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Second edition
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Non-destructive testing — Equipment for eddy current examination —

Part 2: Probe characteristics and verification

Essais non destructifs — Appareillage pour examen par courants de Foucault —

Partie 2: Caractéristiques des capteurs et vérifications

Reference number
ISO 15548-2:2013(E)

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Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2. www.iso.org/directives

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

The committee responsible for this document is ISO/TC 135, *Non-destructive Testing*, Subcommittee SC 4, *Eddy current methods*.

This second edition cancels and replaces the first edition (ISO 15548-2:2008), of which it constitutes a minor revision.

ISO 15548 consists of the following parts, under the general title *Non-destructive testing — Equipment for eddy current examination*:

— *Part 1: Instrument characteristics and verification*

— *Part 2: Probe characteristics and verification*

— *Part 3: System characteristics and verification*

Non-destructive testing — Equipment for eddy current examination —

Part 2:
Probe characteristics and verification

1 Scope

This part of ISO 15548 identifies the functional characteristics of a probe and its interconnecting elements and provides methods for their measurement and verification.

The evaluation of these characteristics permits a well-defined description and comparability of eddy current equipment.

By careful choice of the characteristics, a consistent and effective eddy current examination system can be designed for a specific application.

Where accessories are used, these should be characterised using the principles of this part of ISO 15548.

This part of ISO 15548 does not give the extent of verification nor acceptance criteria for the characteristics. These are given in the application documents.

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 12718, *Non-destructive testing — Eddy current testing — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12718 apply.

4 Characteristics of probe and interconnecting elements

4.1 General characteristics

4.1.1 Application

Probes and interconnecting elements are selected to satisfy the requirements of the intended application.

The design is influenced by the instrument with which they are used.

4.1.2 Probe types

The probe is described by the following:

— type of material to be examined, i.e. ferromagnetic or non-ferromagnetic, with high or low conductivity;

— function, e.g. separate or combined transmit/receive probe;

— family, e.g. coaxial probe, surface probe;

— measurement mode, e.g. absolute, differential;

— purpose of the examination, e.g. detection of discontinuities, sorting or thickness measurement, etc.;

— specific features, e.g. focused, shielded, etc.

4.1.3 Interconnecting elements

They may include the following:

— cables and/or extensions;

— connectors;

— slip rings;

— rotating heads;

— transformers;

— active devices, e.g. multiplexer, amplifier, etc.

4.1.4 Physical characteristics

The following shall be stated among others:

— external size and shape;

— weight;

— information about mechanical mounting;

— model number and serial number;

— material of manufacture of probe housing;

— composition and thickness of facing material;

— presence and purpose of core or shield;

— type of interconnecting elements (see 4.1.3);

— orientation mark (direction for maximum sensitivity, see 6.2.3.3);

— position mark (electrical centre, see 6.2.3.4).

4.1.5 Safety

The probe and its interconnecting elements shall meet the applicable safety regulations regarding electrical hazard, surface temperature, or explosion.

Normal use of the probe should not create a hazard.

4.1.6 Environmental conditions

The temperature and humidity for normal use, storage and transport should be specified for the probe and its interconnecting elements.

The tolerance of the probe and its interconnecting elements to the effects of interference noise and electromagnetic radiation shall conform to electromagnetic compatibility (EMC) regulations.

Materials used in the manufacture of the probe should be resistant to contaminants.

4.2 Electrical characteristics

The external electrical connections to the probe shall be clearly identified or declared in writing.

The electrical characteristics of a probe connected to a specified length and type of cable are as follows:

— recommended range of excitation current and voltage for safe operation;

— recommended range of excitation frequencies;

— impedance of the excitation element in air;

— resonant frequency of the excitation element in air;

— impedance of the receiving element(s) in air.

The electrical characteristics of an extension cable shall also be clearly identified.

4.3 Functional characteristics

The functional characteristics of a probe shall be determined for a defined system.

The measurement of the functional characteristics of a probe requires the use of calibration blocks. The material used for the reference block is determined by the application.

The functional characteristics of a probe are as follows:

— directionality;

— response to elementary discontinuities (hole, slot);

— length and width of coverage;

— area of coverage;

— minimum dimensions of discontinuities for constant response;

— penetration characteristics;

— geometric effects;

— normalised impedance locus (when the frequency is varied) of the exciting element with minimum probe clearance from a homogeneous block of a specified material.

These characteristics cannot be used alone to establish the performance (e.g. resolution, smallest detectable discontinuity, etc.) of the probe in a given test system, for a given application.

When relevant, the influence of interconnecting elements on the functional characteristics of the probe shall be measured.

5 Verification

5.1 General

For a consistent and effective eddy current examination, it is necessary to verify that the performance of the component parts of the eddy current test system is maintained within acceptable limits.

The physical condition of the reference blocks shall be verified to be within acceptable limits, before being used to verify the system or probes.

The measuring equipment used for verification shall be in a known state of calibration.

For a better understanding, the verification procedure is described identically in all three parts of ISO 15548.

5.2 Levels of verification

There are three levels of verification. Each level defines the time intervals between verification and the complexity of the verification.

It is understood that initial type testing has already been carried out by the manufacturer or under his control.

a) **Level 1: Global functional check**

A verification is performed at regular intervals of time on the eddy current test system, using reference blocks to verify that the performance is within specified limits.

The verification is usually performed at the examination location.

The time interval and the reference blocks are defined in the verification procedure.

b) **Level 2: Detailed functional check and calibration**

A verification on an extended time scale is performed to ensure the stability of selected characteristics of the eddy current instrument, probe, accessories and reference blocks.

c) **Level 3: Characterisation**

A verification is performed on the eddy current instrument, probe accessories and reference blocks to ensure conformity with the characteristics supplied by the manufacturer.

The organization requiring the verification shall specify the characteristics to be verified.

The main features of verification are shown in Table 1.

Table 1 — Verification levels

Level	Object	Typical time period	Instruments	Responsible entity
1 Global functional check	Stability of system performance	Frequently, e.g. hourly, daily	Reference blocks	User
2 Detailed functional check and calibration	Stability of selected characteristics of the instrument, probes and accessories	Less frequently but at least annually and after repair	Calibrated measuring instruments, reference blocks	User
3 Characterisation	All characteristics of the instrument, probes and accessories	Once (on release) and when required.	Calibrated laboratory measuring instruments and reference blocks	Manufacturer, user

5.3 Verification procedure

The characteristics to be verified are dependent on the application. The essential characteristics and the level of verification shall be specified in a verification procedure.

The examination procedure for the application shall refer to the verification procedure. This can restrict the number of characteristics of a general-purpose instrument to be verified for a defined application.

Sufficient data on the characteristics featured in an instrument, probe and reference block shall be provided, in order that verification may be performed within the scope of this part of ISO 15548.

5.4 Corrective actions

Level 1: When the performance is not within the specified limits, a decision shall be made concerning the product examined since the previous successful verification. Corrective actions shall be made to bring the performance within acceptable limits.

Level 2: When the deviation of the characteristic is greater than the acceptable limits specified by the manufacturer or in the application document, a decision shall be made concerning the instrument, the probe or the accessory being verified.

