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Non-destructive testing of welds — Ultrasonic testing — Use of automated total focusing technique (TFM) and related technologies

Essais non destructifs des assemblages soudés — Contrôle par ultrasons — Utilisation de la technique d'acquisition automatisée de focalisation en tout point (FTP) et de techniques associées

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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 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by the IIW, *International Institute of Welding*, Commission V, *NDT and Quality Assurance of Welded Products*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 121, *Welding and allied processes*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Non-destructive testing of welds — Ultrasonic testing — Use of automated total focusing technique (TFM) and related technologies

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

This document specifies the application of the TFM technique and related technologies for semi- or fully automated ultrasonic testing of fusion- welded joints in metallic materials of minimum thickness 3,2 mm.

NOTE Unless stated otherwise, in this document 'TFM" and 'TFM technique" refer to the TFM technique as defined in ISO 23243, and to all related technologies, see for example ISO 23865 and ISO 23243.

This document is applicable to components with welds fabricated using metals which have isotropic (constant properties in all directions) and homogeneous conditions. This includes welds in low carbon alloy steels and common aerospace grade aluminium and titanium alloys, provided they are homogeneous and isotropic.

This document applies to full penetration welded joints of simple geometry in plates, pipes and vessels.

This document specifies four testing levels (A, B, C, D), each corresponding to a different probability of detection of imperfections. Guidance on the selection of testing levels is provided. Coarse-grained metals and austenitic welds can be tested when the provisions of this document have been taken into account.

This document gives provisions on the specific capabilities and limitations of the TFM technique for the detection, locating, sizing and characterization of discontinuities in fusion-welded joints. The TFM technique can be used as a stand-alone approach or in combination with other non-destructive testing (NDT) methods for manufacturing, in-service and post-repair tests.

This document includes assessment of indications for acceptance purposes based on either amplitude (equivalent reflector size) and length or height and length.

This document does not include acceptance levels for discontinuities.

The following two typical testing techniques for welded joints are referred to in this document:

a) side scanning, where the probe(s) is (are) positioned adjacent to the weld cap, typically using wedges. Side scanning can be performed from one side or both sides of the weld;

b) top scanning where the probe is positioned on top of weld cap with a flexible, conformable delay line or using immersion technique, or using contact technique after removing the weld cap.

Semi-automated testing encompasses a controlled movement of one or more probes along a fixture (guidance strip, ruler, etc.), whereby the probe position is measured with a position sensor. The scan is performed manually.

In addition, fully automated testing includes mechanized propulsion.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 5817, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections*

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

ISO 17635, *Non-destructive testing of welds — General rules for metallic materials*

ISO 18563-1, *Non-destructive testing — Characterization and verification of ultrasonic phased array equipment — Part 1: Instruments*

ISO 18563-2, *Non-destructive testing — Characterization and verification of ultrasonic phased array equipment — Part 2: Probes*

ISO 23865:2021, *Non-destructive testing — Ultrasonic testing — General use of full matrix capture/ total focusing method technique*

ISO 23243, *Non-destructive testing — Ultrasonic testing with arrays - Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5577, ISO 17635, ISO 23865 and ISO 23243 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Testing levels

Quality requirements for welded joints are mainly associated with the material, the welding process and the service conditions. To accommodate all these requirements, this document specifies four testing levels (A, B, C, and D).

From testing level A to testing level C, an increasing probability of detection is achieved by an increasing testing coverage, i.e. covering the test volume in multiple ways, e.g. number of imaging paths, number of array positions.

Testing level D may be agreed for special applications using a written procedure which shall take into account the general requirements of this document. This includes tests of metals other than ferritic steel, tests on partial penetration welds, tests at object temperatures outside the range of 7.7. For level D, a verification on test blocks is mandatory.

Testing levels related to quality levels shall be in accordance with ISO 5817 or technically equivalent standards. The appropriate testing level can be specified by standards for testing of welds (e.g. ISO 17635), by product standards or by other documents. When ISO 17635 is specified, the recommended testing levels are as given in Table 1.

