

BRITISH STANDARD : AEROSPACE SERIES

METHOD FOR

ULTRASONIC TESTING OF SPECIAL FORGINGS

BY AN IMMERSION TECHNIQUE USING

FLAT-BOTTOMED HOLES AS A

REFERENCE STANDARD

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FOREWORD

This British Standard, prepared at the request of the Aerospace Industry Standards Committee, is one of a series for the non-destructive testing of aerospace materials, components and structures. Others in this series will cover radiographic, magnetic particle, etch and penetrant inspection methods.

The standard describes the procedure and specifies the equipment for detecting internal flaws in special forgings using an ultrasonic immersion technique. Since suitable flat-bottomed hole standards already exist in the aluminium alloy master reference blocks retained by the Aeronautical Quality Directorate, these have been used as reference standards. Procedures are accordingly described which permit flaw size estimation in alloys other than aluminium to be carried out in terms of the standard blocks.

It should be appreciated that the technique described in this standard has inherent limitations due to the unpredictable variations in echo amplitude measurement. This standard, whilst recognizing these limitations, has been prepared to establish a procedure which has considerable acceptance in the aerospace field, pending the possible preparation of further standards in the aerospace series for ultrasonic testing using the DGS (or AVG) diagram and 'traverse' methods.

The units of the SI have been adopted as standard, but, as appropriate, the equivalent imperial units are quoted in parentheses.

This standard makes reference to the following:

British Standards:

BS 1134. Centre-line-average height method for the assessment of surface texture.

BS 3683. Glossary of terms used in non-destructive testing.

Part 4. Ultrasonic flaw detection.

BS 4000. Sizes of papers and boards.

**Ministry of Defence Specifications:*

DEF 151. Anodising of aluminium.

**Ministry of Technology Specifications:*

DTD 5044. Aluminium - zinc - magnesium - copper - manganese alloy bars and extruded sections.

DTD 5054. Aluminium - zinc - magnesium - copper - chromium alloy bars and extruded sections.

METHOD

1. GENERAL

1.1 SCOPE

1.1.1 This British Standard applies to the ultrasonic inspection by an immersion technique of special forgings used primarily for rotating parts, e.g. turbine discs. It accordingly describes the method of testing by which the acceptability of such forgings can be assessed, and specifies flat-bottomed hole reference standards, apparatus requirements, and control and test procedures.

1.1.2 The method, which is confined to pulse echo techniques and the use of single crystal transceiver probes, is limited to use on forgings having a thickness of not less than twice the near surface resolution of the probe (as determined in 2.1.4) which lend themselves, by virtue of their form, to mechanical scanning in which the incident beam is approximately normal to the surface of the section being scanned.

1.1.3 The method is primarily intended and recommended for use on forgings when these are in the raw material state only. However, it can be used during manufacture on machined or part-machined components, provided that these components comply with the shape and thickness described in 1.1.2.

1.1.4 By agreement, the standard may also be used for tests on other types of forgings and wrought forms manufactured in all metallic materials, in which case due allowance has to be made for the differences in ultrasonic attenuation and transmission factors presented by each material.

Factors affecting the apparent flaw size when estimated by comparison with the reference standards, and procedures which will enable due allowance to be made for them are described.

1.2 DEFINITIONS

For the purposes of this British Standard the terms and definitions given in BS 3683, Part 4, apply together with the following:

N-point. The position in an ultrasonic beam where the intensity of sound on the beam axis reaches a final maximum before beginning a uniform reduction with distance.

N-distance. The distance from the probe to the *N-point*.

In addition, 'by agreement' means that specific agreement has been reached between the purchaser and the supplier, and any inspecting authority concerned.

1.3 DESCRIPTION OF TECHNIQUE

The technique employed is one in which both probe and product under test are immersed in a coupling medium, normally water, and the surface of the section under test is mechanically scanned by a pulsed ultrasonic compression wave beam normal to the surface. Echoes from any flaws present in the material are returned to the probe and are shown as indications on the screen of the flaw detector.

* Obtainable from H.M.S.O.



