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Non-destructive testing — Ultrasonic guided-wave testing using the phased-array technique

Essais non destructifs — Essais par ondes ultrasonores guidées utilisant la technique multiélément

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Foreword

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This document was prepared by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 3, *Ultrasonic testing*.

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Introduction

To improve guided-wave tests, coverage will be extended from above-ground to underground facilities, and the technology will transition from single-element use to multi-element phased-array technology. Noticeable advantages in using the phased-array ultrasonic guided-wave technique over the conventional single-element technique are improvements in the signal-to-noise ratio (SN ratio) and in the testing reliability in harsh environments like buried or coated pipelines.

A low signal-to-noise ratio in buried or coated pipe reduces the sensitivity and the range of conventional guided-wave testing. The phased-array guided-wave focusing method presented in this document can overcome this issue. Beam focusing and steering with the proper mode selection is a key benefit.

Non-destructive testing — Ultrasonic guided-wave testing using the phased-array technique

1 Scope

This document specifies a concept of application of phased-array guided-wave testing for various types of inaccessible structures, including buried pipelines.

Materials considered are carbon steel and stainless steel. This document does not include principles and criteria for underground facilities and the phased-array ultrasonic guided-wave testing scheme.

Furthermore, this document consists of an optimized process to draw reliable test results on inaccessible pipe cases. This document provides guidance on the use of phased-array guided-wave testing for various types of inaccessible structures, including buried pipelines made of carbon steel and stainless steel. The methodology outlined in this document includes an optimized process for achieving reliable test results on inaccessible pipe cases, with adjustments made to the beam pattern of the GW's focus location based on the defect type, location, and frequency. The process also takes into consideration the distribution diagram of the guided waves and the characteristics of the selected mode, with optimal focusing and steering achieved by adjusting the excitation time delay for each transducer based on the number of circumferential arrangement intervals of a given array probe.

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 18211, *Non-destructive testing — Guided-wave testing of above-ground pipelines and plant piping using guided-wave testing with axial propagation*

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 18211 and ISO 23243 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/

4 Personnel requirements

The personnel performing phased-array ultrasonic guided-wave testing shall be qualified in accordance with ISO 9712 (Level 1 with an additional 6-month training).

If ISO 9712 is not applicable to a specific situation, such as in cases where the relevant industrial sector has established other equivalent standards, those standards shall be used instead.

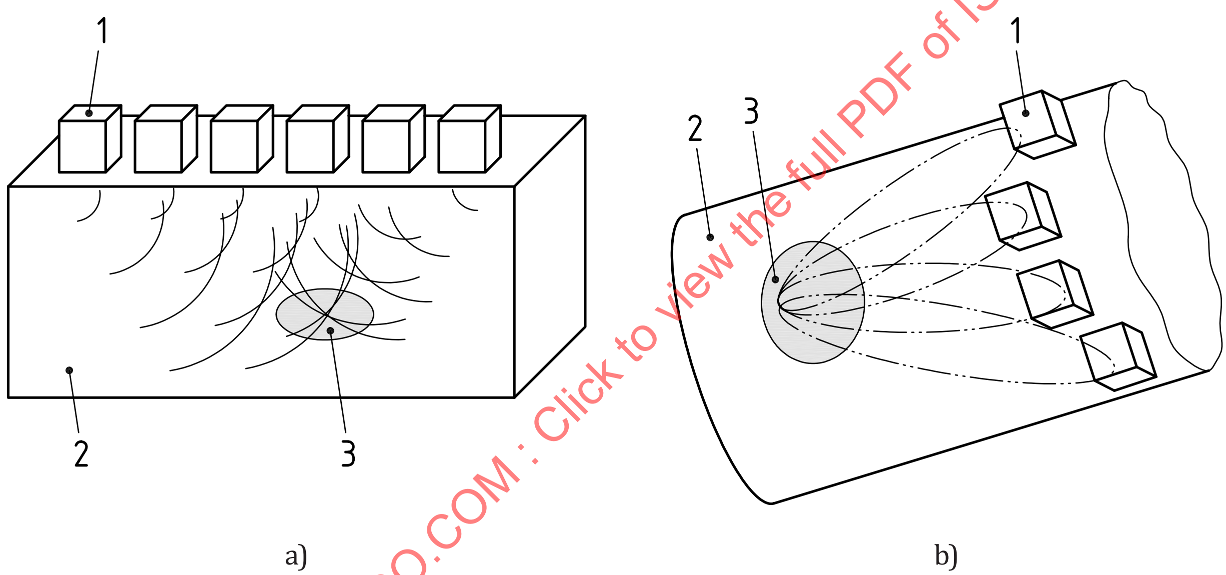
The personnel shall be trained on the use of the specific test equipment because there are significant differences between the available systems and diagnostic approaches.

