TECHNICAL SPECIFICATION

ISO/TS 16829

First edition
2017-10

Non-destructive testing — Automated ultrasonic testing — Selection and application of systems

Essais non destructifs — Contrôle automatisé par ultrasons — Sélection et application des systèmes

Reference number
ISO/TS 16829:2017(E)

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

Contents

Page

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).

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

For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

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

ISO/TS 16829 is based on technical report CEN/TR 15134:2005.

Non-destructive testing — Automated ultrasonic testing — Selection and application of systems

1 Scope

The information in this document covers all kinds of ultrasonic testing on components or complete manufactured structures for either correctness of geometry, for material properties (quality or defects), and for fabrication methodology (e.g. weld testing).

This document enables the user, along with a customer specification, or a given test procedure or any standard or regulation to select:

— ultrasonic probes, probe systems and controlling sensors;

— manipulation systems including controls;

— electronic sub-systems for the transmission and reception of ultrasound;

— systems for data storage and display;

— systems and methods for evaluation and assessment of test results.

With regard to their performance, this document also describes procedures for the verification of the performance of the selected test system.

This includes

— tests during the manufacturing process of products (stationary testing systems), and

— tests with mobile systems.

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*

3 Terms and definitions

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

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

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

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

4 Basic system description

4.1 Systems

There are two major applications for automated ultrasonic testing systems:

a) detection and evaluation of material defects (e.g. cracks, porosity, geometry);

b) measurement and evaluation of material properties (e.g. sound velocity, scattering).

Essential components of an automated test system are:

a) mechanically positioned and controlled ultrasonic probes and/or test objects;

b) automatic data acquisition for the ultrasonic signals;

c) acquisition and storage of probe positions in relation to the ultrasonic signals;

d) storage of test results.

A test system usually consists of several individually identifiable components. These are:

a) manipulators for probes or test objects;

b) probes and cables;

c) supply (pre-wetting), application and removal of the couplant;

d) electronic ultrasonic sub-systems;

e) data acquisition and processing devices;

f) data evaluation and display devices;

g) system controls;

h) sorting and marking of tested objects.

The complexity of a test system depends on the scope of the test and application of the system.

Test systems may be divided into stationary and mobile devices.

Examples of stationary test systems are testing machines:

— for the continuous testing of steel products, e.g. billets, plates, tubes, rails;

— for the testing of components, e.g. steering knuckles, rollers, balls, bolts, pressure cylinders;

— for the testing of composite materials, such as aerospace structures, e.g. complete wings made of composite materials, CRFP and GFRP components;

— for the testing of random samples (batch test) in a process accompanying production checks, e.g. testing for hydrogen induced cracking in steel samples.

Examples of mobile test systems are test rigs:

— for pre-service and in-service testing of components, e.g. valves, vessels, bolts, turbine parts;

— for pre-service and in-service inspection of vehicles;

— for pre-service and in-service testing of pipelines, e.g. oil or gas pipelines;

— ultrasonic testing of rails in railway tracks.

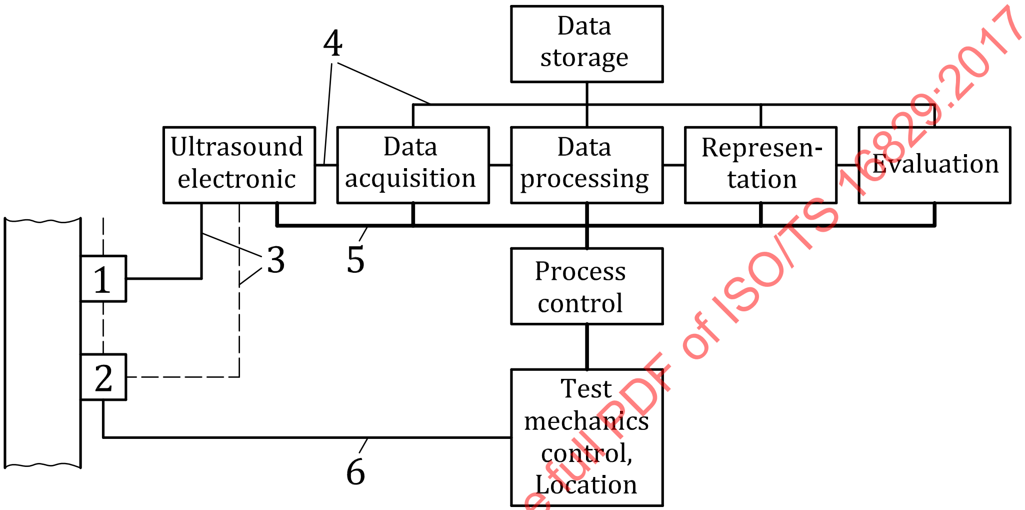
The test systems can be single or multichannel systems.

