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Steel — Ultrasonic testing for steel flat products of thickness equal to or greater than 6 mm

Aciers — Contrôle ultrasonore des produits plats en acier d'épaisseur égale ou supérieure à 6 mm

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 17577 was prepared by Technical Committee ISO/TC 17, *Steel*, Subcommittee SC 7, *Methods of testing (other than mechanical tests and chemical analysis)*.

Steel — Ultrasonic testing for steel flat products of thickness equal to or greater than 6 mm

1 Scope

This International Standard specifies a method for the automated and/or manual ultrasonic testing of uncoated steel flat products for internal discontinuities by the reflection method. It is applicable to non-alloyed or alloyed steel flat products, in a nominal thickness range of 6 mm to 200 mm. However, this standard may be applied to austenitic and austenitic-ferritic steels, provided that the difference between the amplitude of the noise signal and that of the echo detection threshold is sufficient for the limit fixed. Unless otherwise agreed, for testing of steel flat products for welded steel tubes, ISO 12094 applies.

Other methods of testing (e.g. by transmission) or other test equipment may be used at the manufacturer's discretion, provided that they give identical results to those obtained under the conditions of this standard. In the event of a dispute, only the method defined in this standard will prevail.

Testing of flat products, of thickness less than 6 mm and over 200 mm, may be the subject of special agreements between the parties concerned.

The inspection is normally carried out in the place of production or on the premises of the supplier.

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 9712, *Non-destructive testing — Qualification and certification of personnel*

ISO 12094, *Welded steel tubes for pressure purposes — Ultrasonic testing for the detection of laminar imperfections in strips/plates used in the manufacture of welded tubes*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
internal discontinuity
any imperfection lying within the thickness of the flat products, e.g. planar or laminar imperfection, single-plane or multi-plane inclusion bands or clusters

3.2
defect
unacceptable internal discontinuities, i.e. exceeding the specified maximum size or population density limits

3.3
population density
number of individual internal discontinuities of a size greater than a specified minimum size and less than a specified maximum size per specified area of body or length of edge zone

3.4
manual and assisted manual testing
testing by an operator applying an ultrasonic probe to the flat-product surface, manually executing the appropriate scanning pattern on the flat-product surface and visually assessing ultrasonic signal indications on the electronic equipment screen either by direct viewing or by built-in signal amplitude alarm devices

3.5
automated and semi-automated testing
testing using a mechanized means of applying the ultrasonic probe or probes to the flat-product surface and executing the appropriate scanning pattern, together with ultrasonic signal evaluation by electronic means

NOTE Such testing can be either fully automated with no operator involvement or semi-automated when the operator performs basic equipment operation functions.

3.6
dead zone
zone to be measured as the point of time base where the transmitted pulse or surface echo drops to less than 20 % of screen height under the specified test sensitivity.

4 Principle

The method used is based on the reflection of ultrasonic waves (generally longitudinal), the mean direction of which is perpendicular to the main surface of the flat products.

The examination consists of the following:

a) Locating any discontinuity by comparing the amplitude of the discontinuity echo with the amplitude of the echo of a flat-bottomed hole of a given diameter and located at the same depth as the discontinuity.

NOTE Only those discontinuities giving an echo height exceeding in amplitude that of the echo obtained with the reference flat-bottomed hole are taken into consideration.

b) Then determining its area, the contour of the discontinuity being defined by the positions of the center of the probe corresponding to an echo amplitude of half the maximum amplitude of the discontinuity under consideration (6 dB method).

The examination is carried out during the first ultrasonic scan for all the flat-product thicknesses and from one side only.

In the case of automated testing, the location of a discontinuity and the determination of its area can be realized using different algorithms together with high scanning density. In case of dispute, the 6 dB technique in 8.1.1 should be used.

5 Personnel

Testing shall be carried out by qualified personnel under the responsibility of a Level 3 individual, certified in accordance with ISO 9712 or an appropriate national/regional standard.

NOTE Examples of appropriate standards are listed in the Bibliography.

6 Testing system

6.1 General requirements

a) The normal beam technique and the reflection technique shall be used for the ultrasonic testing method.

b) The apparatus shall be equipped with time-base regulation and the gain control shall be calibrated in decibels.

c) The electronic equipment shall be appropriate for the ultrasonic probes and frequencies used.

d) The transmitted pulse repetition frequency shall be appropriate for the applied scanning speed.

e) The apparatus shall detect the ultrasonic signals of internal discontinuities by using a gate function. The output signal shall be provided for devices like display monitor or recording equipment.

f) The coupling medium shall ensure an adequate contact between the probe and the surface of the flat products and maintain sufficient coupling.