5 Principles of phased-array guided-wave testing

The phased-array guided-wave testing is a technique that enables focusing and steering of ultrasonic waves by synthesizing a plurality of ultrasonic beams having a phase difference through a time delay between different ultrasonic probes. The phased-array guided-wave technique enables focusing and steering of ultrasonic beams.

Previously, as shown in Figure 1, only the synthesis of bulk wave signals was used. A similar principle can be applied to the signal synthesis of guided-waves; and this principle is applied to improve the reliability and test signals of guided-wave ultrasonic testing.

The phased-array probe is divided into torsional-mode and multi-mode modules (torsional, longitudinal), and each module is connected to a multi-channel instrument. The multi-channel modules are operated sequentially with time delay, focusing and steering the ultrasonic beam to the volume to be tested.



Key

1 probe element

2 test object

3 imperfection

Figure 1 — Schematic showing the difference between the conventional phased-array ultrasonic testing (UT-PA) and the described guided-wave testing; a) Conventional UT-PA; b) Described guided-wave UT-PA.

6 Test equipment

6.1 General

The pulse-echo mode or pitch-catch mode technology shall be used.

The electronic system used for signal processing and analysis shall be capable of distinguishing the induced wave modes used in specific detection systems.

The instrument shall also have a device to display and record data.

For covered test objects, the following procedure shall be applied:

a) determine the maximum possible distance for testing according to the covering environment;

b) dismantle the covering material and remove the buried soil to install the guided-wave array module;

c) secure access space for the operator;

d) secure access space for equipment, equipment installation and initial software operation checks;

e) prevent interference of the initial diffusely reflected signal in the sound field near the guided-waves.

6.2 Test instrument

The test instrument shall be able to perform the following functions:

a) to generate and receive pulses in a frequency range of 20 kHz to 1 000 kHz;

b) one or more of the following guided-wave modes:

— longitudinal guided-wave mode;

— torsional guided-wave mode;

c) a focusing function to allow specific testing of suspected areas;

d) synthetic focusing:

e) focusing:

   1) deliberate concentration of guided-wave modes at a single circumferential and axial position.

   2) controlling a multi-mode probe module to function differently at different positions on the surface of an object enables the possibility of focusing the testing at a specific axial and lateral position on the object. This enhances sensitivity and spatial selectivity. To achieve this, the data collection process needs to be repeated for each axial and lateral position of interest.

6.3 Probe

a) Probes for transmitting and receiving signals shall be able to tune proper guided-wave modes in a pipe.

b) When using more than two guided-wave modes, the wave modes shall be applied to test object separately, not simultaneously.

c) Probe element with a frequency range of 20 kHz to 1 000 kHz shall be used; either one continuous ring or an individual probe may form a ring, resulting in axial symmetrical waves.

d) Other frequencies may be used for specialized tests specified in the test procedure.

6.4 Environmental requirements

The following environments shall be considered:

a) in the case of cladding or coating, the coating material, the bonding strength of the coating to the pipe surface, the area and volume of the coated area, the installation period of the coating material;

b) for buried test objects, soil quality, earth pressure (depth of burial, compressive strength of soil and pipes, buried period), moisture content, length and area of buried site;

c) other criteria, e.g. whether straight pipe or curved pipe, number of elbow positions, position of welds, support positions and their shape.