The complexity of the manipulator of the system depends on the examination task.

The complexity of the data acquisition and evaluation system depends on the number of test channels, on the required test speed, and on other test requirements.

4.2 System schematic

The essential components of an automated ultrasonic scanning system are shown in Figure 1. More detailed descriptions can be found elsewhere in this document. A detailed description of the individual functions is given in Clause 5.



Key

1 probe no 1
2 probe no 2
3 signal lines
4 data lines
5 control line
6 control line/position data

Figure 1 — System schematic

The probe position shall be determined and be recorded together with the ultrasonic data. This can be achieved by using encoders, ultrasound, or video techniques.

The most simple ultrasonic system uses only one probe (Figure 2).

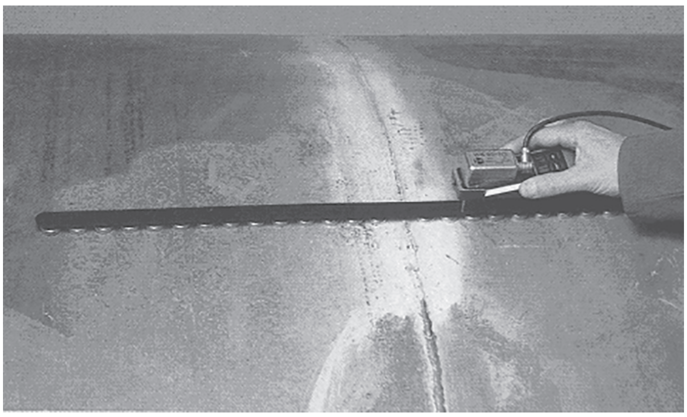


Figure 2 — Simple system with one probe

In order to fulfil more complex test requirement, the system can include several hundred probes, e.g. in a pig for pipeline testing, see Figure 3.

The ultrasonic sub-system is the main component of the complete test system. Figure 4 shows a block diagram of the basic electronic components of the ultrasonic sub-system. Depending on the required complexity, the ultrasonic sub-system can be made from one module for a single-channel system or multiple modules for multi-channel systems. These can be self-contained modules, computer plug-in cards, or rack mounted electronic systems.

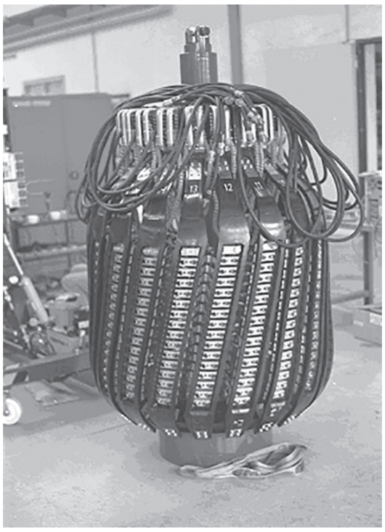


Figure 3 — Probe assembly of an intelligent pig for use on a 40-inch-diameter pipeline