Amendment No. 1
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Method for ultrasonic testing of special forgings
by an immersion technique using flat-bottomed
holes as a reference standard

Revised text

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Clause 2.4.2 Operator

Delete the footnote associated with this clause and substitute the following:

For British civil and military aircraft; the approving authorities are the Civil Aviation Authority and the Ministry of Defence (Procurement Executive) (through an authority approved by them).

Provision may be made for these indications to be permanently recorded where this is possible. Flaw echo amplitudes are related to a reference standard and may be recorded as decibels above or below this reference. An 'A-scope' presentation shall normally be used.

2. OPERATIONAL REQUIREMENTS

2.1 ULTRASONIC FLAW DETECTOR AND PROBE

2.1.1 Operating frequency range. The equipment shall be capable of operating at the frequency, or frequencies, selected by agreement as being suitable for the test.

2.1.2 Sensitivity. The overall probe/flaw detector combination sensitivity at the selected frequency or frequencies shall be such that the smallest standard target, at the minimum and maximum distances relevant to the application, gives an echo indication of at least half screen height with sufficient sensitivity in reserve to allow full compensation to be made for material attenuation in the section to be inspected; see Appendix D.

2.1.3 Linearity of amplification. When using a calibrated attenuator, linearity of amplification is not of prime importance; however, a signal 18 dB below the relevant standard target shall be easily identified on the screen.

2.1.4 Near surface resolution. When set at the working conditions, i.e. at the working sensitivity and using the optimum couplant gap for inspection (see also Appendix E, Fig. 12), the resolution test block described in C.2 shall be scanned along its length to assess the near surface resolution of the equipment. For satisfactory resolution, the echo from the hole should separate from that from the surface echo at a point not less than 12 dB below the datum point as illustrated in Fig. 8 in C.2. In cases where the component can only be inspected from one face, the near surface resolution shall be equal to or better than 7.5 mm (hole 5 in the resolution test block). If the material attenuation and/or grass level is such that inspection at a low ultrasonic frequency is necessary, the resolution requirement may be eased to suit the application, but, in any case, it should be measured by reference to one of the deeper holes in the block and known for the operating conditions selected.

NOTE. Where high energy levels are necessary for dealing with either thick material or attenuating conditions, the resolution test block may not be sufficiently thick for assessing near surface resolution.

2.1.5 Linearity of flaw detector time base. The time base shall, as far as practicable, be linear and for critical examination any deviation should preferably not exceed 1 % over the full width of the screen.

2.1.6 Flaw detector controls. Means of regulating the following parameters shall be provided:

- (1) trace brightness,
- (2) trace focus,
- (3) trace vertical position,
- (4) trace horizontal position,
- (5) time base speed (coarse or fine control),
- (6) time base delay,
- (7) frequency,
- (8) amplifier gain (uncalibrated),
- (9) pulse repetition frequency,
- (10) amplifier input, by means of a constant impedance matched attenuator capable of inserting not less than 60 dB in 2 dB steps. The attenuator control should

preferably be provided with an adjustable zero such that decrease or increase of attenuation reads negative and positive respectively about a preset point.

NOTE. Flaws smaller than the standard will be expressed as negative readings.

2.1.7 Probe calibration. The user of the equipment shall measure the operating frequency of the probe in conjunction with the flaw detector to be used. (A suitable method of measuring the operating frequency is to examine quantitatively the wave form at the input to the video amplifier using a calibrated time base.) The distance-amplitude curve shall also be determined by the method described in Appendix E. The relevant portion of the curve shall be checked at the commencement of each shift in order to ascertain that the position of the *N*-point has not significantly changed.

2.2 IMMERSION TANK AND PROBE MANIPULATOR

The immersion tank and probe manipulator shall be appropriate to the size and type of product to be examined. The unit shall be equipped so that the following requirements are met.

2.2.1 The probe holder shall be capable of all articulated movements necessary to align the probe axis perpendicular to the surface of the product to be inspected.