Level 3: When the characteristic is out of the acceptable range specified by the manufacturer or by the application document, a decision shall be made concerning the instrument, the probe or the accessory being verified.

6 Measurement of electrical and functional characteristics of a probe

6.1 Electrical characteristics

6.1.1 General

The electrical characteristics alone do not define the characteristics of the probe in its application.

The methods and measuring instruments given in 6.1.2 to 6.1.5 are for guidance; other equivalent methods and instrumentation can be used.

6.1.2 Measurement conditions

The measurements are made at the probe connector without the use of interconnecting elements of the inspection system. The probe is placed in air and away from any conductive or magnetic material.

The measurements are made for each element of the probe accessible at the probe connector. The other elements are left in open circuit.

When the probe is designed for use under particular conditions, for example, temperature or pressure, any additional measurements that are required shall be specified in the application document.

6.1.3 Resonant frequency of the excitation element

6.1.3.1 Excitation element with a single coil

Using an impedance meter, measure the resonant frequency f_{res} of the excitation element.

6.1.3.2 Excitation elements with multiple coils

An excitation element containing multiple coils will give multiple resonance frequencies. The lowest frequency shall be reported/measured.

6.1.4 Impedance of the excitation element

Measure the resistance R_0 using a multimeter, and the inductance L_0 using an impedance meter. The inductance is measured at the lowest frequency of the recommended operating range for the probe.

If the capacitance C_0 is too small to be measured directly, calculation should provide a more accurate result:

$$C_0 = \frac{1}{4\pi^2 f_{res}^2 L_0} \tag{1}$$

The model of the excitation-element impedance is given in Figure 1.

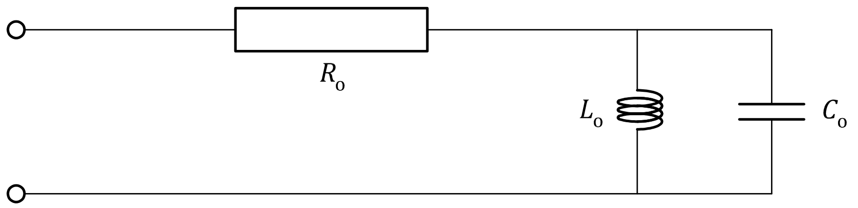


Figure 1 — Excitation-element impedance

6.1.5 Impedance of the receiving element(s)

Measure the resistance using a multimeter, and the inductance and the capacitance using an impedance meter. The measured values of impedance can be given as a curve against frequency.

6.2 Functional characteristics

6.2.1 General

This part of ISO 15548 characterises commonly used probe types. Probes which are designed for special (unusual) applications shall be characterised in accordance with an application document which follows the methodology of this part of ISO 15548. The characteristics described in this part of ISO 15548 can give useful information about such probes.

The functional characteristics are defined for two classes of probes: surface probes and co-axial probes.

6.2.2 Measurement conditions

6.2.2.1 General

A general-purpose eddy current instrument, characterised in accordance with ISO 15548-1, can be used, provided that it has the required accuracy.

Alternatively, sufficient instrumentation comprising a voltage/current generator, synchronous detection amplifier and a voltmeter or oscilloscope can be used.

When the probe does not feature a connecting cable, the characteristics of the cable used for the measurements shall be documented.

The probe characteristics are measured within the frequency range specified by the probe manufacturer using reference blocks containing known features, such as slots and holes.

The reference blocks shall be made using the specifications in the application document for the material, metallurgical properties and surface finish. Its geometry shall comply with the requirements included in the following subclauses. Blocks made from ferromagnetic material shall be demagnetized before use. The reference block can be replaced by any other device, the equivalence of which shall be demonstrated for the measured characteristic (alternative blocks, electric circuit, coil, ball, etc.).

The functional characteristics can be affected by the presence of any perturbing electromagnetic field or ferromagnetic material in the zone of influence of the probe. Care shall be taken to avoid these effects when making the measurements described in 6.2.2.2 and 6.2.2.3.

The measurement conditions for each characteristic shall be recorded, for example, excitation frequency and voltage/current, details of the reference block, etc.

The measured values are the amplitude of the signal and, when applicable, the phase of the signal.

6.2.2.2 Measurement of the amplitude of the signal

a) **Absolute measurements**

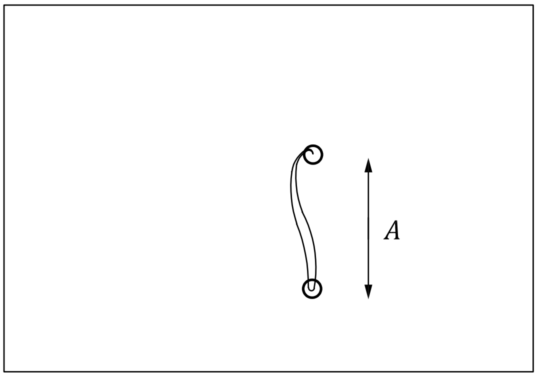
The amplitude of the signal is the length of the vector joining the balance point to the point corresponding to the maximum excursion of the signal from the balance point, unless otherwise specified in an application document, see Figure 2 a).

b) **Differential measurements**

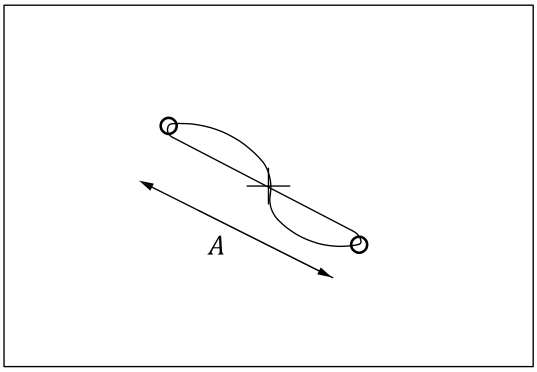
The amplitude of the signal is the length of the line joining the two extreme points of the signature, i.e. peak to peak value, unless otherwise specified in an application document; see Figure 2 b).

c) **Other measurements**

The method shall be specified in an application document.



a) Amplitude measurement for an absolute signal



b) Amplitude measurement for a differential signal

Figure 2 — Amplitude measurements for signals

6.2.2.3 Measurement of the phase angle of the signal

The reference for the measurement of phase angle shall be the positive x-axis.

The span shall be 360°, either as 0° to 360° or 0° to ±180°.

The polarity of measurement shall be specified as follows:

— P360: 0° to 360°, positive is anticlockwise (mathematical convention);

— N360: 0° to 360°, positive is clockwise;

— P180: 0 to ±180°, positive is anticlockwise;

— N180: 0 to ±180°, positive is clockwise.

The phase angle is the angle between the reference line and the line representing the signal amplitude determined in 6.2.2.2.

6.2.3 Surface probes

Unless otherwise specified, the measurements shall be conducted with constant probe clearance, which will be specified in the application document.

6.2.3.1 Reference blocks

Reference blocks (A1 to A5) are described in general terms in Figure 3.

The detailed requirements of each block shall be given in a procedure.

For each of these reference blocks, the length and width shall be at least 10 times the length of coverage of the probe as defined in the probe specifications. When this feature is not known, it shall be replaced by the largest (active) dimension of the probe in the scanning plane. Verification can be made after having measured the length of coverage as described in 6.2.3.8.