7 Periodical check of the test equipment

7.1 Periodical check of the instrument

The instrument shall be checked every 12 months by the manufacturer or a qualified test laboratory. After repairs and when a new software version is loaded, a check shall also be performed on the following:

a) power capacity;

b) pulser frequency and amplitude;

c) receiver input impedance;

d) DAC (distance amplitude curve);

e) linearity of TCG (time-corrected gain).

7.2 Periodical check of probe

Perform a visual check of the probe. If there is a damage, replace the probe. A visual and functional check of testing hardware system is required.

The periodical checks shall be performed according to ISO 18563-3.

7.3 Check of the complete system setting

The setting of the system shall be performed by default using pipes in service. Based on the checklist in Annex A, it shall be checked before and after the test.

The following processes shall be performed.

a) The integrity of a probe shall be verified.

b) The checks shall take into consideration the positions of the weldment, branch and coupling zone of the test object.

c) System configuration and setting are required for each testing (including a series of similar tests) and for system alterations.

7.4 Recording level

The recording level shall always be more than 6 dB above the noise level.

8 Test procedure

8.1 General

The test procedure includes the following steps:

a) preparation of testing;

b) probe test position;

c) data collection;

d) data interpretation;

e) detection sensitivity;

f) visual confirmation.

8.2 Pre-requisites for object

The following information on the test object shall be provided as a minimum:

a) material, diameter and thickness;

b) clearance of the pipe;

c) welding treatment, e.g. circumferentially, axially welded, helically welded;

d) expected test range of the pipe;

e) pipe configuration (buried, coated, bends);

f) probe arrangement on test object;

g) information on pipe support;

h) conditions of pipe surface (insulation, coating);

i) fluid flow rate in pipe;

j) temperature of pipe;

k) limitations of testing;

l) testing timeline.

8.3 Setting of the equipment

8.3.1 Coating removal process for probe setup

For the purpose of setting up the probe, the process of removing the coating of the setting region, a non-metallic paint and epoxy up to 1 mm thickness, may be used, as long as it is well-bonded.

8.3.2 Setting of sensitivity and range

The main parameters that govern the propagation of guided-wave are:

— generated wave mode (e.g. $L(0,1)$, $T(0,1)$);

— test frequency;

— pulse bandwidth (determined by the excitation pulse duration and shape);

— pulse repetition frequency.

When no basic guideline exists for the setting of the instrument, the minimum requirements are as follows.

a) The frequency and bandwidth shall match the specific guided-wave mode, related to the pipe geometry and evaluation processing.

b) The pulse repetition frequency shall be chosen considering the attenuation of the previous pulse amplitude. The previous pulse amplitude of the wave packet shall be attenuated as zero.

c) A sufficient signal-to-noise ratio shall be provided by gain adjustment and frequency filtering to be able to cover the maximum possible range according to the probe type used.

8.3.3 Setting of DAC and TCG

The setting of DAC and TCG shall be performed according to the following procedure.

a) When a pipe section of the test range has an appropriate reflector, such as a flange or open end, it shall be used for setting with a 100 % section change.

b) In the absence of flanges or openings, one or more circumferential welds in the test range shall be used for setting.

c) The nominal wall thickness shall be between 6 mm to include quarter inch material and 13 mm.

d) The reflection at a circumferential weld may be confirmed by a 20 % section change.

e) If possible, the weld cap should be tested to achieve a precise value of the section change.

f) If inaccessible, the reflection at a circumferential weld may be replaced by the reflection of a 20 % section change.

g) To establish DAC or TCG with respect to the standard amplitude, a guided-wave attenuation factor shall be specified by considering the distance along the axis.

h) Normal to the pipe axis, the machined surface defines a 100 % sound level, i.e. 0 dB in the logarithmic decibel system.

Thus, the circumferential weld with a 20 % sound level corresponds to −14 dB; and the 5 % sound level corresponds to −26 dB.

