

Methods for

Ultrasonic detection of imperfections in steel forgings

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 Compressed Air Society
- British Forging Industry Association
- British Gas plc
- British Shipbuilders
- British Steel Industry
- Electricity Supply Industry in England and Wales
- Engineering Equipment and Materials Users Association
- High Pressure Pipework Consultative Committee
- Process Plant Association
- Seamless Steel Tube Association
- Welding Institute
- Coopted experts

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

- British Valve Manufacturers Association Ltd.

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Foreword

This new edition of this British Standard has been prepared under the direction of the Iron and Steel Standards Policy Committee. It replaces BS 4124:1987 which is withdrawn. This edition introduces technical changes to bring the standard up to date but does not reflect a full review of the standard, which will be undertaken in due course. Notes for guidance on the distance gain size (DGS) diagram have been included in this edition in a new Appendix G. Reference to the withdrawn BS 3923-3 has been deleted.

Since 1967, when BS 4124-1 was first published, ultrasonic testing techniques have undergone considerable development. The use of assessment methods by which flaw detections are related to artificial defects in test blocks (e.g. flat-bottomed holes, horizontal holes and notches), for comparison and evaluation purposes, has seen widespread acceptance. In addition, the distance gain size (DGS) diagram technique of expressing flaw indications in terms of disc reflectors has found many applications and this technique therefore is included in this standard.

The possibility also of introducing acceptance levels in this revision was carefully considered, but it was decided that, because of the large number of variable factors, e.g. size of component, application, desired standard of integrity, stress levels and fracture toughness properties of many types of steels used, it was not feasible to produce acceptance levels that would meet the requirements of all parties. Consequently, it will be necessary for acceptance levels to be agreed between the parties concerned when they are not specified in the appropriate product standards.

An objective in this standard has been to enable its users to draw up appropriate procedures to cover their own specific requirements. Attention is drawn to the last paragraph of clause 1, from which it will be evident that it is necessary that, when reference to this standard is made in an enquiry or order, requirements governing the procedures to be adopted and acceptance levels to be met are clarified between the contracting parties.

It is important to recognize that non-destructive testing methods are generally complementary to one another and therefore should be considered collectively in relationship to testing as a whole, so that the most suitable methods are employed and the extent of the inspection is compatible with the ultimate application of the product.

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 20, 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.

0 Introduction

Ultrasonic testing involves the reflection of a high frequency beam of sound by internal imperfections in a piece of material and is complementary to magnetic particle and dye penetrant testing. It is capable of examining much greater thicknesses of material than is possible with X-ray and gamma ray techniques and is generally a much more sensitive and versatile method.

The ultrasonic testing technique selected in any particular circumstance is governed by the degree of confidence required that all significant imperfections in specific parts of the material under test can be detected. No ultrasonic test can give a completely unequivocal answer. Experience and the degree of confidence sought determine how detailed an examination is required and these factors will normally be taken into account in a technique sheet detailing the types of probe(s), scanning coverage, etc. to be used.

This standard is predominantly intended for the examination of machined forgings after completion of the final heat treatment. The inspection techniques are governed by the geometry of the forging under test. If the ultrasonic coverage is restricted by the geometry of the component in its final heat treated and/or finish machined condition, then the principal test is conducted at an intermediate stage of machining or production when the component presents a simple geometric form.

NOTE 1 It may only be possible to obtain a limited test result on forgings examined at intermediate stages of heat treatment where structural refinement has not occurred.

NOTE 2 There is a possibility of the introduction of defects during subsequent heat treatment.

NOTE 3 Knowledge of the method of manufacture of the component assists in the correct interpretation of the results of the examination.

NOTE 4 Special consideration should be given to zones affected by changes of section and radii.

The minimum extent of scanning coverage is described in **6.6**; the precise degree of testing may be agreed between the parties concerned depending upon, for example, whether the test is a final examination of an important component, whether it is desired to detect extremely small imperfections, or whether the test is designed to indicate if a component is suitable for further processing having been shown to be free from significant imperfections in certain areas.

1 Scope

This British Standard describes four methods for the ultrasonic testing of ferritic and austenitic steel forgings using A-scope pulse echo ultrasonic equipment, under surface contact and manual operation conditions, for the detection of imperfections. It gives descriptions of equipment and its use including methods of setting the test sensitivity and of assessing the size of imperfections.