The thickness of the reference block shall be at least twice the standard depth of penetration for the lowest frequency nominated in the probe specification.

Block A1

It contains a slot in its centre.

As a minimum:

— the slot shall be longer than the "minimum slot length for constant probe response", determined according to the methodology described in 6.2.3.10;

— the slot shall be deeper than the "minimum depth of surface-breaking slot for constant probe response", determined according to the methodology described in 6.2.3.11;

— the slot width shall be defined in the application document.

Block A2

It contains a hole in its centre.

The diameter of the hole is defined in the application document. It is recommended that the depth of the hole be the same as that of the slot in block A1.

Block A3

It is the same as block A1, without a slot, and with varying thicknesses up to 3 times the standard depth of penetration, or twice the active dimension of the probe.

Block A4

It is the same as block A1, with *n* parallel slots.

— all the slots have the same length and width as the slot of block A1;

— the slot depth increases from slot 1 to *n* by a constant step specified in the application document;

— the spacing between two consecutive slots shall be at least 5 times the length of coverage (6.2.3.8);

— the distance from the first and the last slot to the adjacent edge shall be at least 2,5 times the edge-effect length.

The number of slots and their depths are defined in the application document.

Block A5

It is the same as block A1, with *n* parallel slots.

— all the slots have the same depth and width as the slot of block A1;

— the slot length increases from slot 1 to *n* by a constant step specified in the application document; the ends of the longest slot shall be further than 2,5 times the edge-effect length away from the edge;

— the spacing between two consecutive slots shall be at least 5 times the length of coverage (6.2.3.8);

— the distance from the first and the last slot to the adjacent edge shall be at least 2,5 times the edge-effect length;

— all the slots are centred with respect to the block;

— the number of slots and their lengths are defined in the application document.

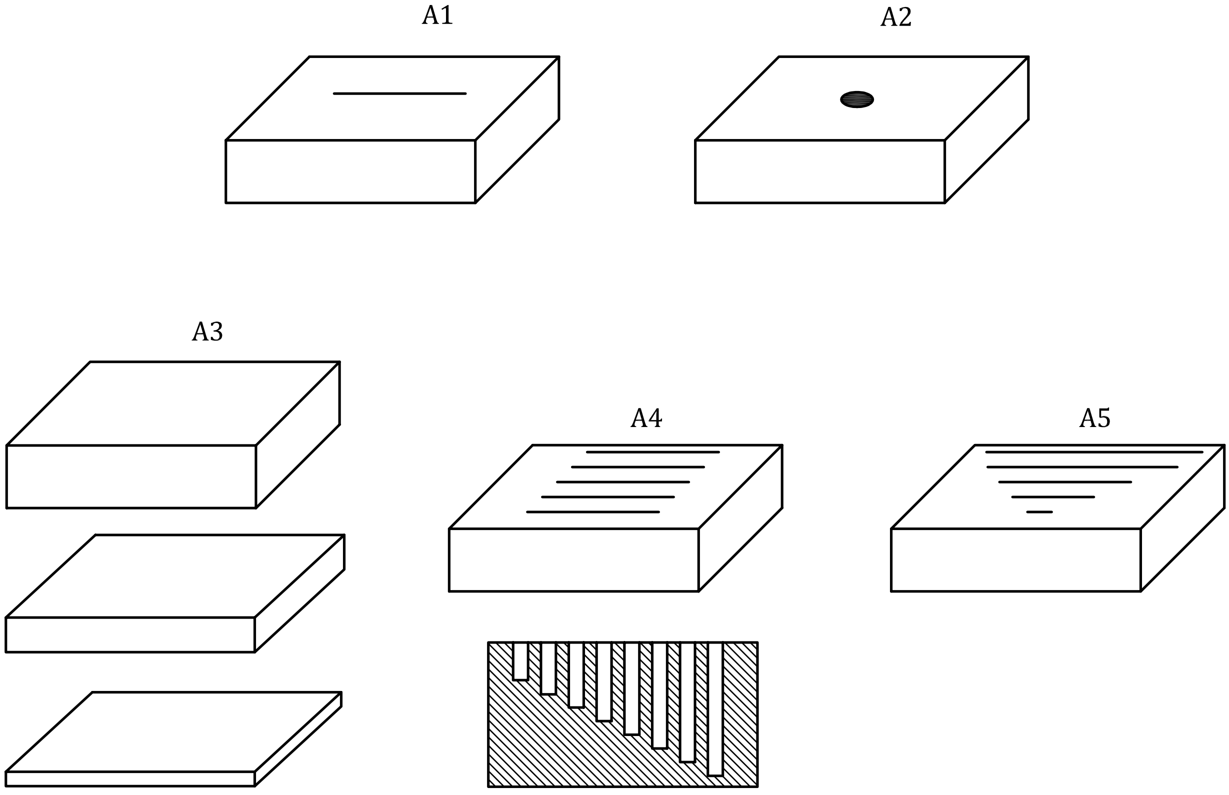


Figure 3 — Reference blocks for surface probes

Block A6

This block is defined to obtain a transfer signal. See 6.2.3.16

6.2.3.2 Reference signal

Reference block: block A1 shall be used for this measurement.

Probe motion

Balance the probe on the block with the probe mid-way between the slot and the adjacent edge of the block.

Verify that no significant change occurs when moving the probe in the vicinity of this position, in the direction of the slot and that of the edge.

A linear scan is performed over the middle of the slot, with the preferred orientation of the probe perpendicular to the slot (see Figure 4). For this measurement, the preferred orientation shall be the one defined by the manufacturer. In the case where the probe is explicitly designed for scanning slots non-perpendicular to the probe motion (e.g. parallel), an alternative procedure shall be described in the application document.

Results

The instrument is adjusted so that the maximum signal corresponds to a given value of the instrument dynamic range (e.g. 25 %). It shall be verified that no signal saturation occurs in the subsequent measurements.

The reference signal S_{ref} is the maximum value of the signal during the scan.

The phase of the reference signal is taken as the origin of phases for subsequent measurements.

In the following subclauses, all results shall be expressed relatively to S_{ref}.

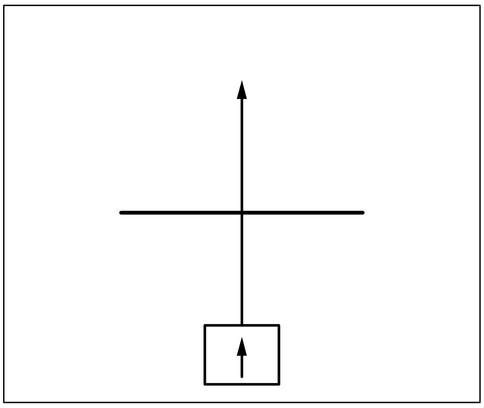


Figure 4 — Probe motion to obtain reference signal

6.2.3.3 Angular sensitivity

Reference block: block A1 shall be used for this measurement.

Probe motion

Scan the central portion of the slot for a range of angles of the probe preferred orientation indicated by the manufacturer with the scanning direction (α goes from 0° to 180°), in steps giving adequate resolution but not exceeding 20° (see Figure 5). The values of α are specified in the application document.