2.2.2 If, by agreement, it is necessary to meet the requirements of 4.3, the probe holder shall allow not less than 9° tilt in any plane and shall also be capable of rotation about a vertical axis through the flaw in order to allow accurate alignment of the beam with the apparent inclination of the flaw. The movements shall be fitted with calibrated controls to enable the exact angle of tilt to be determined to within $\pm \frac{1}{2}^\circ$ of arc.

2.2.3 The relative distance between the probe and the product being inspected shall be independently variable without affecting the alignment of the other controls.

2.2.4 Notwithstanding the method of scanning employed, the distance between the probe and the surface of the product being examined shall be capable of being maintained, once set, so that the out-of-parallelism between the surface of entry and the plane formed by the relative movement of the probe does not exceed $\frac{1}{2}^\circ$ in any direction in that plane.

2.3 ANCILLARY EQUIPMENT

In addition to the requirements of 2.1 the following ancillary equipment may also be utilized by agreement.

NOTE. It should be appreciated that both of the automatic flaw alarms and flaw recording systems described operate solely on the basis of indications on the display exceeding a particular preset height. Since the height of the indication on the display is dependent upon both the size of a particular flaw and its depth below the material surface, it is not possible for this equipment to function at a particular flaw size. The errors involved in the indiscriminate use of either piece of equipment can be considerable and are dependent upon the thickness of the item being inspected.

2.3.1 Automatic flaw alarm. This apparatus shall present either a visual or audible alarm when an indication on the flaw detector display or the flaw signal exceeds a particular preset level.

2.3.2 Automatic recording. By this means a permanent record either in the form of a facsimile or a chart recording of the inspection shall be obtained. The recording instrument shall be electronically coupled to the flaw detector in order that the recorder registers any indications on the display above a certain predetermined height.

2.3.3 Monitoring. Whenever an automatic system is relied upon for the recognition and recording of flaw signals, it shall be verified that the efficiency of the entire flaw detection system is maintained at all times during the test. This requirement may be fulfilled by continuously observing, for example, that the amplitude of the first back surface echo displayed on the cathode-ray screen never suffers more than a certain reduction in amplitude, or by installing an ancillary alarm system arranged to interrupt the test when an operational fault occurs.

2.4 APPROVALS

2.4.1 Equipment. It shall be demonstrated that the equipment complies with the requirements of 2.1, 2.2 and 2.3.

2.4.2 Operator. The operator shall be adequately instructed and supervised by a person approved by the purchaser and the appropriate approving authority*.

3. REFERENCE STANDARDS

3.1 GENERAL

Reference standards shall be used for setting the sensitivity of the equipment and for evaluating the apparent size of flaws. It is emphasized that the overall sensitivity depends on the probe/instrument combination and setting. Changes of probe and instrument shall not be made without recalibration.

3.1.1 Master reference blocks. The ultimate standards for aluminium alloy products are the master reference blocks retained by the Aeronautical Quality Directorate which are described in Appendix C.

3.1.2 Standard reference blocks. Standard reference blocks are to take the form of aluminium alloy blocks of specified size, containing flat-bottom hole targets as shown in Appendix C, Fig. 6. The response of the standard blocks relative to that of the corresponding master reference blocks shall be known.

3.1.3 Working reference blocks. For routine inspection, instrument adjustment and classification of flaw size, working reference blocks may be used. These blocks may be manufactured of aluminium or steel, but other materials should not be used due to unpredictable variations in attenuation characteristics. They may be of cylindrical form, but shall have a minor sectional dimension of not less than 75 mm. The blocks shall be compared at the testing frequency with standard reference blocks. Any deviation shall not be more than 3 dB from the standard reference block and shall be noted.

3.1.4 Materials other than aluminium alloys. When products manufactured in material other than aluminium alloys are to be tested, the standard reference blocks shall be of the material, form and dimensions shown in Appendix C, Fig. 6. The acceptance level shall be stated in terms of these reference blocks and due allowance made for the difference in the acoustic properties of the materials (see 1.1.4 and Appendix D).

3.2 USE OF REFERENCE BLOCKS

As a preliminary to the inspection procedure, reference blocks shall be used to adjust the instrument sensitivity to the working level as follows.

* For British civil and military aircraft the approving authorities are the Air Registration Board (through an authority approved by the Board) and the Ministry of Technology, respectively.