Although the techniques described are applicable to both ferritic and austenitic materials, the test may be limited on austenitic steels since they may possess a coarse grain size that cannot be refined by heat treatment (see note 1 in Appendix D).

It is important for users of this British Standard to recognize that all the requirements to be met for compliance are specified in the main body of the standard and that, in certain instances, these are minimum requirements only. Several additional aspects, however, are referred to as the subject of agreement between the contracting parties or to definition by the purchaser. For these, it is essential that the purchaser establishes clearly at the outset, with the agreement of the supplier, the precise nature and extent of his requirements. Information and guidance in these matters are given in Appendix A, Appendix B and Appendix C.

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

2 Definitions

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

2.1

imperfections

discontinuities that cause ultrasonic indications

2.2

flaws

imperfections “detected” at the testing sensitivity that, when evaluated, meet the agreed acceptance criteria

2.3

defects

imperfections “detected” at the testing sensitivity that, when evaluated, do not meet the agreed acceptance criteria

3 Principle

3.1 General

An ultrasonic beam, transmitted through the forging from a surface contact probe, is reflected by internal imperfections. Detection of the reflection enables the depth, location and size of an imperfection to be established and thereby permits the imperfection to be assessed as either a flaw or a defect.

The four techniques for the detection and assessment of imperfections described in this standard are listed in **3.2** to **3.5**.

3.2 20 dB drop technique

The relatively sudden fall in the intensity of the acoustic energy near to the perimeter of the ultrasonic beam permits a beam profile to be plotted. From the profile, the – 20 dB contour, relative to the axial intensity of the beam, is known at any depth. By means of the – 20 dB contour, the edge of an imperfection can be related to the position of the probe on the surface of the forging.

The 20 dB drop technique is suitable for the detection and assessment of imperfections in rectangular forgings. It may also be used to assess the longitudinal dimension of an imperfection in a cylindrical forging, but may assess the circumferential dimension of an imperfection incorrectly.

The 20 dB drop technique is an appropriate technique for assessing imperfections less than the probe crystal size and having a dimension, in the test direction of probe movement, greater than 5 mm.

The 20 dB drop technique has the advantage that results are independent of attenuation.

3.3 6 dB drop technique

When half the ultrasonic beam strikes an imperfection and the other half passes it, the echo amplitude is reduced by 6 dB from the maximum echo amplitude obtainable. This fact enables the periphery of an imperfection to be established with respect to the beam axis at the depth of the imperfection.

The 6 dB drop technique is also suitable for the detection and assessment of imperfections in rectangular forgings and for assessing the longitudinal dimension of an imperfection in a cylindrical forging. However, like the 20 dB technique (see **3.2**), it may assess incorrectly the circumferential dimension of an imperfection in a cylindrical forging.

The 6 dB drop technique is suitable for assessing the size of an imperfection that is near to, or larger than, the probe crystal dimension.

The 6 dB drop technique has the advantage that the results are independent of attenuation.

3.4 Distance amplitude technique using reference blocks

The response from an imperfection is compared with that from known reflectors, at known depths in a test block, enabling the location and size of the imperfection to be assessed.

The distance amplitude technique is suitable for the detection and assessment of imperfections in forgings of most shapes and sizes. It is an appropriate technique for assessing imperfections smaller than the probe crystal diameter in forgings where the beam path length can be conveniently reproduced in reference blocks.

3.5 Distance gain size (DGS) technique

The distance gain size (DGS) technique is similar in principle to the distance amplitude technique using reference blocks (see **3.4**) without the need for reference test blocks. A DGS diagram such as shown in Figure 2 indicates, by means of a number of distance-amplitude curves for various ideal disc reflectors, the relationship of the intensity of the sound reflection from different diameter reflectors at varying distances to the back wall echo (see **7.5**). The diagram is related to attenuation free material.

The DGS technique is suitable for the assessment of imperfections in forgings of all shapes and sizes. It is suitable for assessing the size of an imperfection of dimensions up to that of the probe crystal, the size being described in terms of an equivalent ideal disc shaped reflector.

4 Equipment

The ultrasonic testing equipment shall be capable of working at test frequencies within the range 0.5 MHz to 6 MHz and shall feature an A-scope presentation. The trace shall be well defined and associated with permanent graticule scale markings or both depth range and echo amplitude.