For some probes, scanning the slot in its middle does not correspond to their optimal use. In this case, an alternative procedure shall be provided in the application document.

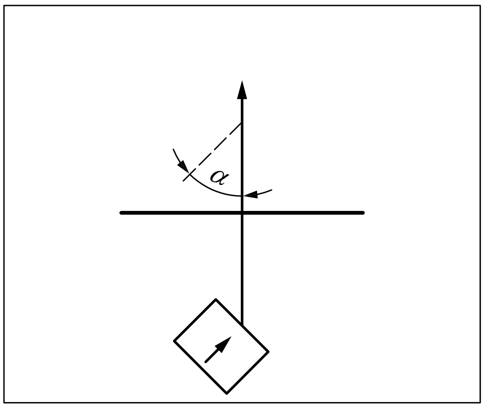


Figure 5 — Probe motion to measure angular sensitivity

Results

The maximum value $S_{max}(\alpha)$ of the signal for each scan is recorded. Then $S_{max}(\alpha)/S_{ref}$ is plotted against α.

The orientation for which the maximum value, $\max(S_{max})/S_{ref}$ of $S_{max}(\alpha)/S_{ref}$ is obtained defines the actual preferred orientation of the probe, which shall be used for the following measurements.

Where the actual preferred orientation of the probe differs significantly from the preferred orientation indicated by the manufacturer, this situation shall be documented; a new orientation mark could be made; the corresponding value of S_{ref} shall be used in all subsequent measurements.

The case where there are several distinct maxima of S_{max}/S_{ref} indicates that the probe has several preferred orientations. Therefore, it is desirable to measure the probe characteristics for each preferred orientation.

Additional parameters can be defined through such measurement. For instance, a probe anisotropy factor k may be calculated:

$$k = [\max(S_{max}) - \min(S_{max})]/\max(S_{max}) \quad (2)$$

where $\min(S_{max})$ is the minimum of $S_{max}(\alpha)$.

6.2.3.4 Position mark

The position mark is different from the orientation mark. This mark placed on the body of the probe shall unambiguously define the position of the electrical centre, according to the measurement method given below.

When this mark cannot be properly made on the probe, it shall be defined by means of a sketch, or the distance of the mark from a fixed point of the probe can be recorded.

Reference block: block A1 shall be used for this measurement.

Probe motion

A linear scan is performed over the middle of the slot with the preferred orientation of the probe perpendicular to the slot.

Results

Where there is one peak signal, the probe-position mark is one point of the probe housing over the slot where the signal is a maximum, e.g. an absolute signal.

Where there are two maxima, the probe-position mark is one point of the probe housing over the slot where the signal is zero between the two peaks, e.g. a differential signal.

6.2.3.5 Edge effect

Reference block: block A1 shall be used for this measurement.

Probe motion

With the probe mid-way between the slot and the adjacent edge of the block, the probe is moved from the former balance position on a scanning line to the closest edge of the reference block:

a) along its preferred orientation;

b) perpendicular to its preferred orientation.

Results

a) The edge effect is characterised by the distance from the probe-position mark to the edge of the block at which the signal S is such that:

$$S/S_{ref} = A \quad (3)$$

(*A* is a value mentioned in the application document.)

b) The edge effect is characterised by the distance from the secondary probe-position mark to the edge of the block at which the signal S is such that:

$$S/S_{ref} = A \quad (4)$$

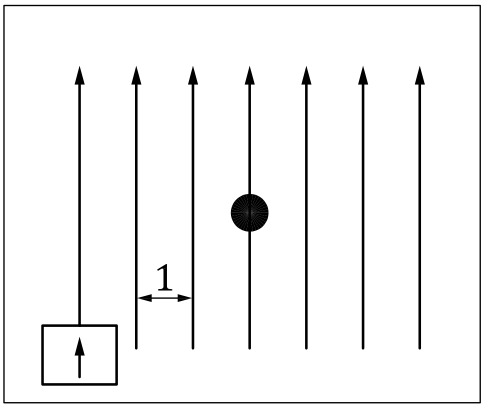
(*A* is a value mentioned in the application document.)

6.2.3.6 Response to a hole

Reference block: block A2 shall be used for this measurement.

Probe motion

The block is scanned in a series of paths parallel to the preferred orientation, with the distance between two successive paths not greater than 20 % of the width of coverage of the probe, as given by the manufacturer, (see Figure 6).



Key

1 step

NOTE The arrow on the probe indicates the probe's preferred orientation.

Figure 6 — Probe motion to measure the response to a hole

Results

The maximum value S_{max}/S_{ref} of the signal over the whole scan is taken.

For each scanning path, the points corresponding to the signal which is 6 dB less than S_{max}/S_{ref} shall be plotted to form a map of the probe response around the hole.

The scanning path shall be related to the mapping by the representation of the hole and the probe-position mark for the first recorded point (e.g. bottom left).

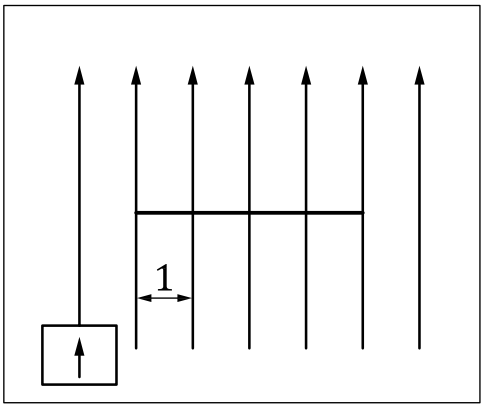
A more complete representation can be achieved through the use of more level lines or any equivalent representation (3D mapping, coloured map, etc.).

6.2.3.7 Response to a slot

Reference block: block A1 shall be used for this measurement.

Probe motion

The block is scanned in a series of paths with the distance between two successive paths (step) no greater than 10 % of the length of the slot. Scanning is performed with the preferred orientation of the probe perpendicular to the direction of the slot (see Figure 7).



Key

1 step

NOTE The arrow on the probe indicates the probe's preferred orientation.

Figure 7 — Probe motion for the measurement of the response to a slot

Results

The maximum value S_{max}/S_{ref} of the signal over the whole scan is taken.

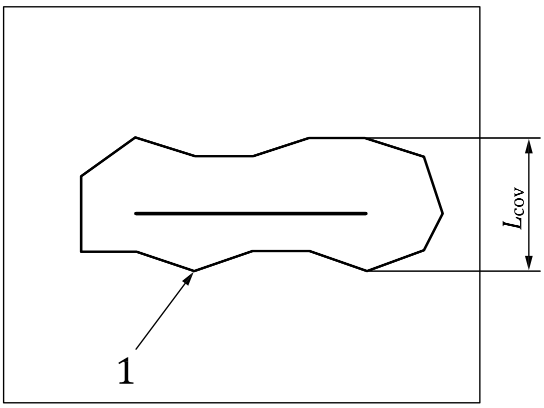
For each scanning path, the points corresponding to the signal which is 6 dB less than S_{max}/S_{ref} shall be plotted to form a map of the probe response to the slot.

The scanning path shall be related to the mapping by the representation of the slot and the probe-position mark for the first recorded point (e.g. bottom left).

A more complete representation can be achieved through the use of more level lines or any equivalent representation (3D mapping, coloured map, etc.).