3.2.1 The appropriate reference block shall be positioned in the immersion tank so that the appropriate surface:

- (1) can be fully scanned by the probe,
- (2) maintains a constant angle to the axis of the beam,
- (3) maintains a constant distance from the probe.

3.2.2 The probe distance shall be adjusted to the optimum couplant gap (see Appendix E, Fig. 12).

3.2.3 Where a manual suppression control or similar device is fitted to the instrument it shall be set to, and left at, the zero or 'off' position.

3.2.4 The instrument sensitivity, delay controls, etc., shall be set so that the first echo from the top surface of the block is visible on the screen and has an amplitude of about $\frac{1}{2}$ screen height.

3.2.5 The angle of the probe shall be adjusted to maximize the top surface echo.

3.2.6 The instrument controls shall, if necessary, be adjusted until the indication from the reference hole is visible on the screen; the probe carriage shall then be moved until the maximum indication from the hole is obtained.

3.2.7 The instrument sensitivity shall be adjusted so that the indication from the reference hole is at a fixed datum level between 50 % and 70 % of full screen height. Without adjusting the sensitivity, the attenuator scale shall be set to read zero. If this facility is not available the attenuator setting shall be noted.

4. INSPECTION PROCEDURE

4.1 GENERAL

4.1.1 Surface condition. The surface of the workpiece to be scanned shall be free from any condition, local or general, which will prevent ultrasonic examination to the required standard. Such conditions may be caused by damage marks, hardness test indentations, fettling and stamped identification marks, laps, folds, etc.

Normally, the surface finish for immersion testing should be better than 6.3 μm (250 μin) CLA as defined in BS 1134.

Where special surface conditions are required for the purpose of ultrasonic examination, these shall be specified on the relevant drawing.

4.1.2 Preliminary setting-up procedure. The preliminary setting-up procedure shall be as follows.

4.1.2.1 The product shall be positioned in the immersion tank in order that the appropriate surface:

- (1) can be fully scanned by the probe,
- (2) maintains a constant angle to the axis of the beam,
- (3) maintains a constant distance from the probe.

4.1.2.2 Where a manual suppression control or similar device is fitted to the instrument, it shall be set to, and left at, the zero or 'off' position throughout the examination.

4.1.2.3 The sensitivity shall be set to the working level in the manner described in 3.2. When necessary, see 1.1.4 and 3.1.4, the sensitivity shall be adjusted to cater for the differences in the ultrasonic attenuation and transmission factors determined by the method given in Appendix D. Once set, it shall not be re-adjusted during subsequent scanning. The instrument settings shall be such that the relevant holes in the reference blocks can be detected and discrimination obtained between them.

4.1.3 Probe adjustment

4.1.3.1 The probe height shall be re-adjusted to the optimum couplant gap (see Appendix E, Fig. 12).

4.1.3.2 The angle of the probe shall be adjusted so that the echo from the near face of the product is a maximum.

4.1.3.3 Where the surface of the product is stepped, the couplant gap shall be correct for that portion of the surface nearest to the probe. Where the step exceeds 10 % of the *N*-distance the probe shall be re-positioned to the optimum water gap before examining the stepped portion.

4.1.4 Scanning procedure³

4.1.4.1 Unless otherwise agreed, the required area shall be scanned by one of the following methods, as appropriate.

(1) *Concentric scanning*. The product shall be rotated about its axis. After each revolution and before continuing the next, the probe shall be removed through a radial distance of not more than 3 mm ($\frac{1}{8}$ in).

(2) *Spiral scanning*. The product shall be rotated about its axis and the probe moved continuously in a radial direction so that the distance moved in one revolution of the product does not exceed 3 mm ($\frac{1}{8}$ in).

(3) *Helical scanning*. The product shall be rotated about its longitudinal axis and the probe moved parallel to that axis so that the distance moved in one revolution of the product does exceed 3 mm ($\frac{1}{8}$ in).

(4) *Rectilinear scanning*. The probe shall be moved backwards and forwards over the surface being scanned and parallel to one side, usually the longest, of that surface, each sweep being separated from the previous one by not more than 3 mm ($\frac{1}{8}$ in).