NOTE The probe type and probe frequency are subject to agreement between the contracting parties and should be stated on the technique or procedure sheet [see Appendix C, item d)]. For guidance concerning probe frequency, see Appendix D.

5 Surface condition

5.1 General

The minimum requirements for the test surface condition shall be as specified in **5.2** and **5.3**.

NOTE If the purchaser requires a special surface finish, this should be stated on the enquiry, order or drawing [see **B.2 l**] and on a technique or procedure sheet [see **B.2 l**] and Appendix C g)].

5.2 Unmachined forgings

The test surface of unmachined forgings shall be clean and free from loose scale, to ensure that acoustic coupling is maintained.

NOTE 1 It is generally impracticable to carry out a comprehensive examination on unmachined forgings. Therefore, while unmachined forgings may be subjected to a preliminary examination, it is usually necessary for the final examination to be carried out between machining stages.

NOTE 2 It may be necessary for the contracting parties to agree to shot blasting, or surface grinding to metallic brightness of an agreed array of longitudinal/circumferential paths.

5.3 Machined forgings

The surfaces of machined forgings to be scanned shall be machined to a surface finish of $6.3 \mu\text{m } R_a$ or better, as assessed by the method given in BS 1134-1.

NOTE 1 A surface finish having an appearance resembling that of a gramophone record, i.e. with regular, sharp ridged grooves, may cause spurious indications.

NOTE 2 Surface tears should be avoided.

6 Requirements for testing

6.1 General

The inspection procedures shall be carried out in accordance with the details given in 6.2 to 6.7 and clause 7.

NOTE It is essential that personnel conducting ultrasonic testing be trained personnel who have proved their competence to perform the examination. If the purchaser requires that the operator has an agreed, minimum level of competence, this should be stated [see B.2 a)].

6.2 Coupling medium

Interpose a coupling medium between the probe and forging to allow efficient transmission of ultrasound. The same medium shall be used for the calibration of the equipment and for the examination of forgings.

NOTE Suitable coupling media are oil, grease, glycerol and water/cellulose paste

6.3 Procedures for checking and calibrating the equipment

6.3.1 General

Check the equipment and calibrate it in accordance with the procedures given in 6.3.2 to 6.3.7.

6.3.2 Linearity of time base

Check the linearity of the time base at least once weekly and formally record the results. The procedure for calibration and the deviation tolerances shall be as given in 5.1, 5.2 and 5.3 of BS 4331-1:1978.

6.3.3 Calibration of time base

Calibrate the time base on each of the following occasions:

- a) the beginning of a working period;
- b) whenever the probe is changed;
- c) after any period during which the power to the equipment has been switched off;
- d) after a change of testing range.

Perform the calibration either as described in 6.1 and 6.2 of BS 4331-1:1978 or, when geometry permits, by using a suitable measured section of the forging under test. The calibration tolerance shall be as given in 6.3 of BS 4331-1:1978.

6.3.4 Linearity of equipment gain

Check the linearity of the equipment gain at least once weekly and formally record the results. The procedure for calibration and the deviation tolerance shall be as given in 7.1, 7.2 and 7.3 of BS 4331-1:1978.

6.3.5 Sensitivity and signal-to-noise ratio

Check the sensitivity and signal-to-noise ratio at least once per day for each probe to be employed for testing, using the method described in 10.1 and 10.2 of BS 4331-1:1978. The calibration tolerance shall be as given in 10.3 of BS 4331-1:1978.

6.3.6 Resolution

The ultrasonic instrument/probe shall be capable of clearly resolving adjacent targets when their separation in depth along the beam axis is equal to or less than twice the wavelength. Resolution shall be checked monthly in accordance with 14.2 of BS 4331-3:1974.

6.3.7 Probe dead zone

Measure the dead zone of each test probe monthly, by the method described in 9.2.1 of BS 4331-3:1974. Any dead zone deviation which would adversely affect the examination of the forging shall be cause for withdrawal of the probe.

6.4 Probe characteristics

6.4.1 Establish the probe characteristics given in a) to c) only where imperfections are to be located accurately or assessments are to be carried out in accordance with 7.2 and 7.3.