6.2.3.8 Length of coverage

The length of coverage L_{cov} is derived from the map of the probe response to the slot, made in 6.2.3.7, by taking the maximum dimension of the envelope in the scanning direction, (see Figure 8).



Key

1 −6 dB line

Figure 8 — Example of determination of the length of coverage

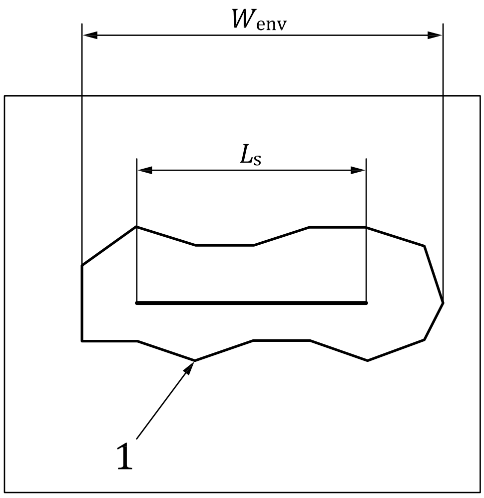
6.2.3.9 Width of coverage

The width of coverage is derived from the map of the probe response to the slot, made in 6.2.3.7, by taking the maximum dimension W_{env} of the envelope perpendicular to the scanning direction, (see Figure 9).

The width of coverage is defined as:

$$W_{cov} = W_{env} - L_s \quad (5)$$

where L_s is the slot length.



Key

1 −6 dB line

Figure 9 — Example of determination of the width of coverage

6.2.3.10 Minimum slot length for constant probe response

Reference block: block A5 shall be used for this measurement.

Probe motion

A linear scan is performed over the reference block surface with the centre of the probe passing over the middle of each slot and with its preferred orientation perpendicular to the slots.

Results

Starting the measurement from the first slot, longer than the measured width of coverage of the probe, and for increasing slot lengths, for each slot i of length l_i, the maximum signal S_i is recorded:

l_{min} is the smallest length l_i for which $(S_i - S_{i-1})/S_{ref} \le 0{,}1$, unless otherwise specified in an application document;

l_{min} is the minimum slot length which does not modify the probe response. Any longer slot will give the same response.

More detailed information on the probe performance during detection can be obtained from the curve plotted for all the slots.

6.2.3.11 Minimum depth of surface-breaking slot for constant probe response

Reference block: block A4 shall be used for this measurement.

Probe motion

A linear scan is performed over the reference block surface with the centre of the probe passing over the middle of each slot and with its preferred orientation perpendicular to the slots.

Results

For slot *i* of depth d_i, the maximum signal over the slot S_i is recorded:

d_{min} is the smallest depth for which $(S_i - S_{i-1})/S_{ref} \leq 0{,}1$ unless otherwise specified in an application document;

d_{min} is the minimum depth of the surface-breaking slot, influencing the probe response.

6.2.3.12 Lift-off effect

Reference block: block A1 shall be used for this measurement.

Probe motion

The probe is located over the balance area of the block and is moved vertically in defined steps, e.g. using non-conductive shims. Balance the probe when it is in contact with the reference block, i.e. when $z = 0$.

Results

Plot $S(z)/S_{ref}$ for height z, varying by defined steps.

The effect of lift-off is characterised by plotting $S(z)$ against z.

6.2.3.13 Effect of probe clearance on slot response

Reference block: block A1 shall be used for this measurement.

Probe motion

A linear scan is performed over the middle of the slot with the preferred orientation of the probe perpendicular to the slot.

The probe clearance varies from zero to a value representative of the exit from the zone of influence, specified in the application document.

The probe is balanced for each value of probe clearance on the balance area of the block.

Results

For each value of the probe clearance z, repeat the measurements described in 6.2.3.2.

The effect of probe clearance on a defect signal is characterised by plotting $S_{max}(z)/S_{ref}$ against z.

6.2.3.14 Effective depth of penetration

Reference block: blocks A3 shall be used for this measurement.

Probe motion

The probe is located over the centre of each block and does not move.

Results

Balance the probe over the block having the smallest thickness.

S_0 is the signal obtained over the thickest block.

Signal over block A3 of thickness $t = S(t)$

$S(t)$ is plotted against t.

The effective depth of penetration P_{eff} is the value of t for which:

$[S(t) - S_0]/S_0 \leq 0{,}1$ unless otherwise specified in the application document.

6.2.3.15 Effective depth of detection of sub-surface slot

Reference block: block A1 and blocks A3 shall be used for this measurement.

Probe motion

The procedure of 6.2.3.2 is repeated for each thickness of blocks A3 positioned between the probe and block A1.

Results

The probe is balanced for each block A3. The signal $S_{max}(t)$ for a block of thickness t is plotted against t.

The effective depth D_{eff} is the value of t given by $S_{max}(t)/S_{max}(0) \leqslant 0.1$, unless otherwise specified in an application document.

In the case where the maximum value of $S_{max}(t)$ does not occur at zero thickness (a probe which is insensitive to a surface-breaking defect), then $S_{max}(0)$ shall be replaced with the maximum value obtained for a greater thickness t.

6.2.3.16 Transfer signal

A transfer signal is obtained from a predefined block; it can be used to compare signals from different probes on an absolute scale.

This transfer signal cannot be used to characterise a probe by itself.

Reference block: the reference block A6, not being application-related, is standardized in dimensions and material: high conductivity, low conductivity and non-ferromagnetic, low conductivity and ferromagnetic. The block shall nevertheless be of the same class as those used for A1 to A5.

The characteristics of the block, the tolerances and the manufacturing requirements are given in Annex A. See Figure 10.

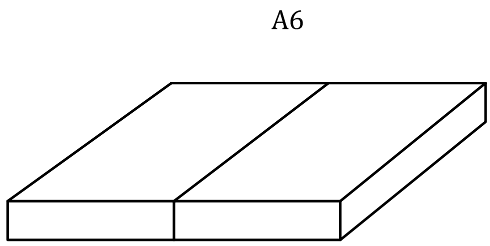


Figure 10 — Reference block A6

Probe motion

Balance the probe on the block with the probe mid-way between the slot and the adjacent edge of the block.

A linear scan is performed over the reference block surface with the centre of the probe passing over the middle of the slot and with its preferred orientation perpendicular to the slot.

Result

The instrument is adjusted with the settings obtained in 6.2.3.2. It shall be verified that no signal saturation occurs in the subsequent measurements.

The transfer signal S_{trans} is the maximum value of the signal during the scan.

If saturation occurs, adjust the instrument to a lower gain G_{low}. The result in this case is

$$S_{trans} \times \frac{G}{G_{low}}$$

6.2.3.17 Phase-transfer signal

A ferrite can be used to get a reproducible phase transfer signal. The shape of the ferrite is indifferent as well as the distance of the probe to the ferrite.

To obtain the signal, it is necessary to have a relative probe/ferrite movement, in the preferred orientation of the probe.

The phase angle of the reference signal and/or the phase angle of the transfer signal is recorded.

