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Non-destructive testing — Ultrasonic testing — Time-of-flight diffraction technique for detection and sizing of discontinuities

Essais non destructifs — Contrôle par ultrasons — Technique de diffraction du temps de vol pour la détection et le dimensionnement des discontinuités

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Foreword

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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 document 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).

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This document was prepared by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 3, *Ultrasonic testing*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 138, *Non-destructive testing,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 16828:2012), which has been technically revised.

The main changes are as follows:

— title revised by removing “as a method”;

— clarifications of abbreviations and symbols;

— figures have been updated;

— formulae have been corrected;

— term "dead zone" replaced by "obscured zone".

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.

Introduction

The following standards on ultrasonic testing developed by ISO/TC 135 are related.

ISO 16810, *Non-destructive testing — Ultrasonic testing — General principles*

ISO 16811, *Non-destructive testing — Ultrasonic testing — Sensitivity and range setting*

ISO 16823, *Non-destructive testing — Ultrasonic testing — Through-transmission technique*

ISO 16826, *Non-destructive testing — Ultrasonic testing — Testing for discontinuities perpendicular to the surface*

ISO 16827, *Non-destructive testing — Ultrasonic testing — Characterization and sizing of discontinuities*

Non-destructive testing — Ultrasonic testing — Time-of-flight diffraction technique for detection and sizing of discontinuities

1 Scope

This document specifies the general principles for the application of the time-of-flight diffraction (TOFD) technique for both detection and sizing of discontinuities in low-alloyed carbon steel components.

This document also applies to other types of materials, provided the application of the TOFD technique is performed with necessary consideration of geometry, acoustical properties of the materials, and the test sensitivity.

Although this document is applicable, in general terms, for discontinuities in materials and applications covered by ISO 16810, it contains references to the application on welds. This approach has been chosen for reasons of clarity as to the probe positions and directions of scanning.

Unless otherwise specified in the referencing documents, the minimum requirements specified in this document apply.

Unless explicitly stated otherwise, this document is applicable to the following categories of test objects as specified in ISO 16811:

- category 1, without restrictions;
- categories 2 and 3, specified restrictions apply (see Clause 10);
- categories 4 and 5 require special procedures, which are also addressed (see Clause 10).

NOTE Techniques for the use of TOFD for weld testing are described in ISO 10863 and the related acceptance criteria are given in ISO 15626.

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

ISO 16810, *Non-destructive testing — Ultrasonic testing — General principles*

ISO 22232-1, *Non-destructive testing — Characterization and verification of ultrasonic test equipment — Part 1: Instruments*

ISO 22232-2, *Non-destructive testing — Characterization and verification of ultrasonic test equipment — Part 2: Probes*

3 Terms and definitions

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

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

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

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

3.1
scanning surface obscured zone
scanning surface dead zone
zone where indications may be obscured due to the presence of the *lateral wave* (3.6)

3.2
back wall obscured zone
back wall dead zone
zone where signals may be obscured due to the presence of the back wall echo

3.3
perpendicular scan
scan perpendicular to the ultrasonic beam direction

Note 1 to entry: Refer to Figure 4.

3.4
parallel scan
scan parallel to the ultrasonic beam direction

Note 1 to entry: Refer to Figure 5.

3.5
time-of-flight diffraction setup
TOFD setup
probe arrangement defined by probe characteristics and *probe centre separation* (3.7)

Note 1 to entry: Probe characteristics are e.g. frequency, transducer size, beam angle, wave mode.

3.6
lateral wave
longitudinal wave traveling the shortest path from transmitter probe to receiver probe

3.7
probe centre separation
PCS
distance between the index points of transmitter and receiver probe

Note 1 to entry: The PCS for two probes located on a curved surface is the straight-line, geometric separation between the two probe index points and not the distance measured along the surface.

4 Symbols and units

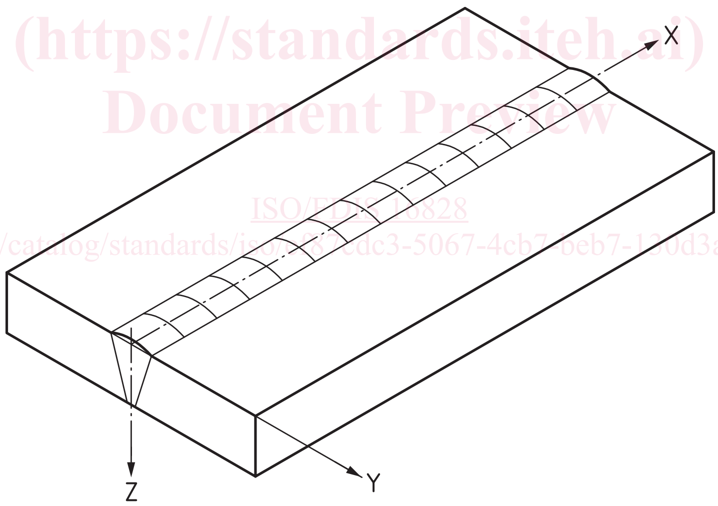
A list of the symbols and units used in this document is given in Table 1.