4.1.4.2 Unless automatic recording is employed, the linear speed of the probe relative to the product shall not exceed 10 m (30 ft) per minute. Attention is drawn to the limiting effects of pulse repetition frequency.

4.1.4.3 In order to ensure that the full volume of the workpiece is effectively examined it shall be scanned, when necessary, over more than one face. The number and identity of the faces of which examination is to be made shall be noted upon the relevant drawing.

4.2 DETERMINATION OF FLAW PARAMETERS

4.2.1 General

4.2.1.1 When a flaw has been located in the component under test the following parameters related to it shall be determined in the order given.

- (1) Position of the flaw (refer to 4.2.2).
- (2) Depth of the flaw below the surface (refer to 4.2.3).
- (3) Equivalent flat-bottomed hole (refer to 4.2.4).

4.2.1.2 When the plan position of the flaw has been determined the flaw shall be given an identification number and its position, in relation to an agreed and preset datum, shall be measured and recorded.

4.2.1.3 When specified on the contract or order, all indications of amplitude between those of the acceptance standard and 12 dB below that standard, or any sudden drop in the bottom echo, shall be subjected in addition to special investigation in accordance with 4.3.

NOTE. When a sudden drop in bottom echo occurs unaccompanied by a flaw indication it is advisable first to re-normalize the probe to the surface of the product to ensure that the drop is not due to a local change in surface angle.

4.2.2 Plan position of flaw. The recommended method for determining the plan position of the flaw is as follows.

(1) With the probe correctly positioned normal to the workpiece and the sensitivity set at standard, the maximum echo amplitude shall be obtained using movements parallel to the workpiece surface only.

(2) A thin sheet of acoustically absorbent material, such as 2 mm thick acrylic sheet, shall be introduced across the workpiece surface, adjacent to the defective area and supported obliquely.

(3) The plastics sheet shall be slid under the probe to a position where the echo is reduced to half amplitude and a line drawn on the surface of the workpiece along the leading edge of the sheet.

(4) The above procedures shall be repeated for two other directions of approach.

If these procedures are carefully carried out, the three lines will intersect at a point directly above the defect.

4.2.3 Depth of flaw. The following are the two recommended methods for determining the depth of the flaw.

4.2.3.1 The flaw detector trace shall be calibrated against a known thickness of material which has the same acoustic properties as the material under test. The flaw depth shall then be obtained directly from the screen graticule. When calibrating, several repeated bottom echoes from the standard block shall be used to obtain the necessary degree of accuracy.

4.2.3.2 The distance between the top surface and flaw echo shall be compared with distance between top and bottom surface echoes. This will give the ratio of flaw depth to total thickness, from which the actual flaw depth shall be calculated after the total thickness has been determined.

4.2.4 Equivalent flat-bottomed hole

4.2.4.1 It is not possible to determine the actual size of a flaw by comparison of the maximum indication obtained from it with that obtained from the reference standard: this comparison only determines the size of the equivalent flat-bottomed hole.

4.2.4.2 After a flaw has been located in the component under test, its indicated size shall be classified by a direct comparison of the amplitudes of indication received from it and from the appropriate hole in a test block. When classifying any one flaw in this way by use of the calibrated attenuator, the probe arrangement, testing frequency and instrument settings shall remain the same throughout.

4.2.4.3 When classifying the size of a flaw the sensitivity of the instrument shall be so adjusted that the indications are easily compared at the datum level (see 3.2.7). Use should be made of the calibrated attenuator and the indicated size recorded as decibels, above or below the nearest reference hole, corrections being made, when necessary, for differences in response and acoustic properties between the master reference blocks and those in use (see 3.1 and Appendix D). Additional adjustments in the recorded size of the flaw should be made to take account of any difference in acoustic properties between the material under test and the material used for the standard test blocks.

4.2.4.4 If flaw evaluation is essential, a probe with a *N*-point is used so that the flaw to be evaluated is situated in the far zone of the probe. Failure to observe this condition may result in false evaluation of the flaw because of