6.2.4 Coaxial probes

6.2.4.1 General conditions

Unless otherwise specified:

— the measurements apply to inner or encircling coaxial probes with cylindrical geometry and circular section; they shall be conducted with constant probe clearance, which will be specified in the application document;

— the results will concern the modulus and the phase of the signal.

The case of coaxial probes with non-circular sections shall be examined on a case-by-case basis in the application document.

6.2.4.2 Reference blocks

Reference blocks (B1 to B4, C1 to C4) are described in general terms in Figures 11 to 16.

They consist of tubes or bars.

The length *L* will be greater than 4 times the end effect of the probe, as defined by the manufacturer. When this feature is not known, it shall be replaced by the active dimension of the probe in the scanning direction.

The thickness of the tube wall (respectively the diameter of the bar) is defined in the application document. The wall thickness (respectively the diameter) shall remain constant on the whole length of the tube.

In the case of tubes, if this is industrially achievable, any influence from the wall thickness variation is safely reduced, if the thickness of the reference block is at least 4 times the standard depth of penetration for the lowest frequency nominated in the probe specification.

The detailed requirements of each block shall be given in a procedure.

The only probe motion considered for characterisation is a translation parallel to the reference block axis.

Block B1 (respectively C1), Figure 11

A tube (respectively a bar) featuring four (respectively two) through holes, on the same cross-section, and with a diameter defined in the application document (at least equal to 0,6 mm).

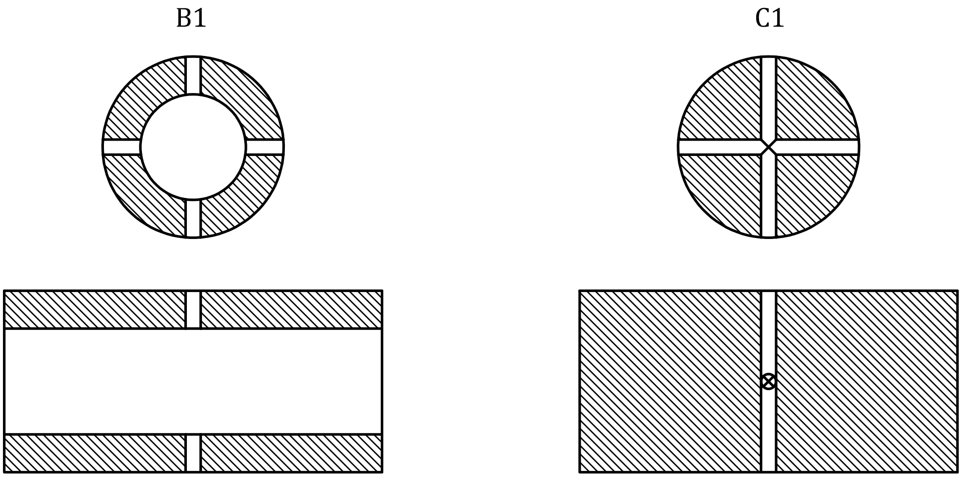


Figure 11 — Blocks B1 and C1

Block B2 (respectively C2), Figure 12 a)

It is the same as B1, with only one through hole, diameter twice the diameter of the holes on B1.

It is the same as C1, with only one hole, the depth of which is equal to the bar radius.

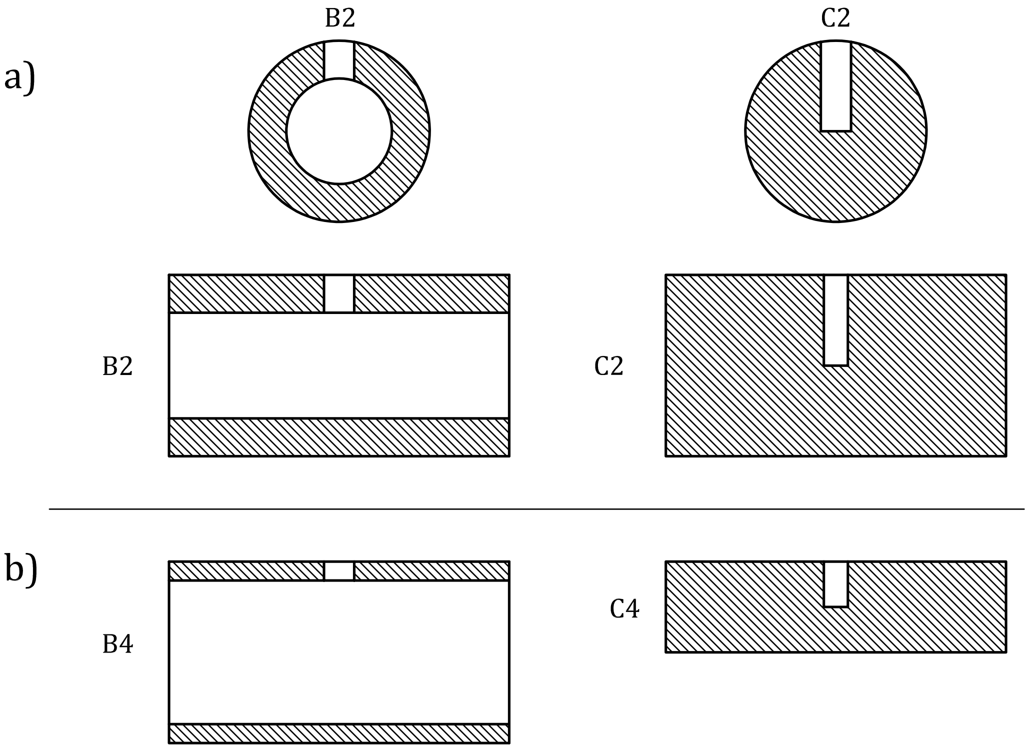


Figure 12 — Blocks B2, C2 and B4, C4

Block B3 (respectively C3), Figure 13

A tube (respectively a bar), with the same dimensions as B1 (respectively C1), with *n* longitudinal slots, lined up on the same generating line of the tube (respectively the bar).

All slots have an identical transverse profile; their length *l* increases from 0 mm to the highest value of the end effect distance, determined in 6.2.4.5, with constant steps. In the case of tubes, the depth of the slots is 100 % of the tube wall thickness; in the case of bars, the depth of the slots is 50 % of the bar diameter. Less deep slots can be used, provided that the depth exceeds the effective depth of penetration as measured in 6.2.4.12. The distance between two successive slots is 5 times the length of coverage (6.2.4.8).

The distance between the end of the first and the last slot and the ends of the tube (respectively the bar) shall be 2,5 times the end effect.

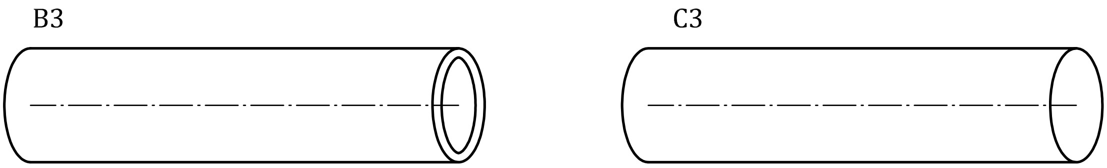


Figure 13 — Blocks B3 and C3

Block B4 (respectively C4), Figure 12 b)

It is the same as B2, with a larger internal diameter.

It is the same as C2, with a smaller diameter.