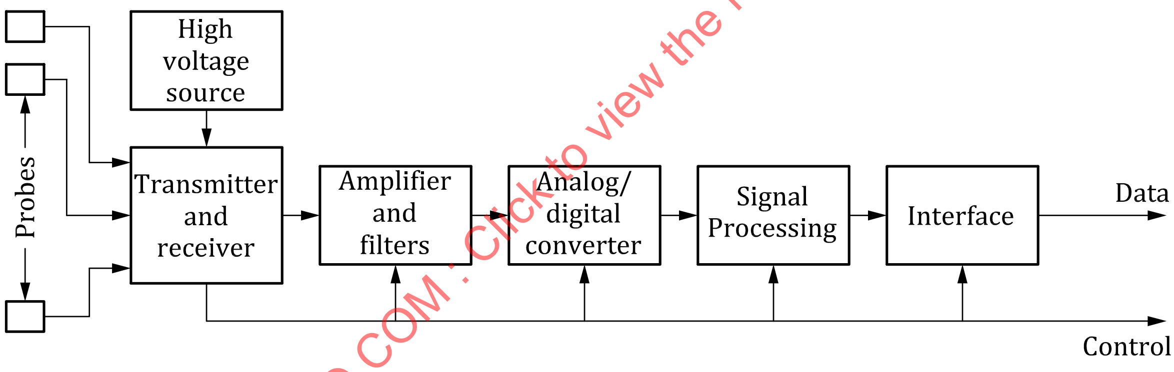


Figure 4 — Block diagram of the electronics of the ultrasonic sub-system

Some digital systems used for testing provide acquisition and storage of full RF ultrasonic signals. This mode offers the most information compared to other acquisition methods.

In order to reduce the time for testing, data processing and storage, other methods use data reduction techniques such as signal peak evaluation. For many applications, this provides a perfectly adequate level of data for the purposes of the testing.

Methods for data reduction are described in 6.6.5.2.

The data, which are transferred from the ultrasonic unit to the data acquisition unit, are referred to as test data.

In the data processing unit, the test data are processed in a way which enables them to be visualized on a display for the interpreter (user) performing the evaluation.

The data can be assessed and the test verified automatically during automated testing of objects.

In certain industrial sectors, the evaluation has to be performed by experienced test personnel, e.g. for welds on vessels and pipelines, or for safety-critical components in the aerospace industry. In these cases, the data processing unit has to provide images from the test data as a projection or sectional image. Other tasks are possible by filtering of the data to remove unwanted information. This can be achieved by software in a computer or by special hardware.

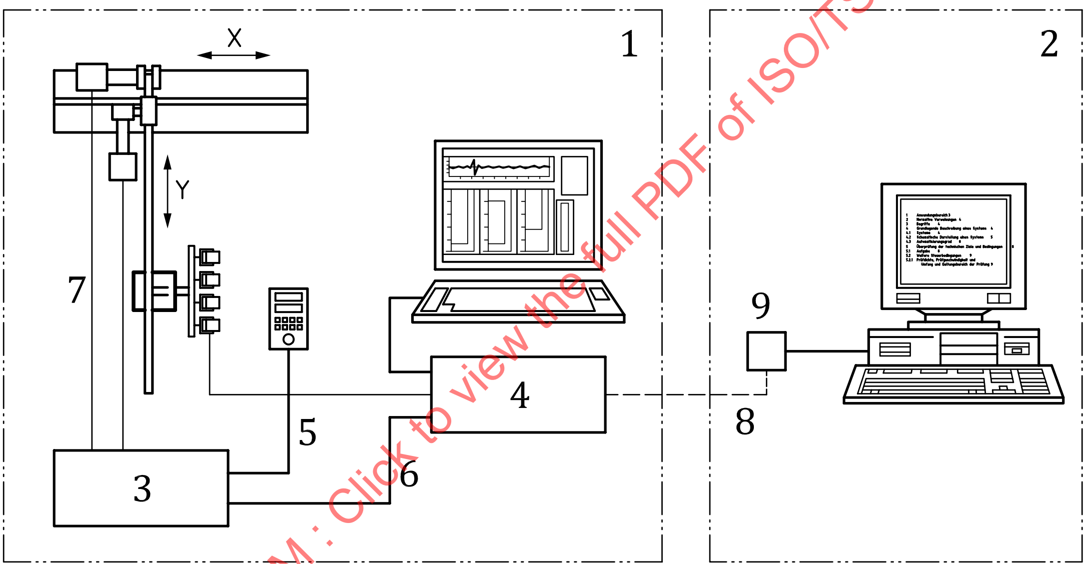
Data can be stored at different moments during the signal processing, as shown in Figure 1. If this is a simple go/no go test, only the final test result needs be recorded. In contrast, during testing of safety-critical components, the test data are stored together with any assessment result.

The control and synchronization of the individual system components is achieved by the system control. This ensures that the proper test sequence is performed.

The system control also synchronizes the storage of the probe positioning data and the ultrasonic data.

In-process testing can provide automated sorting or marking of unacceptable test objects.

A practical example of a basic system for automated scanning is shown in Figure 1. The set-up of a multi-channel test system is shown in Figure 5. This system has an XY-manipulator, and can be used for testing of vessels and pipes.