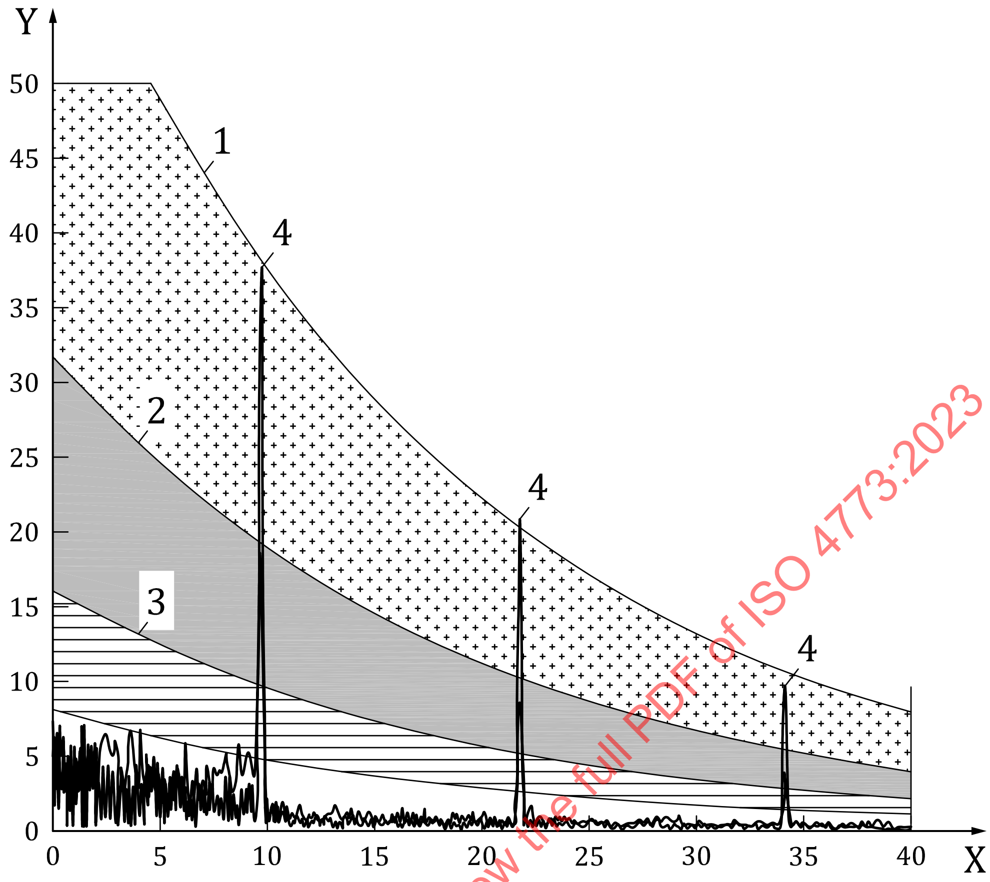
8.4 Classification of signals

The classification levels are illustrated in Figure 2. Three categories are specified:

Category 1 — signals between the −26 dB curve (5 % curve) and the noise level (2,5 % curve);

Category 2 — signals between the −20 dB curve (10 % curve) and the −26 dB curve (5 % curve);

Category 3 — signals between the −14 dB curve (20 % curve) and the −20 dB curve (10 % curve).



Key

X	distance in m	Y	signal in mV
1	curve -14 dB		category 1
2	curve -20 dB		category 2
3	curve -26 dB		category 3
4	weld signal		

Figure 2 — Example of DAC curves and categories

8.5 Periodical check of settings

If a guided-wave system setup is changed, the following points shall be properly checked and adjusted.

a) When a part of the test system is changed, a verification shall be performed using a basic test object to verify whether there is a change in the detection range and sensitivity setting.

b) Check whether the selected mode and frequency are well generated.

c) Check the setting table for equipment operation procedure standards.

8.6 Performing the test

The placing of the probes shall be done according to the following procedure.

a) The position of the probe shall be at the centre of the test object or at the end of its longitudinal axis.

b) In near field of the probe, considering the near field zone, the guided-wave mode is not properly formulated. Moreover, no additional structure shall exist for a well-propagating wave signal.

c) When attached structures exist within the near field, the probe set shall be positioned on the test object, as far away as possible from these structures.

d) When placing probes between weld regions or over two attached structures, they shall not be mounted overly close to the regions to avoid the near field effect.

e) The probe shall be positioned on a clean surface.