6.2 Manual-testing instrument

The instrument shall be equipped with an A-scan display monitor that allows the assessment of the path of ultrasonic waves in the flat products. The oscillograms shall be clearly visible, the peaks corresponding to the successive echoes being sharp and very clear.

6.3 Automated testing system

The automated testing system shall be equipped with the following:

a) a suitable mechanical means for scanning the surface of flat products with a defined density;

b) probe holders which are capable of following the surface contour of a flat product to be tested, in order to maintain straight incidence;

c) appropriate electronics including, for example, transmitters, receivers, multiplexer, gates, display monitor, as well as a means for data collection;

d) appropriate means for signal evaluation, recording (e.g. mapping) and storing;

e) means for calibration of the equipment (i.e. sensitivity, time base and gate position), for example, by the use of reference blocks, input of artificial signals, input of distance-amplitude curves (DAC) or input of stored calibration files;

f) means for control of pulse repetition frequency related to the scanning speed;

g) means for coupling and function check (e.g. by surveillance of back-wall echo);

h) function to indicate the location of discontinuities from the edge of flat products (printer, recorder or display).

6.4 Performance of electronic equipment

The electronic equipment shall have the following performance.

a) Linearity

— Linear amplifiers: The deviation of the vertical linearity shall not exceed ± 1 dB in any part of a 20 dB span.

— Logarithmic amplifiers: The deviation of the vertical linearity shall not exceed ± 1 dB in any part of a 20 dB span and ± 2 dB in any part of a 60 dB span.

— Horizontal linearity: The deviation of the horizontal linearity shall not exceed ± 2 % of the testing range.

The vertical linearity shall be checked at least once a year, unless the conditions dictate a higher frequency of checking. The results of all checks shall be recorded.

b) Dead zone

The dead zone of single-element probes shall be as small as possible, i.e. max. 15 % of the thickness of the flat products or 15 mm, whichever is the smaller. For product thicknesses less than 10 mm, their dead zone shall be less than or equal to 1,5 mm.

6.5 Probes

The probes shall be single-element probes, dual-element probes or multiple dual-element probes, depending on the thickness of the flat products as given in Table 1.

Table 1 — Type of probe

Specified thickness of the flat products or path length (e) mm	**Type of probe** [a, b]
$6 \leqslant e \leqslant 60$	Dual-element probe
$60 < e \leqslant 200$	Single or dual-element probe

[a] In the event of dispute, the type of probe to be used shall be the subject of an agreement between the purchaser and manufacturer.

[b] As long as the stipulation of the dead zone is satisfied, where testing is carried out using immersion or water-column techniques, it is permissible to use single probes for flat products of less than or equal to 60 mm thickness.

The probes shall have a nominal frequency in the range of 2 MHz to 5 MHz. Probes with a frequency outside the range of 2 MHz to 5 MHz can be used for the material that has high attenuation or special acoustic characteristics, if agreed between the purchaser and manufacturer.

The focusing zone of dual-element probes shall be adapted to the thickness of the flat products.

The relevant dimension of transducers is less than or equal to 30 mm in diameter or in rectangularity.

6.6 Coupling medium

The coupling medium shall ensure an adequate coupling between the probe and the surface of the flat products.

Water is normally used, but other coupling media (e.g. oil, paste) may be used at the discretion of the supplier.

The coupling medium should be chosen to avoid intercrystalline corrosion, e.g. when applied to austenitic steel, and in such cases should be adequately removed after testing by an appropriate method.

7 Procedure

7.1 Inspection timing

Unless otherwise agreed, the ultrasonic test shall be carried out at the final stage.

7.2 Scanning plan

7.2.1 General

For the flat-product body, the testing is based on statistical methods unless otherwise specified in the order. Scanning of the flat products shall be carried out in accordance with 7.2.2 and/or 7.2.3 and corresponding to the required quality class.

By agreement at the time of ordering, a scanning with a defined scan coverage or a scanning of all body parts of the flat products may be provided, the operating conditions being included in the agreement.