- a) *Probe index and beam angle.* Determine the probe index and beam angle for shear wave probes using the methods described in clauses 4 and 5 of BS 4331-3:1974.
- b) *Beam alignment.* Determine the beam alignment (squint) for shear wave and compression wave probes using the method described in clause 13 of BS 4331-3:1974.

c) *Beam profile*. Establish the beam profile for compression wave and shear wave probes where measurements or assessments are to be carried out by probe movement in accordance with the 20 dB drop technique described in 7.2. The method described in clause 6 and A.2.1 of BS 4331-3:1974 shall be used.

6.4.2 Establish the probe characteristics given in a) and b) where imperfections are to be evaluated by the distance gain size (DGS) technique described in 7.5.

a) *Near field*. Measure the near field by the method described in clause 10 of BS 4331-3:1974.

b) *Dominant frequency*. Where the dominant frequency of the probe is not certified by the manufacturer, measure the dominant frequency before the probe is put into service using the procedure given in clause 7 of BS 4331-3:1974.

6.5 Scanning speed and scanning index

6.5.1 Scanning speed

The scanning speed shall not exceed 150 mm/s.

6.5.2 Scanning index

The scanning index (i.e. the crystal path overlap/overlay) shall be at least 10 % of the scanning crystal diameter/dimension.

NOTE If the purchaser reburies a specific scanning index or scanning speed within the provisions specified in 6.5.1 and 6.5.2 this should be stated on the enquiry, order or drawing [see B.2 e)] and on the technique or procedure sheet [see Appendix C , item h)].

6.6 Scanning coverage

NOTE See notes 1 and 2 to 5.2 concerning limitations due to surface condition on unmachined forgings.

6.6.1 General

The minimum scanning coverage shall be in accordance with 6.6.2 to 6.6.7.

NOTE 1 If the purchaser requires extra scanning, this should be stated clearly on the enquiry, order or drawing [see B.2 f)] or on a technique or procedure sheet [see Appendix C , item i)].

NOTE 2 For complex forgings and small diameter forgings it may be necessary to develop and agree special techniques including the use of contoured probes. Where possible, examination should take place at the stage of manufacture which presents the simplest geometrical outline.

NOTE 3 If circumferential angle tests are specified the depth examined is limited. The axis of a 35° probe can cover up to a depth of $0.213 \times$ the diameter of the component. The factors for 45°, 60° and 70° probes are 0.146, 0.067 and 0.030 respectively. This applies to both solid and hollow cylinders.

NOTE 4 In the case of both cylindrical and rectangular forgings (see 6.6.2 and 6.6.3) which are to be bored, it is often desirable to carry out the ultrasonic examination while the forging is still solid.

6.6.2 Cylindrical forgings longitudinally forged

6.6.2.1 Solid

Examine solid forgings over a minimum angle of 180° round their periphery, along their entire length, using a compression wave probe(s) with a 0° angle of incidence.

6.6.2.2 Bored

Examine bored forgings over 360° round their periphery, along their entire length, using a compression wave probe(s) with a 0° angle of incidence.

6.6.2.3 Solid and bored

Where practicable, also examine both solid and bored forgings in a longitudinal direction, using either compression or angle probes, as appropriate to forging geometry.

6.6.3 Rectangular forgings, longitudinally forged

6.6.3.1 Solid

Examine solid forgings from at least three mutually adjacent faces over their complete surface using a compression wave probe(s) with a 0° angle of incidence.

6.6.3.2 Bored

Examine bored forgings from all six faces over their entire surface, using a compression wave probe(s) with a 0° angle of incidence.

6.6.4 Multi-sided forgings

Examine multi-sided forgings from all faces, using a compression wave probe(s) with a 0° angle of incidence.

6.6.5 Upset forgings

In cases where the final forging involves an upsetting operation, examine the forging through the thickness using a compression wave probe(s). Where practicable, carry out compression wave examination round a minimum of 180° of the periphery of unbored forgings and 360° of bored forgings. Use angle probes where the shape of the forging prevents a comprehensive examination with compression wave probes. In such instances, carry out scanning with angle probes, from the same face in both a radial and tangential direction.

6.6.6 Hollow forgings

Examine hollow forgings over 360° round their periphery, along their entire length, using a compression wave probe(s) with a 0° angle of incidence.