9 Evaluating the test results

9.1 General

Not all reflected signals indicate imperfections, e.g. a pipe support, girth welding zone, clamping zone, branch and rug.

The depth and circumferential extent of an imperfection and the axial sound path affect the guided-wave reflection factor.

The main factor of reflection is the variation of the change of cross section.

9.2 Procedure

The data evaluation shall be done with the following principles and shall be considered in the evaluation.

a) A frequency sweeping shall be conducted over the recommended frequency range (e.g. 20 kHz to 1 000 kHz for a metallic material with expected thickness range in 1 mm to 10 mm), allowing for variation in the small circumferential extent or gradual changes in a longitudinal axial discontinuity.

b) All indications more than 6 dB above the surrounding noise level shall be evaluated by the classification criteria.

c) The main factor of reflection is the variation of the change of cross section.

d) The guided-wave signal is also generated by other reflection sources in the test object.

e) Visible conditions, e.g. welds, supports, position of branches, elbows and flanges are needed for the evaluation of guided-wave signals.

f) The depth and circumferential extent of an imperfection and axial sound path affect the guided-wave reflection factor.

g) All reflected signals do not indicate discontinuities due to additional factors such as a support, girth welding zone, clamping zone, branch and rug.

10 Test report

The test report shall include the following information as a minimum:

a) reference to this document (i. e. ISO 4773:2023);

b) identification of the tested pipeline;

c) type and manufacturer of the pipeline;

d) information about parts and locations;

e) pipe nominal wall thickness;

f) pipe diameter;

g) surface condition;

h) length of pipe;

i) number of reports or revisions;

j) test conditions;

k) identification of the test equipment (ID number);

i) manufacturer of the test equipment;

m) software version used (latest update);

n) guided-wave modes and frequencies used;

o) evaluation results;

p) name and dated signature of the responsible operator/inspector.

Annex A
(normative)

Checklist for the testing with ultrasonic guided-waves

A.1 Testing conditions

A.1.1 Removal of soil and insulation

The soil around the test object and the insulation outside shall be removed to inspect for defects using ultrasonic guided-wave. After proper excavation procedures to ensure the safety of personnel and equipment, the soil around the test object shall be removed, the insulation shall be carefully removed to inspect the test object for any defects using guided ultrasound or other non-destructive testing techniques. It is important to take care not to damage the piping or adjacent infrastructure during the removal of insulation. The removed insulation shall be properly disposed of in accordance with applicable regulations.

A.1.2 Placement of probes

The guided-wave probe test target shall be placed at a distance of at least the near field away from the location of the zone to be tested, which is usually 1 m for metallic test objects.

A.1.3 Pre-processing of test object

a) The surface of the collar position shall be free from obstructions such as dirt, grease, lint, rust, welding flux, weld spatter, oil and other foreign matter.

b) The coating thickness shall be checked.

c) A layer that is well coated with non-metallic paint or epoxy, i.e. 0,5 mm thickness, does not need to be removed.

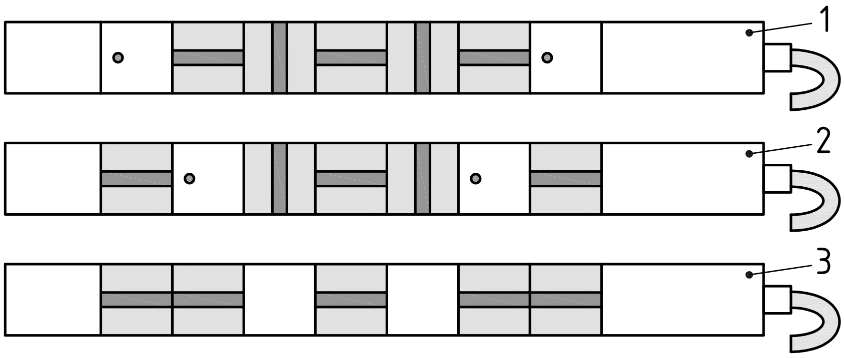
A.1.4 Measurement of thickness of joints at collar position

a) Prior to testing, the thickness of the collar joint part shall be measured.

b) If there is a problem, a part shall be measured that does not show the problem.