7.2.2 Testing of the flat-product body

The following testing conditions apply.

a) For the flat-product body, the scanning comprises continuous examination along the lines of a grid parallel to the edges of the flat products, or along the parallel or oscillating lines distributed uniformly over the area, given the same degree of control.

b) For Classes B_1 and B_2, the scanning shall be the lines of grid of a 200 mm square, or along vertical or horizontal lines at 100 mm pitch.

c) For Classes B_3 and B_4, the scanning shall be the lines of grid of a 100 mm square, or along vertical or horizontal lines at 50 mm pitch.

d) In the event of probe failure, the above-mentioned pitch requirements can be exempted, as long as defective probes are not consecutive and if the following requirements for coverage rates are met:

   1) Classes B_1 and B_2: the required coverage rate of the scanning area shall be equal to or larger than 20 %.

   2) Classes B_3 and B_4: the required coverage rate of the scanning area shall be equal to or larger than 40 %.

   3) These coverage rates shall be calculated, based on the width of operating probes including the scanned area of the flat-product edges.

7.2.3 Testing of the edges of the flat products

Scanning of the edges comprises a full examination of a zone in accordance with Table 2, over the four edges of the flat products.

Table 2 — Zone width for flat-product edges

Thickness of the flat products (e) mm	Zone width mm
$6 \leqslant e \leqslant 60$	50
$60 < e \leqslant 100$	75
$100 < e \leqslant 200$	100

7.3 Scanning condition

a) In the case of scanning with a dual-element probe, the direction of the acoustical barrier shall be oriented perpendicular or 45° to the scanning direction.

b) The scanning speed shall not impede the testing.

1) In the case of automated testing, the scanning speed and the pulse repetition frequency shall be set to ensure full coverage.

2) The scanning speed of manual testing without an automated alarm system shall be less than or equal to 200 mm/s.

7.4 Sensitivity and range setting

a) The test sensitivity shall be determined using the flat-bottomed holes of the flat products or the reference block.

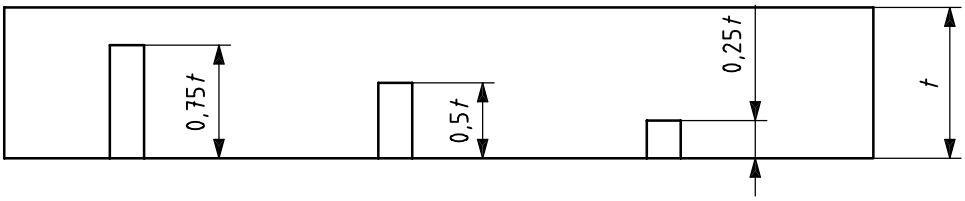
b) At least three flat-bottomed holes for each class shall be used for determination of the test sensitivity as given in Table 3.

Table 3 — Diameters of flat-bottomed holes for setting test sensitivity

Classes		Diameters of the flat-bottomed holes mm	
Flat-product body	Flat-product edges	Single probe	Dual-element probe
B_1, B_2	E_1	11 [a]	
B_3	E_2, E_3	8 [a]	5
B_4	E_4	5	
[a] By agreement at the time of enquiry and order, the 5 mm flat-bottomed hole may be specified.			

NOTE Flat-bottomed holes of diameter 5,6 mm may be used, provided that the sensitivity is adjusted with the same level as 5,0 mm flat-bottomed holes.

c) The depth of the flat-bottomed holes is given in Figure 1.



Key

t thickness

Figure 1 — Depths of flat-bottomed holes for setting the test sensitivity

d) The tolerance on the diameter of the flat-bottomed holes shall be ± 5 %. The tolerance on the depth of the flat-bottomed holes shall be ± 10 % or ± 2 mm of the product thickness, whichever is the smaller.

e) The reference block shall be made of steel that has similar acoustical properties to the tested flat products. The reference block may not necessarily be from the same production lot. Unless otherwise agreed, the deviation of thickness of the reference block from that of the flat products to be tested shall not exceed $^{+25}_{0}$ %.

f) The test sensitivity shall be determined from at least three points distributed over the entire field of use of the probe. After adjusting the lowest echo level or adjusting the same echo-height level using the distance-amplitude correction, the test sensitivity of the apparatus shall be adjusted, regarding the required class.

g) In the case of manual testing, the distance-amplitude characteristics from the relevant flat-bottomed holes may be used and the curves drawn on the display.

h) When testing with a dual-element probe, a 5,0 mm diameter hole is used for setting the test sensitivity.

i) Where the relation between the back-wall echo amplitude and the flat-bottomed-hole echo amplitude is defined, the back-wall echo may be used for adjusting the test sensitivity.