Table 1 — Recommended testing levels

Testing level	Quality level in accordance with ISO 5817
A	C, D
B	B
C	by agreement
D	special application

Table 2 shows the minimum requirements. As described in 7.3, the setup shall be verified with reference blocks and/or test blocks in all cases.

Top scanning can be performed with TFM if the weld cap has been removed and the test surface is flat, otherwise adaptive focusing is required to take the geometry of the weld cap into account.

Side scanning with two probes simultaneously at both sides of the weld allows for imaging paths from one probe to the other probe (see ISO 23865).

Table 2 — Details of testing levels, minimum requirements

Testing technique	Testing levels			
	A[a]	B[a]	C[b]	D[b]
Top scanning at fixed probe position to the weld (line scan)	Direct imaging path	Direct imaging path and imaging path using reflection at the opposite surface	Direct imaging path and imaging path(s) which ensure(s) reflected signals from planar discontinuities on the weld bevel	Suitable imaging paths and positions (sides) by agreement
Side scanning at fixed probe position to the weld (line scan)	Direct imaging path, two sides	Direct imaging path and imaging path using reflection at the opposite surface, two sides or two probe positions	Direct imaging path and (multiple) imaging path(s) using reflection at the opposite surface, two sides or two probe positions	Suitable imaging paths and positions (sides) by agreement
Side scanning with raster scanning	Direct imaging path, one side	Direct imaging path and imaging path using reflection at the opposite surface, one side	Direct imaging path and (multiple) imaging path(s) using reflection at the opposite surface, one side, images from different probe positions to the weld are merged	Suitable imaging paths and positions (sides) by agreement

[a] For testing levels A and B: imaging using reflection at the opposite surface can be done by extending the ROI (only for TT-TT or LL-LL) or by using corresponding imaging paths.

[b] For testing levels C and D: The choice of the imaging paths shall depend on weld bevel design and be motivated in the scan plan based on Table 3.

5 Information required before testing

5.1 Items to be defined before procedure development

Information on the following items is required:

a) purpose and extent of testing;

b) type(s) of parent material (i.e. cast, forged, rolled); grain size and anisotropy;

NOTE 1 Several properties of the parent material, in particular deviations in grain elongation due to rolling, have influence on the images generated by TFM. This influence also exists in other ultrasonic testing techniques but is experienced differently. ISO 23865:2021, Clause 15, gives guidance.

NOTE 2 Variation in wall thickness has an influence on the image generated, in particular when using imaging paths containing one or more reflections. ISO 23865:2021, Clause 15, gives guidance.

c) testing level;

d) acceptance criteria, including method for evaluation of indications and method for establishing reference level;

e) specification of calibration blocks, reference blocks, test blocks used;

f) stage (e.g. manufacturing or in-service) at which the testing is to be carried out;

g) object and weld geometry details and information on the size of the heat-affected zone. If the size of the heat affected zone is not known, practical values according to the welding process used may be considered;

h) requirements for access, surface conditions and temperature. Material temperature has a significant influence on the images generated by TFM. Where the test object has a temperature outside the range specified in 7.7, ISO 23865:2021, Clause 15, gives guidance;

i) personnel qualifications;

j) reporting requirements.

5.2 Specific information required by the operator before testing

Before any testing of a welded joint can begin, the operator shall have access to all the information as specified in 5.1, together with the following additional information:

a) the written test procedure (see 5.3);

b) joint preparation and dimensions;

c) relevant information on the welding process;

d) time of testing relative to any post-weld heat treatment.