Table 1 — Symbols and units

Symbol	Unit	Meaning
D_{ds}	mm	depth of the scanning surface obscured zone
D_{dw}	mm	depth of the back wall obscured zone
d	mm	depth of a discontinuity tip below the scanning surface
δd	mm	error in depth
R	mm	spatial resolution

Table 1 *(continued)*

Symbol	Unit	Meaning
s	mm	half the distance between the index points of the two ultrasonic probes (half the PCS)
δs	mm	inaccuracy in half the probe centre separation
t	µs	time of flight from the transmitter to the receiver
Δt	µs	time-of-flight difference between the lateral wave and a second ultrasonic signal
δt	µs	inaccuracy in time of flight
t_d	µs	time of flight at depth d
t_p	µs	duration of the ultrasonic pulse measured at 10 % of the peak amplitude
t_w	µs	time of flight of the back wall echo
W	mm	wall thickness
X	mm	coordinate parallel to the scanning surface and parallel to a predetermined reference line. For weld testing this reference line should coincide with the weld. The origin of the axes may be defined as best suits the test object (see Figure 1)
Δx	mm	discontinuity length
Y	mm	coordinate parallel to the scanning surface, perpendicular to the predetermined reference line (see Figure 1)
δy	mm	inaccuracy in lateral position
Z	mm	coordinate perpendicular to the scanning surface (see Figure 1)
Δz	mm	discontinuity height
v	mm/µs	sound velocity
δv	mm/µs	inaccuracy in sound velocity



Key

X, Y, Z main coordinates (see Table 1)

Figure 1 — Definition of coordinates

5 General

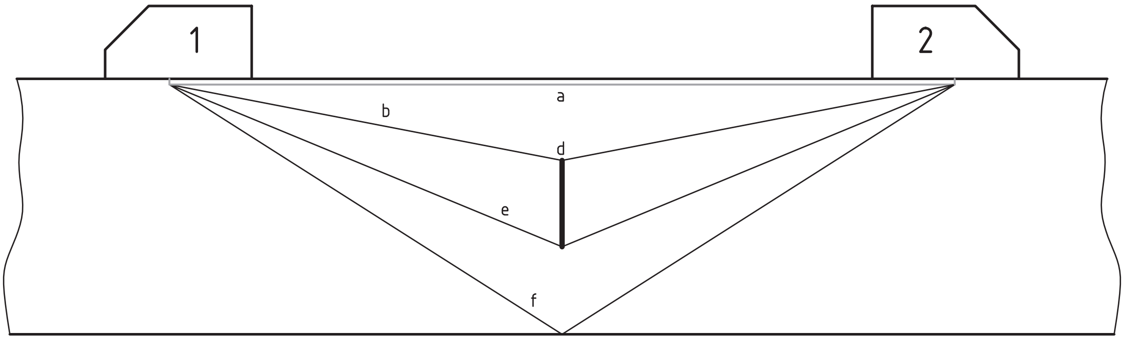
5.1 Principle of the technique

The TOFD technique relies on the interaction of ultrasonic waves with the tips of discontinuities. This interaction results in diffracted waves over a large angular range. Detection of the diffracted waves makes it possible to establish the presence of the discontinuity.

The time of flight of the recorded signals is a measure for the height of the discontinuity, thus enabling sizing of the discontinuity.

The dimension of the discontinuity is always determined from the time of flight of the diffracted signals.

The signal amplitude is not used in size estimation.



Key

1 transmitter probe

2 receiver probe

a Lateral wave path.

b Upper tip path.

d Discontinuity.

e Lower tip path.

f Back wall echo path.

Figure 2 — Basic TOFD configuration

The basic configuration for the TOFD technique consists of separate ultrasonic transmitter and receiver probes (see Figure 2).

Longitudinal wave probes with wide-angle beams are typically used since the diffraction of ultrasonic waves is only weakly dependent on the orientation of the discontinuity tip. This enables the testing of a certain volume in one scan.

However, restrictions apply to the size of the volume that can be tested during a single scan (see 8.2).

The first signal to arrive at the receiver probe after emission of an ultrasonic pulse is usually the lateral wave which travels just beneath the scanning surface of the test object.

In the absence of discontinuities, the second signal to arrive at the receiver probe is the back wall echo.

These two signals are typically used for reference purposes. If mode conversion is neglected, any signals caused by discontinuities in the material should arrive between the lateral wave and the back wall echo, since the latter two correspond, respectively, to the shortest and longest paths between transmitter and receiver probe. For similar reasons the diffracted signal generated at the upper tip of a discontinuity will arrive before the signal generated at the lower tip of the discontinuity. A typical pattern of indications (A-scan presentation) is shown in Figure 3 for the configuration shown in Figure 2.

The height of the discontinuity can be deduced from the difference in time of flight of the two diffracted signals (see 9.1.5).

Note the phase reversal between the lateral wave and the back wall echo, and between echoes of the upper and lower tip of the discontinuity.

Where access to both surfaces of the test object is possible and discontinuities are distributed throughout the wall thickness, scanning from both surfaces will improve the overall precision, particularly in regard to discontinuities near the surfaces.