Block B5 (respectively C5), Figure 14

This is a series of tubes, the same as B1, with increasing inner diameters, while keeping the wall thickness constant.

This is a series of bars, the same as C1, with decreasing diameters.

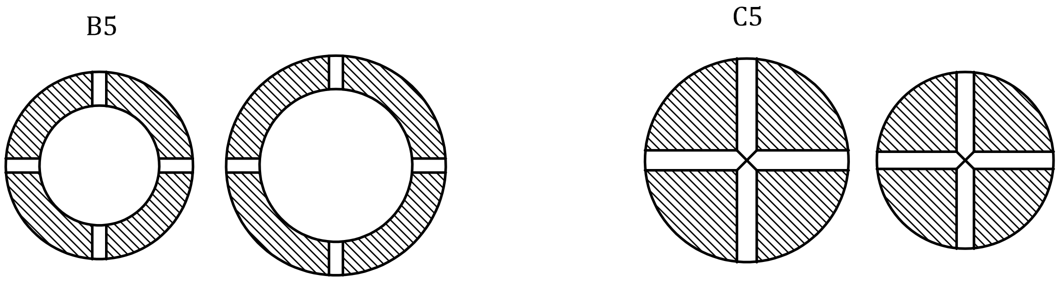


Figure 14 — Blocks B5 and C5

Block B6 (respectively C6), Figure 15

A series of tubes, the same as B1, with constant inner diameter and increasing wall thickness, or one single tube reproducing this situation.

A series of bars, the same as C1, with constant bar diameter and central bores of increasing diameters, or one single bar reproducing this situation.

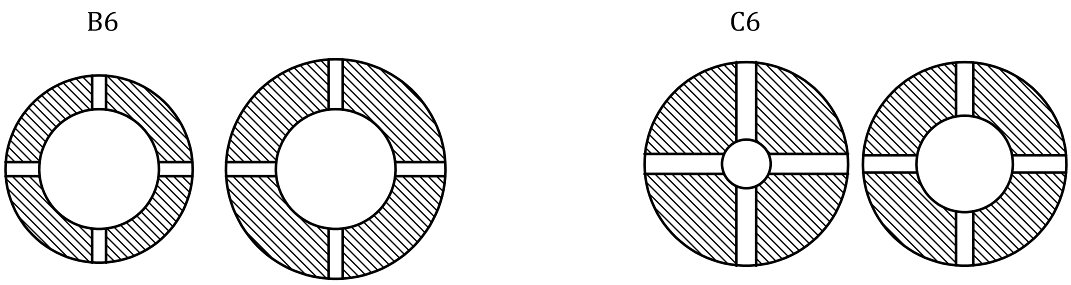
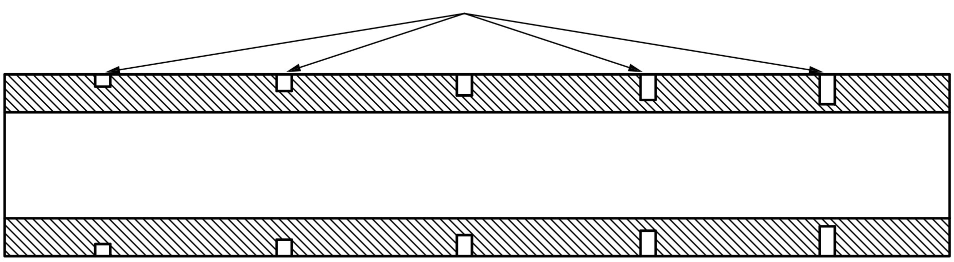


Figure 15 — Blocks B6 and C6

Block B7, Figure 16

A tube, the same as B1, with circumferential grooves with a rectangular section.

The groove width is equal to the diameter of the hole on B1. The depth of the grooves increases in constant steps defined in the application document. The spacing between two grooves is 5 times the length of coverage as defined in 6.2.4.8.



Key

1 360° grooves

Figure 16 — Block B7

6.2.4.3 Reference signal

Reference block: block B1 (respectively C1) shall be used for this measurement.

Results

Balance the probe at a point located at $L/4$. Move the probe over the holes.

The instrument is adjusted so that the maximum signal corresponds to a given value of the instrument dynamic range (e.g. 25 %). It shall be verified that no signal saturation occurs in the subsequent measurements.

The reference signal S_{ref} is the maximum value of the signal during the scan.

The phase of the reference signal is taken as the origin of phases for subsequent measurements.

In the following subclauses, all results shall be expressed relative to S_{ref}.

6.2.4.4 Probe position mark

The probe-position mark placed on the probe body, unambiguously defines the electrical centre of the probe according to the measurement method given below.

A position mark can be applied where the size and shape of the probe body or the probe response permits this.

Where this is not possible, it shall be defined by means of a sketch, or the distance of the position mark from a fixed point of the probe can be recorded.

Reference block: block B1 (respectively C1) shall be used for this measurement.

Results

Balance the probe at $L/4$. Scan the block past the holes to $3L/4$.

Where there is one peak signal, the probe position mark corresponds to the points of the probe which are in the same axial position as the holes, where the signal is a maximum (e.g. absolute signal).

Where there are two maxima, the probe-position mark is defined as follows:

— a first mark is determined for the first maximum as described above;

— a second mark is determined for the second maximum.

The probe-position mark shall be placed at an equal distance from those two marks.

6.2.4.5 End effect

Reference block: block B1 (respectively C1) shall be used for this measurement.

Starting from a point at $L/4$, balance the probe. Move it towards the adjacent end of the block.

Results

The end effect is characterised by the distance from the probe-position mark to the end of the block at which the signal S is such that:

$$S/S_{ref} = A \quad (6)$$

where A is a value mentioned in the application document.

The same measurement shall be repeated over the other end of the block, without changing the probe orientation.

6.2.4.6 Axial symmetry

Reference block: block B2 (respectively C2) shall be used for this measurement.

Results

Mark an angular origin on the blocks.

Scan the probe over the whole length of the block.

Turn the block or the probe on α and scan again.

Make α vary from 0° to 360°, in steps that are specified in the application document.

Plot $S_{max}(\alpha)/S_{ref}$ against α.

The deviation from the axis of symmetry is defined as:

$$[\max(S_{max}) - \min(S_{max})]/\max(S_{max}) \times 100 = d\ \%$$

6.2.4.7 Response to a hole

Reference blocks: block B1 (respectively C1) shall be used for this measurement.

Results

Plot S/S_{ref} as a function of the position of the probe-position mark.

The curve defines the probe response to a hole.

6.2.4.8 Length of coverage

Take the extreme −6 dB points of the curve plotted in 6.2.4.7. The distance between them is the length of coverage of the probe.

6.2.4.9 Minimum slot length for constant probe response

Reference blocks: block B3 (respectively C3) shall be used for this measurement.

Results

Balance the probe as in 6.2.4.3. and scan all the slots.

For slot i, the signal is $S_i = S_{i\max}/S_{\text{ref}}$

The minimum slot length for stable response is l_i such as:

$$S_i - S_{i-1} < 0{,}1$$

6.2.4.10 Eccentricity effect

Reference blocks: block B4 (respectively C4) shall be used for this measurement.

Results

a) **Geometric effect**

Balance the probe on a position centred in the section and located on $L/4$.

