.1.2.1 Bottom-echo monitoring test

This is the first test used to determine the locations at which to drill flat-bottomed reference reflectors, both in the lowest attenuation region and in the highest attenuation region. In addition, the average velocity in the test block is determined from the flight time of the bottom echo for multiple test points.

B.1.2.2 Attenuation-compensation test

This is the second test undertaken, subsequent to drilling flat-bottomed holes and after the bottom-echo monitoring test. It is intended to adjust the specified sensitivity to the level found in the reference blocks. Echo heights of flat-bottomed holes located in multiple positions are determined using two-axis swivel scanning. The coefficient of attenuation compensation, α, is obtained from the minimum value among the maximum echo heights.

B.2 Procedure for the bottom-echo monitoring test

B.2.1 Test block

The test block shall be a cylinder with 15 mm excess height, which shall be milled off before primary inspection.

B.2.2 Ultrasonic test equipment

This test shall use the same probe, water path, ultrasonic instrument and scanning equipment as those used for automatic ultrasonic inspection.

B.2.3 Bottom-echo monitoring

B.2.3.1 Scanning

Scanning shall be carried out in the Y-Z directions on the top/bottom surfaces and in the R-Z directions on the side surface.

B.2.3.2 Scanning pitch

Scanning pitch shall be 0,5 mm in the Y direction, 0,5 mm in the Z direction and 0,2° in the R direction.

B.2.3.3 Sensitivity

Test sensitivity shall be adjusted so that the maximum bottom-echo height is 100 %.

B.2.3.4 Display

The display shall be a C-scope of the bottom-echo height.

B.2.4 Wave-velocity distribution

Widely spread testing points, 16 on the top/bottom surface and 20 on the side surface, are selected in order to measure velocity. At each testing point, the difference between the arrival time of the surface echo and that of the bottom echo shall be determined at a resolution of 1 µs or better. The wave velocity shall be calculated using the diameter or height of the test block (propagation distance).

The average velocity of all testing points (36 points) shall be recorded.

B.3 Procedure for the attenuation-compensation test

B.3.1 Test block

The test block shall be a cylinder with 15 mm excess height, which shall be milled off before the flaw detection test. Referring to the C-scope bottom-echo heights obtained during bottom-echo monitoring, a flat-bottomed hole equivalent to the flaw to be detected, with a depth of 10 mm, shall be drilled in the bottom end of the test block at the position of maximum echo height, with another at the position of minimum echo height, and multiple holes in the low-echo-height region.

B.3.2 Ultrasonic test equipment

This test shall use the same probe, water path, ultrasonic instrument and scanning equipment as those used for automatic ultrasonic inspection.

B.3.3 Testing procedure

The maximum echo height of each reflector shall be obtained using two-axis swivel scanning. The maximum echo height and beam path at each testing point shall be recorded.

B.3.4 Apparent attenuation-compensation rate, α

The apparent attenuation-compensation rate, α, is applied in the compensation of maximum beam path of the detection region in the determination of detection sensitivity. The value of the apparent attenuation-compensation rate, α, is obtained using the following equations:

$$\alpha = \frac{\Delta G}{2(l_3 - 10)} \quad \text{(dB/mm)}$$

$$\Delta G = -\left(G_{\text{F, max}} - G_{\text{T, min}}\right) \quad \text{(dB)}$$

where

l_3 is the height of the test block, in millimetres;

$G_{F, max}$ is the sensitivity of the test instrument at which the highest of the maximum echo heights of the flat-bottomed holes is adjusted to 80 % on the instrument display; these holes are equivalent to the flaw to be detected and are drilled in the RB-F reference block with the longest beam path;

$G_{T, min}$ is the sensitivity of the test instrument at which the lowest of the maximum echo heights of the flat-bottomed holes is adjusted to 80 % on the instrument display; these holes are equivalent to the flaw to be detected and are drilled in the test block.

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