Key

1 sector of testing
- online survey
- data acquisition

2 sector of evaluation
- test planning
- data acquisition
- display
- assessment
- documentation

3 manipulator control

4 ultrasonic electronics

5 probe cable

6 position data

7 motor control, encoder signals

8 optional network link to ultrasonic electronics

9 network interface

Figure 5 — Set-up of a multi-channel test system

4.3 Levels of automation

Various levels of automated testing are possible, ranging from simple probe movement assisted by mechanical means through to fully automated acquisition and assessment of test data, and marking or sorting of test objects.

5 Examination of technical objectives and conditions of the testing

5.1 Test task

The test task specifies the discontinuities or material properties that the test is intended to detect or to measure.

The specification for the test system shall be designed within practical and economical viable limits, with due consideration to the properties of the test object.

Any existing relevant normative documents shall be taken into consideration.

The technical limits of the test system are governed, by amongst other things, the following parameters:

a) overall signal-to-noise ratio of the ultrasonic sub-system;

b) bandwidth of the probe(s) and the ultrasonic sub-system;

c) spatial resolution of the sound beam(s).

The most important factor in all methods of automated scanning is the system's dynamic lateral resolution. The scanning pattern and the scanning speed shall be specified in accordance with the sound beam dimensions as determined by a relevant reflector.

5.2 Other important conditions

5.2.1 General

The following conditions shall be considered for the specification of the test system:

a) requirements governed by the material properties, e.g. surface conditions and coupling requirements;

b) standards, guidelines and other specifications;

c) limitations to perform the testing, e.g. by test environment, accessibility, weather conditions, and power restrictions.

5.2.2 Scanning density, test speed, extent and coverage of testing

High speed testing is typical in automated scanning. This generates large amounts of data. If this is to be automatically assessed, processing speed is a key issue.

There is a relationship between the gap between points of testing, speed of probe motion, pulse repetition frequency, and speed of data acquisition. This relationship shall also consider the number of channels.

If the probe is moved in a direction x and test data have to be taken equidistantly (either amplitude or time-of-flight), the following condition shall be satisfied:

$$v < \left(\Delta x * f_r\right) / n \quad (1)$$

where

- v is the scanning speed on the test object (mm/s);
- Δx is the distance between test points (mm);
- f_r is the pulse repetition frequency (Hz);
- n is the number of pulses required per test point.

If the complete A-scan has to be acquired at each test point, Formula (2) applies:

$$v \leq \Delta x / t_s \tag{2}$$

where

- v is the relative speed between probe and test object (mm/s);
- Δx is the distance between test points (mm);
- t_s is the acquisition and storage time of an A-scan.

Normally, the transfer time of an A-scan to a storage medium (e.g. hard disk) is longer than the duration (length) of an A-scan. In this case, t_s shall be equal to the slowest process step in the system.

5.2.3 Environment

Special consideration shall be given when the test system has to be used in harsh environments, e.g.:

- — ionizing radiation;
- — extreme temperature of the test object or the environment it is in;
- — very high or low pressure in the environment (air or water pressure);
- — aggressive atmosphere;
- — areas at risk of explosion.

5.2.4 Material properties

Material properties may cause problems in performing an ultrasonic test. The following material properties may cause problems:

- — coarse grain structure (castings, austenitic steel, and concrete);
- — inhomogeneous structure (varying structure in the same object);
- — anisotropy (texture of wrought and forged products, columnar crystalline structure in austenitic welds, and in fibre-reinforced composites);
- — interfaces (dissimilar welds, composites, hardened zones).

These properties are often combined. They interfere with the propagation of the sound waves and may cause the following problems:

- — spurious indications;
- — errors in locating of indications;

— wave mode conversion;

— sensitivity variations;

— local zones, which are not tested.

By selecting suitable techniques, these problems may be reduced or eliminated. An example is the testing of austenitic welds where the evaluation of the test results is often possible only after processing of B-scans and C-scans, which may be compared with the pattern of indications from previous tests or from tests on test blocks containing known reference reflectors.

5.2.5 Complex component geometry

On complex geometries, an A-scan alone is insufficient for the evaluation. In such cases, position related B-scans or C-scans, as well as imaging, e.g. synthetic aperture focusing techniques (SAFT), holography or tomography, shall be considered.

These images, produced from time-of-flight and amplitude information (data), enable differentiation between indications caused by geometry and those caused by discontinuities. Pattern recognition may also be used to detect items of interest.