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

k) A reference block that has a thickness differing from that of the flat products to be tested may be used for adjusting the test sensitivity, if the difference of the sensitivity between the two thicknesses has been measured and compensated.

l) Distance-amplitude curves can be supplied by the manufacturer of the probe.

m) The frequency of checking the test sensitivity shall be at least once per 8 h shift.

NOTE The sensitivity of a dual-element probe may be adjusted when it is considered to have different sensitivity between the directions of the acoustical barrier and the rolling direction.

8 Determination of the discontinuity size

8.1 Testing the flat-product body

8.1.1 Testing with dual-element probes

The area of discontinuities giving responses that exceed the distance-amplitude curve shall be determined using the 6 dB technique, i.e. the contour of the discontinuity being defined as positions of center of the probe, when the response from the discontinuity is equal to half the maximum amplitude. A rectangle that encompasses the whole of the discontinuity is then determined, the major dimension of which is called the length of the discontinuity, and the minor dimension, the width of the discontinuity. The area of the rectangle is also calculated. The area of the rectangle defines the area S of the discontinuity. Two nearby discontinuities shall be considered to represent a single discontinuity, the area being equal to the sum of the two, if the distance between them is less than or equal to the length of the smaller of the two.

In the case of automated testing, the location of a discontinuity and the determination of its area can be realized using different algorithms, together with high scanning density. In case of dispute, the 6 dB technique should be used.

8.1.2 Testing with single-element probes

The test consists of the following:

a) for flat products of Class B_1 and B_2: determination of the area in accordance with the method defined in 8.1.1;

b) for flat products of Class B_3 and B_4: simple counting of the discontinuities which can be done when they are detected using the distance-amplitude curves for 5 mm, 8 mm and 11 mm diameter holes.

c) The following is thus determined:

   1) for Class B_3: the number of discontinuities giving echoes with an amplitude greater than the 11 mm diameter curve, and the number N2 of discontinuities (Table 5) giving echoes with an amplitude between characteristic curves for the 8 mm and 11 mm holes;

   2) for Class B_4: the number of discontinuities giving echoes with an amplitude greater than the 8 mm diameter curve, and the number N3 of discontinuities (Table 5) giving echoes with an amplitude between characteristic curves for the 5 mm and 8 mm holes.

In the case of automated testing, the location of a discontinuity and the determination of its area can be realized using different algorithms, together with high scanning density. In case of dispute, the adequate technique described in this subclause should be used.

8.2 Testing the edges

The test consists of scanning the total area of the edges (or areas to be welded according to sketches) where discontinuities were located as defined in 7.2.3, under the same conditions as for the flat-product body in 8.1.

The following shall be determined:

a) the maximum dimension (L_{max}) and the minimum dimension (L_{min}) of the discontinuity in the direction parallel to the edge of the products;

b) the area (S) of the discontinuity;

c) the number of discontinuities smaller than the maximum area (S_{max}) and longer than the minimum dimension (L_{min}) per 1 m length.

The determination of these properties of the discontinuity is obtained using the 6 dB method.

The area of the rectangle defines the area (S), of the discontinuity. Two nearby discontinuities shall be considered to represent a single discontinuity, the area being equal to the sum of the two, if the distance between them is less than or equal to the length of the smaller of the two.

In the case of automated testing, the location of a discontinuity and the determination of its area can be realized using different algorithms together with high scanning density. In case of dispute, the 6 dB technique in 8.1.1 should be used.

9 Acceptance criteria

Tables 4 and 5 give the acceptance criteria for the quality classes (B_1, B_2 B_3 and B_4) for the flat-product body, depending on the type of probe used, and Tables 6 and 7 for the edge classes (E_1, E_2, E_3 and E_4) (see also Figure 2).

If no quality class is specified by the purchaser at the time of enquiry and order, Class B_1 for flat-product body and Class E_1 for flat-product edges apply.