The problem is usually defined as a reduction in wall thickness of 10 % or more from normal. The surface temperature of the test object shall be between 0 °C and 120 °C.

A.2 Probe module type



Key

 longitudinal probes

 torsional probes

1 Multi-mode probe module (longitudinal, torsional)
2 Multi-mode probe module (longitudinal, torsional)
3 Single-mode probe module (longitudinal)

Figure A.1 — Probe modules

For this technique, piezoelectric, MsS, EMAT may be applied. But, the S/N ratio has to be checked to meet the application.

One of the following module types shall be selected:

a) Multi-mode probe module (L + T).

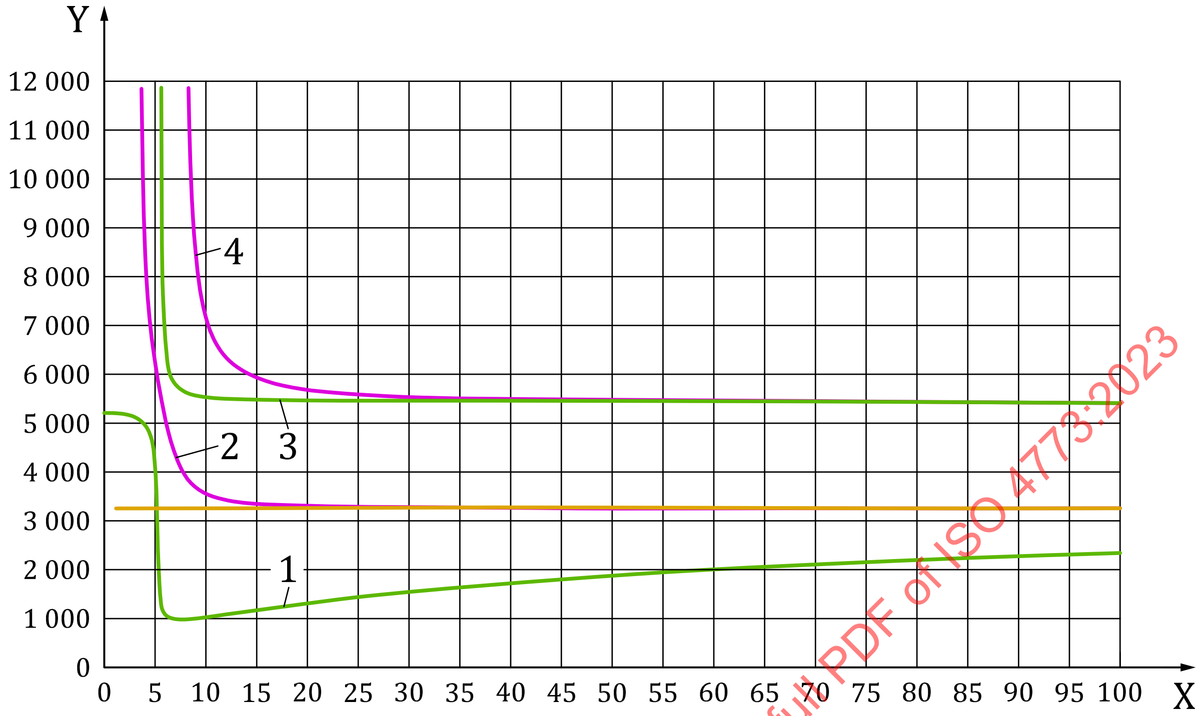
In multi-module implementation, longitudinal and torsional probes can be used together.

For longitudinal wave 30 mm or 46 mm shall be selected and 30 mm for the torsional mode.

b) Torsional module (T)

The torsional module can use 30 mm and 46 mm wavelengths at the same time.