EXAMPLE For the testing of the spherical heads and bottom sections of nuclear pressure, vessels, very often array probes, are used. These run on the spherically curved surface on predetermined tracks between the nozzles for control and measuring rods. Testing for cracks on the inner surfaces is done by varying the skew and beam angles of the probes. B-scans from these tracks running parallel to each other are then compared. It is simple to differentiate between indications from cracks and from geometry.

5.3 Test data

The collected data shall be extensive enough to enable an assessment according to the required test specification.

5.4 Reference blocks

It is recommended to use a set of reference blocks representative of the test object to ensure the sensitivity and suitability of the overall system. The reference blocks shall have acoustical properties same or similar to the tested material. The blocks shall contain reference reflectors that represent the various discontinuities that need to be detected.

The reference reflectors allow to determine the detectability of a particular type of discontinuity and the limits of detection.

The overall system should be checked with the reference blocks at regular intervals to maintain the reliability of testing.

6 Components and features of an automated test system

6.1 General

The requirements on any individual test system are dictated by the application. The set-up and the operation mode are determined by the technical objectives of the test technique and all prevailing conditions.

Selection of any single component of the system is based on the test task and its ability for achieving the desired test results.

Major characteristics of a test system are discussed in the following subclauses.

6.2 Test mechanics and positioning systems

6.2.1 General

Automated ultrasonic testing requires a movement of probe(s) and test object relative to each other. The probe guidance mechanism provides the spatial relationship between the probe(s) and the test object. The probe position is usually determined by electro-mechanical and/or electronic means (position encoders).

The control of the mechanism may also provide:

a) control/guidance of other sensors (manually or mechanically);

b) control/guidance of the test object;

c) synchronization between other sensors and the test object;

d) feeding and removal of the test objects;

e) supply, application, and removal of the couplant.

In mobile test systems. the mechanics usually move the probe in relation to the test object. In stationary (fixed) test systems, the mechanics usually move the test object in relation to the probe. Stationary test systems are usually integrated into the production process of the test object.

Some of the parameters that shall be considered when designing a test system:

6.2.2 Grade of mechanisation/automation required

Different grades might be:

a) mechanized or hand-operated guidance of the probes;

b) machine-operated mechanized guidance of the probes;

c) manual feeding and removal of the test objects;

d) mechanized or automated feeding and removal of the test objects;

e) automated guidance of the sensors when the test object is outside the production process;

f) automated guidance of the sensors when the test object is in the production process;

g) marking or sorting of the test objects after semi- or fully automated assessment.

6.2.3 Test object

a) shape;

b) material;

c) surface condition;

d) temperature.

6.2.4 Scale of testing

a) testing of the whole test object or only parts of it;

b) single or multiple tests on each test object.

6.2.5 Test speed/speed along the scanning path

The test speed is determined by the following parameters:

a) approach and reset period;

b) pulse repetition frequency;

c) sound path length;

d) single or multi-channel operation.

6.2.6 Precision of positioning

The following requirements determine the accuracy of positioning:

a) detection of specified discontinuities;

b) characterization of discontinuities (position and size);

c) reproducibility of the test results (precision of access).

For some applications, the accuracy of positioning is stipulated by standards and specifications.

6.2.7 Coupling

The mechanical system shall provide suitable and appropriate coupling for the ultrasonic waves (5.2), with particular concern to:

a) compatibility of couplant and test object (corrosion);

b) pressure;

c) temperature of the test object;

d) distance between the probe(s) and the test object;

e) viscosity of couplant;

f) supply application and removal of the coupling medium.

6.2.8 Additional system requirements

Consideration shall be given to the system's actual mechanical condition:

a) environmental conditions;

b) availability (wear resistance);

c) life cycle;

d) maintainability/repairability;

e) long-term availability of the control software and firmware.

6.2.9 Health and safety requirements

All relevant health and safety regulations shall be observed.

6.3 Coupling techniques

6.3.1 General

A coupling medium (couplant) is necessary to enable the transfer of mechanical energy (vibration) from the electro-mechanical transducer in the probe to the test object and back to the transducer.

There are other ultrasonic test techniques which operate without a coupling medium, e.g. with ultrasound generated by electromagnetic transducers (EMAT) or by lasers. With these techniques, the elastic vibrations are produced in the test object itself (5.3).