5.3 Written test procedure

For all testing using the TFM technique, a written test procedure is required. The procedure shall include the following information as a minimum:

a) the purpose and extent of testing, including details of the region of interest (ROI) and grid;

b) the testing technique, including acquisition scheme and imaging algorithm (processing parameters);

c) the testing level;

d) the personnel qualification/training requirements;

e) the equipment to be used (including but not limited to frequency, sampling rate, pitch, element size, wedge dimensions and velocity);

f) the reference and/or test blocks;

g) examples of calibration and reference scans;

h) the sensitivity settings;

i) required access and surface conditions;

j) requirements for testing of parent material;

k) evaluation of indications, including sizing methodology;

l) acceptance level and/or recording level;

m) reporting requirements;

n) any environmental and safety issues;

o) scan plan showing the following, to provide a standardized and repeatable methodology for testing:

- object and weld geometry;
- probe positioning and movement, relative to the weld;
- the imaging path(s) used, and how these correspond to the location and orientation of expected discontinuities;
- the coverage of the test object and the ROI.

6 Requirements for personnel and equipment

6.1 Personnel qualifications

Personnel performing testing in accordance with this document shall be qualified to an appropriate level in accordance with ISO 9712 or equivalent in the relevant product sector or industrial sector.

In addition to general knowledge of ultrasonic weld testing, the operators shall be familiar with, and have practical experience in, the use of the TFM technique or related technology. Specific training and examination of personnel should be performed on representative test pieces. These training and examination results should be documented. If this is not the case, specific training and examination should be performed with the finalized ultrasonic test procedures and selected ultrasonic test equipment on representative samples containing natural or artificial reflectors similar to those expected. These training and examination results should be documented.

6.2 Test equipment

6.2.1 General

In selecting the system components (hardware and software), ISO/TS 16829 gives useful information.

6.2.2 Instrument

The ultrasonic instrument used for the TFM testing shall be in accordance with ISO 18563-1, if applicable.

The instrument shall be able to acquire a full or partial matrix and either process it by itself or transmit it to a computer for post-processing. It is recommended that a sampling rate of the A-scan be used of at least five times the nominal probe frequency. It is recommended that the bandwidth of the ultrasonic instrument is sufficient to receive signals of at least two times the centre frequency of the probe, and that high- and low-pass filters are set to appropriate values, e.g. high-pass set not higher than half the centre frequency and low-pass set to at least twice the centre frequency. The specific values selected for these parameters, if applicable, shall be explicitly specified within the written procedure.

The minimum spatial resolution of data points within the image (i.e. grid spacing, nodes) should be chosen such that the amplitude of a reference reflector is stable within a specified tolerance on small

deviations (one wavelength) in the probe position. ISO 23865 contains suggested values for the spatial resolution of data points, and suggestions for the validation of the amplitude stability.

6.2.3 Probes

Ultrasonic arrays used for the TFM testing shall be in accordance with ISO 18563-2.

In order to achieve good quality images, the following properties of the array probe should be taken into consideration:

a) adequately small pitch to avoid spatial aliasing;

b) highly damped elements to decrease the length of the ultrasonic wave train;

c) sufficiently small elements to avoid too much directivity;

d) appropriate dimensions (both along the primary axis and the secondary axis of the array) to allow for imaging at a distance away from the probe, as the TFM algorithm has optimal results in the near field of the probe;

e) wedge dimension optimized for effectiveness.

6.2.4 Scanning mechanisms

To achieve consistency of the images (collected data), guiding mechanisms and scan encoder(s) shall be used.

Unlike other ultrasonic techniques, maintaining a constant distance from the weld is not as important, if the resulting image consistently contains the complete area to be tested. However, for a correct evaluation, the position of the weld in the image is required, e.g. by using geometrical indications.

7 Preparation for testing

7.1 Volume to be tested

The purpose of the testing shall be defined by specification. Based on this, the testing volume shall be determined. The region of interest (ROI), or combination of ROIs, shall cover the testing volume.

For testing thicknesses <8 mm at the manufacturing stage, the testing volume shall include the weld and parent material for at least 1,25 times the thickness, *t*, of the test object on each side of the weld preparation (1 *t* for laser welds and for electron beam welds), or the proven width of the heat affected zone (based on the manufacturer's information).