Vary the eccentricity E. The signal is $S_0(E)$. Plot $S_0(E)/S_{\text{ref}}$ against E.

b) **Effect on the response of the hole**

Eccentricity is now varied in the section of the tube (the bar) containing the hole.

Scan the tube (the bar) moving the probe axially. The signal is the maximum signal obtained during the scanning, $S_{\max}(E)$. Plot $S_{\max}(E)/S_{\text{ref}}$ against E.

6.2.4.11 Fill effect

This characteristic is not an essential functional feature of a probe as it is rather application-related. If required, the following shall be needed.

Reference blocks: block B5 (respectively C5) shall be used for this measurement.

Results

a) **Geometric effect**

Balance the probe on a position centred in the cross-section and located on $L/4$.

The signal is $S_0(D)$, where D is the inner diameter of the tube (the diameter of the bar).

Plot $S_0(D)/S_{\text{ref}}$ against D

b) **Effect on the response of the hole**

Scan each tube (each bar) by moving the probe axially. The signal is the maximum signal obtained during the scanning, $S_{\max}(D)$.

Plot $S_{\max}(D)/S_{\text{ref}}$ against D.

6.2.4.12 Effective depth of penetration

Reference blocks: block B6 (respectively C6).

Results

Balance the probe with the block having the smallest thickness.

S_0 is the signal obtained over the thickest block. The signal over B6 (respectively C6) of thickness t is $S(t)$. $S(t)$ is plotted as a function of t.

The effective depth of penetration P_{eff} is the value of t for which

$$[S_0 - S(t)]/S_0 \leq 10\ \%,$$

unless otherwise specified in the application document.

6.2.4.13 Effective depth of detection under ligament

This characteristic shall only be verified for internal coaxial probes.

Reference blocks: block B7 shall be used for this measurement.

Results

Balance the probe on B1, in a portion away from the grooves.

The signal obtained from the deepest groove is S_1:

$$S_{max}/S_{ref} = S_i \text{ for each groove;}$$

$S_i/S_1 < 10$ % defines the detection limit under the ligament.

6.3 Normalised impedance plane diagram

This measurement can be of interest in the case of absolute probes, featuring one receiving element.

An impedance meter shall be used. The probe clearance is kept as low as allowable.

Reference blocks: A3 for surface probes (use the thickest block);

B1 or C1 for coaxial probes.

Place the probe at a point located at $L/4$.

The normalised impedance-plane diagram is plotted by varying the frequency.

7 Influence of interconnecting elements

Both electrical and functional characteristics can be affected by the addition of interconnecting elements.

This influence shall be evaluated by repeating the measurements described in 6.1 and 6.2.

Of specific importance are

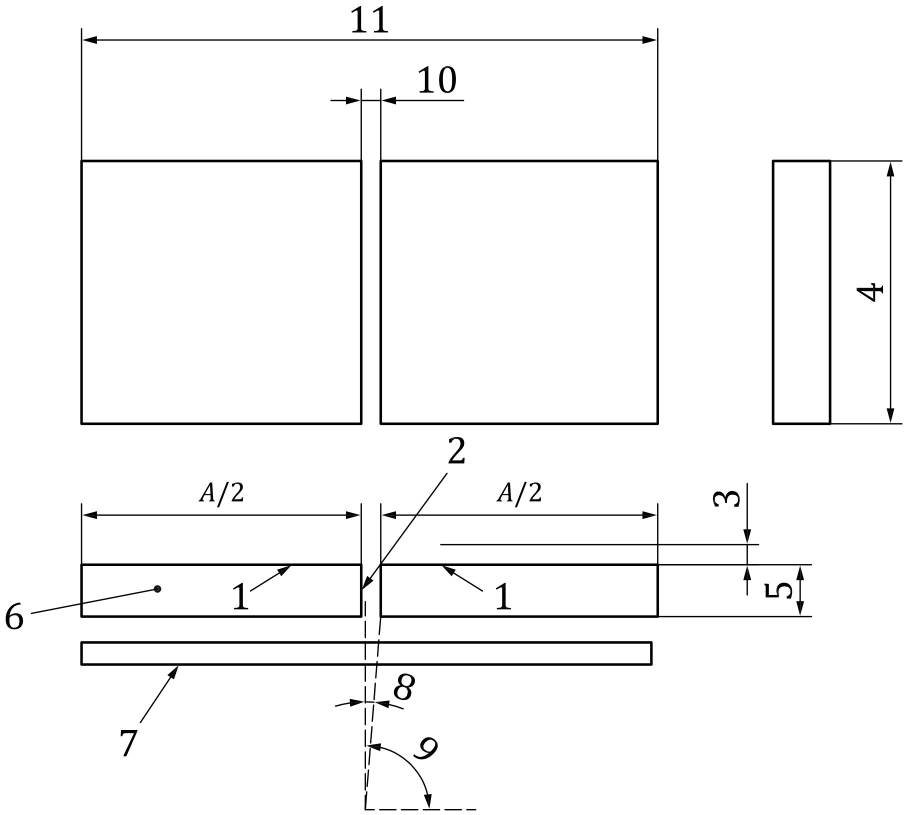
— amplitude response, and

— phase response.

Annex A
(informative)

Reference block A6

See Figure A.1.



Key

1 working surfaces
2 gap surfaces
3 edge displacement E
4 block length B
5 block height C
6 electrical conductivity σ
7 supporting structure
8 angular deviation F from parallel F
9 angle G relative to working surface
10 gap width D
11 block width A

Figure A.1 — Transfer signal block A6

A.1 Nominal values and tolerances of characteristics

See Table A.1.

Table A.1 — Nominal values and tolerances

Characteristic	A	B	C [a]	D	E	F	G	σ_{Aust} [c]	σ_{Al} [c]
Nominal value	≥4 times probe Ø ≥100 mm	≥A/2	>3δ [b] ≥5 mm	0,1 mm	0 mm	0°	90°	1,5 MS/m	30 MS/m
Permissible deviation from nominal value	±1 mm	±1 mm	±0,5 mm	±0,05 mm	≤0,1 mm	≤0,1°	±5°	±0,5 MS/m	±10 MS/m

[a] Proposal for a frequently used variant:

C = 5 mm for magnetisable materials (e.g. low-alloy steel);

C = 5 mm for high-conductivity materials (e.g. Al alloys);

C = 15 mm for low-conductivity materials (e.g. 18/8 steel).

[b] δ = Standard depth of penetration.

[c] Only relevant for non-magnetisable materials.

A.2 Manufacturing

It is advised to manufacture the reference block A6 by means of milling and grinding. Alternatively, wire EDM can be used. The quality of the gap surface should be at least 0,8 µm average roughness CLA (N6).The surface quality of all other surfaces should be at least 1,6 µm average roughness CLA (N7), if possible 0,8 µm average roughness CLA (N6).

The supporting structure should be of the same material or of electrically non-conducting material. Its thickness shall be sufficient, to prevent bending of the reference block.

Bibliography

[1] ISO 15549, *Non-destructive testing — Eddy current testing — General principles*

[2] ISO 15548-1, *Non-destructive testing — Equipment for eddy current examination — Part 1: Instrument characteristics and verification*

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