A.3 Dispersion curves for phase and group velocities



Key

X frequency in kHz

Y phase velocity in m/s

1 L(0,0) mode

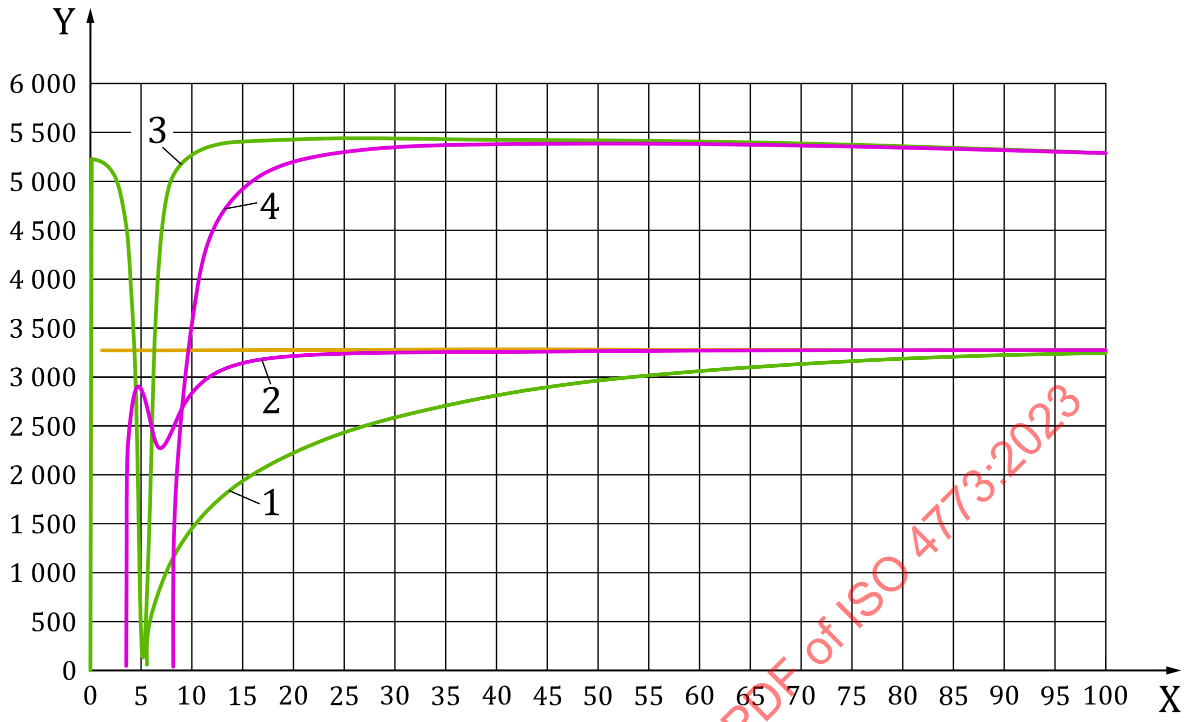
2 T(0,0) mode

3 L(0,1) mode

4 T(0,1) mode

Figure A.2 — Dispersion curves for phase velocity

Phase velocity dispersion curves can be easily recognized because, at their frequency cut off, (V_p) tends to be toward infinity. Figure A.2 shows the variation of the phase velocity (V_p) versus the frequency (f). The phase velocity (V_p) is the apparent speed of a point of constant phase within the pulse.