For testing thicknesses ≥8 mm at the manufacturing stage, the testing volume shall include the weld and parent material for at least 10 mm on each side of the weld preparation (5 mm for laser welds and for electron beam welds), or the proven width of the heat affected zone (based on the manufacturer's information), whichever is greater.

A scan plan shall be provided in the written procedure to document the coverage, see 5.3.

7.2 Imaging typical weld discontinuities

7.2.1 Discontinuity orientation

Compared to PAUT, TFM is typically less sensitive to discontinuity orientation. However, when planar discontinuities are expected, imaging paths shall be employed that anticipate on the way ultrasound is reflected from these discontinuities. If amplitude-based sizing is to be used, then perpendicular incidence/specular reflection is required. Detection and sizing may also be performed using diffraction

signals, which rely on a pre-defined imaging path to a much lesser extent, but it should be realized that the resulting images have a lower signal-to-noise ratio and are harder to interpret.

In general, discontinuities perpendicular to the scanning surface, such as lack of fusion on a weld bevel with a low angle, require an imaging path where either the transmitted or the received path contains a reflection from the opposite surface (e.g. TT-T).

In general, discontinuities parallel to the scanning surface require an imaging path where sound reflected by the discontinuity can travel to an array element. This can be achieved by using an array directly above the discontinuity (top scanning) or by simultaneously using two arrays on both sides of the weld.

7.2.2 Discontinuity location

Compared to PAUT, the performance of TFM is typically less sensitive to the location of the discontinuity inside the weld. However, it should be taken into consideration that TFM has limitations concerning the angle, against the normal to the probe, over which discontinuities are detected.

With side scanning, discontinuities in the lower part of the weld are generally best detected with an imaging path where at least one of the transmitting or receiving paths is a direct path from the probe to the discontinuity.

With side scanning, discontinuities in the upper part of the weld are generally best detected with an imaging path containing at least one reflection at the opposite surface. This can be achieved by imaging as a direct imaging path by extending the ROI (only for testing levels A and B, only for TT-TT or LL-LL) or by imaging via an imaging path that takes into account reflection(s) on the back wall (e.g. TT-T/T-TT or TT-TT, all testing levels).

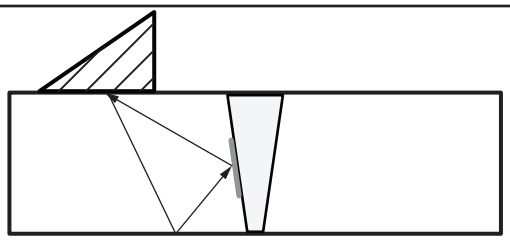
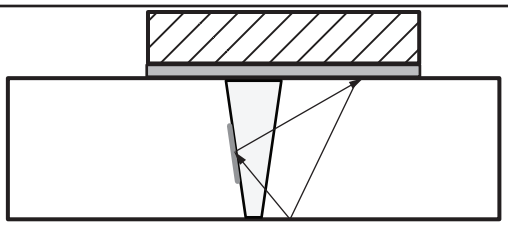
7.2.3 Suitable imaging paths for specific discontinuity types

For suitable imaging paths related to typical discontinuity types, see Table 3 which shows testing from the surface at the weld cap side.

Selected imaging path(s) may not work over the entire aperture of the array. Determination of the workable aperture should be considered in the scan plan taking into account increased diffusion and scattering of ultrasound in the weld metal.

Amplitude-based sizing requires imaging paths based on specular reflection on the discontinuities.

Table 3 — Recommended imaging paths for typical weld discontinuities

Weld discontinuity	Side scanning	Top scanning
Lack of fusion, low-angle weld bevel	 LL-L/L-LL or TT-T/T-TT or LL-T imaging path as this discontinuity is nearly vertical. Discontinuity height sizing is best performed based on diffraction signals received with a direct imaging path.	 LL-L/L-LL imaging path as this discontinuity is nearly vertical. Direct imaging path with a sufficiently large aperture.