10 Test report

When requested, the manufacturer shall submit a test report which includes at least the following points:

a) a reference to this International Standard: ISO 17577;

b) reference data of the flat products examined (identification of the grade, heat-treatment condition, surface condition, dimensions);

c) the characteristics of the ultrasonic probe (type, dimensions, frequency) and of the apparatus;

d) the operation conditions (coupling medium, scanning, method of area determination used, setting of the apparatus);

e) the test results;

f) date of the test report;

g) name and signature of the inspector/operator.

Table 4 — Acceptance criteria for testing the body of flat product using dual-element probes

Class	Unacceptable individual discontinuity mm²	Acceptable frequency of discontinuities	
		Area [a] considered mm²	Maximum population density
B_1	$S > 1\,000$	$500 < S \leqslant 1\,000$	15 in the most populated/1 m × 1 m square
B_2	$S > 500$	100 [b] $< S \leqslant 500$	
B_3	$S > 100$	50 [b] $< S \leqslant 100$	10 in the most populated/1 m × 1 m square
B_4	$S > 50$	$20 < S \leqslant 50$	10 in the most populated/1 m × 1 m square

[a] Area of each discontinuity in the cluster in question.
For 1 000 mm², 500 mm²,100 mm² and 50 mm² are determined in 8.1.1.
For 20 mm², the discontinuity giving echoes with an amplitude above the distance-amplitude curve of a flat-bottomed hole of diameter 5,0 mm.

[b] By agreement at the time of enquiry and order, a minimum area of 20 mm² may be specified.

Table 5 — Acceptance criteria for testing the body of the flat product using single-element probes

Class	Unacceptable individual discontinuity	Acceptable frequency of discontinuities	
		Area [a] considered	Maximum population density
B_1	$S > 1\,000$ mm^2	$500 < S \leqslant 1\,000$ mm^2	15 in the most populated/ 1 m × 1 m square
B_2	$S > 500$ mm^2	100 [b] $< S \leqslant 500$ mm^2	
B_3	Discontinuities where the flaw echo has an amplitude greater than the distance-amplitude curve for a flat-bottomed hole 11 mm in diameter	N2 between diameters of 8 mm [b] and 11 mm	10 in the most populated/ 1 m × 1 m square
B_4	Discontinuities where the flaw echo has an amplitude greater than the distance-amplitude curve for a flat-bottomed hole 8 mm in diameter	N3 between diameters of 5 mm and 8 mm	10 in the most populated/ 1 m × 1 m square

[a] Area of each discontinuity in the cluster in question (see 8.1.2).

[b] By agreement at the time of enquiry and order, the 5 mm flat-bottomed hole may be specified.

Table 6 — Acceptance criteria for testing the edge zone of the flat product with dual-element probes

Class [a]	Permissible individual discontinuity size		Minimum discontinuity dimension considered	Permissible number of discontinuities smaller than the maximum area S_{max} and longer than L_{min} per 1 m length
	Maximum dimension L_{max} mm	Maximum area S_{max} mm^2	L_{min} mm	
E_1	50	1 000	25	5
E_2	40	500	20 [b]	4
E_3	30	100	15 [b]	3
E_4	20	50	10	2

NOTE 1 Counting of the discontinuities is carried out using the distance-amplitude curves for the 5,0 mm diameter holes.

NOTE 2 The length and area of the discontinuity of E_1, E_2, E_3 and E_4 are determined in 8.1.1.

NOTE 3 The number of discontinuities are determined as the number of discontinuities giving echoes with an amplitude above the distance-amplitude curves of flat-bottomed holes of diameter 5,0 mm.

[a] The discontinuity giving echoes with an amplitude over the distance-amplitude curve of a flat-bottomed hole of diameter 5,0 mm shall be considered.

[b] By agreement at the time of enquiry and order, a minimum dimension (L_{min}) of 10 mm may be specified.

Table 7 — Acceptance criteria for testing the edge zone of the flat product with single-transducer probes

Class	Permissible individual discontinuity size diameter D	Maximum dimension L_{max} [a] mm	Permissible number of discontinuities per 1 m length
E_1	11 mm $< D$	50	5
E_2	8 mm [b] $< D \leqslant 11$ mm	40	4
E_3	8 mm [b] $< D \leqslant 11$ mm	30	3
E_4	5 mm $< D \leqslant 8$ mm	20	2

[a] L_{max} is determined in 8.1.1.

[b] By agreement at the time of enquiry and order, the 5 mm flat-bottomed hole may be specified.