Key

X frequency, in kHz

Y group velocity, in m/s

1 L(0,0) mode

2 T(0,0) mode

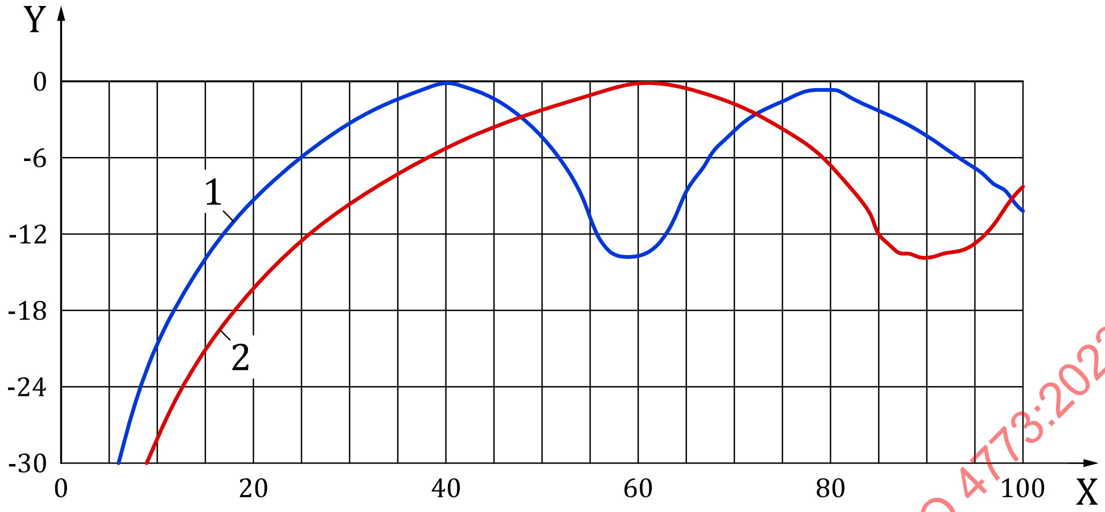
3 L(0,1) mode

4 T(0,1) mode

Figure A.3 — Dispersion curves for group velocity

The group velocity dispersion curves can be easily recognized because, at their frequency cut off, (V_g) tends towards zero. Figure A.3 shows the variation in the group velocity (V_g) versus the frequency (f). The group velocity (V_g) is the apparent propagation speed of the pulse.

A.4 Frequency selection



Key

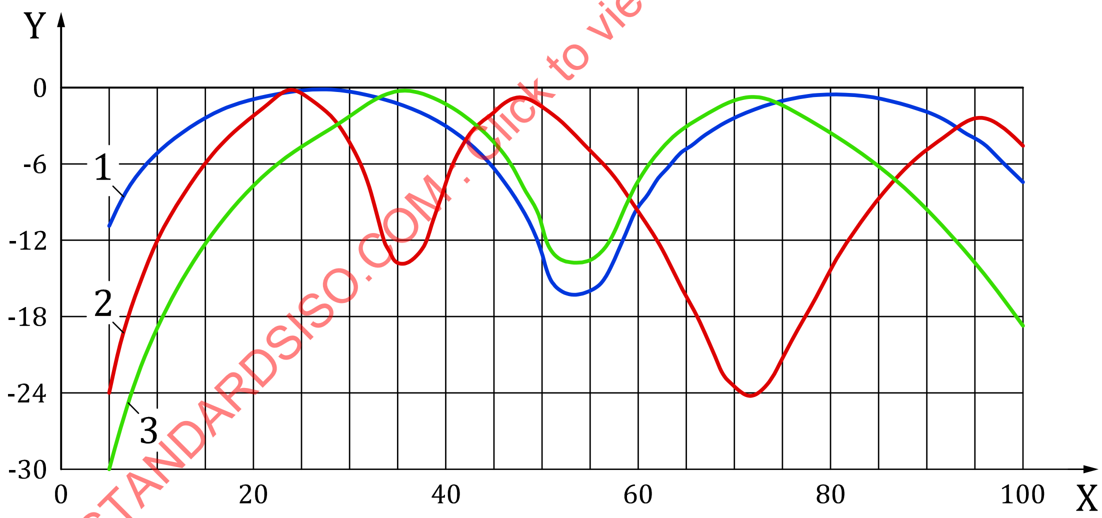
X frequency in kHz

Y output in dB

1 3 ring, 46 mm

2 3 ring, 30 mm

Figure A.4 — Effect of frequency and ring spacing on *L*(0,2) output



Key

X frequency in kHz

Y output in dB

1 2 Ring, 30 mm

2 3 Ring, 30 mm

3 3 Ring, 45 mm

Figure A.5 — Effect of frequency and ring spacing on *T*(0,1) output

The optimum test frequency bands for each probe module are shown in Figure A.4 and Figure A.5.

The closer the output is to zero, the higher the sensitivity.