Media in all states can be used as couplant:

— gaseous state air

— liquid state water, oil, gel, etc.

— solid state metal foils, polymer foils, low melting crystals

However, not all of these are suitable for automated scanning systems. The most common couplants are water, oil and emulsions, air if applicable or combined liquid/solid coupling (as by an ultrasonic wheel probe).

6.3.2 Selection of couplant with regard to the testing environment

Conditions regarding the testing environment shall be considered when selecting couplants:

a) compatibility with the test object (e.g. avoidance of corrosion);

b) contamination of the test object by the couplant and decontamination/cleaning after testing where necessary;

c) surface of the test object (e.g. flatness or roughness of the surface);

d) contour (complex geometry) and accessibility of the test object;

e) temperature of the test object with respect to the testing couplant and probe(s);

f) testing speed;

g) contamination of the couplant by the test object (e.g. radioactivity, dangerous chemicals);

h) environmental compatibility and disposal of the couplant.

6.3.3 Selection of couplant with regard to the ultrasonic requirements

The ultrasonic test itself shall be considered when selecting a couplant:

a) wave type used;

b) transferability of ultrasound by the couplant (distortion by bubbles or other scatterers);

c) frequency and bandwidth;

d) sound beam dimensions;

e) sound path in the delay line and in the test object;

f) test technique (through-transmission or pulse echo).

6.3.4 Liquid couplants

Suggestions for coupling techniques and applications are given in Table 1.

Table 1 — Various coupling techniques using liquids

Technique	Description	Guidance of the probes
a) Immersion technique	test object completely immersed in liquid	by external mechanics
b) Partial immersion technique	liquid chamber or basin as immersion vessel for a part of the test object	by external mechanics, by test object
c) Squirter technique	sound is conducted via a long, free liquid jet	by external mechanics
d) Jet technique	liquid column is guided by nozzles close to the test object	by external mechanics, by test object
e) Contact technique	probe mounted in a shoe with a couplant filled slot between probe, probe shoe and test object	by test object
f) Flow gap coupling	thin liquid film between probe and test object; probe floats	by test object
g) Direct contact technique	direct contact of the probe shoe (with wear sole) with coupling pressure onto the test object while the surface is wettened	by test object

Immersion techniques are particularly useful for testing single objects, the others are more suitable for testing in a continuous production process.

6.3.5 Gaseous couplants

Using gaseous couplants, air for instance, offers particular flexibility on complex geometries and high testing speed. It greatly simplifies couplant handling. Other problems arising with liquid couplants are removed.

By the enormous differences of acoustic impedance between the gas and the test object result in high signal losses, this necessitates the use of low frequency ultrasound (up to 1 MHz), usually in through-transmission mode. Due to the low acoustic velocity of air testing, this is also restricted to low pulse repetition rates.

6.3.6 Solid couplants

If required, a solid couplant can be used. A silicone foil offers dry coupling through a soft solid.

The wheel probe has an oil-filled tyre containing a probe transmitting sound waves radially, this offers a combination of liquid and dry coupling. A slight wetting of the surface of the test object is advantageous when using a wheel probe.

In practice using solid couplants is problematic since undesirable air/gas interface layers may arise between the test object and the probe.

6.4 Probes

6.4.1 General

Probes contain transducers, usually piezo-electric devices, which convert electrical vibrations into mechanical onces and vice-versa. Probes can therefore transmit ultrasonic waves as well as receive.

Other principles of ultrasound generation and reception are also available for non-destructive testing. Examples are electro-magnetic ultrasonic (EMAT) probes and laser sources. With both techniques, the surface layer of the test object forms part of the acoustic transducer.

In most cases, the pulse-echo technique is used. Short ultrasonic pulses are transmitted into the test object. They are reflected, diffracted or scattered by discontinuities in the test object creating signals which are then received as echoes. Some parameters of the received signals are extracted and used for evaluation of the discontinuity. The amplitude of the signals can be used to evaluate the size of the discontinuity. The time-of-flight of the signals enables the location of the discontinuity.

6.4.2 Piezo-electric probes

6.4.2.1 General

Piezo-electric probes can be specifically designed to suit the application. The geometry of the test object, the area to be covered, the required resolution and the required wave type [longitudinal (compressional) or transverse (shear)] shall be considered.

Besides the active piezo-electric transducer other important elements of a probe for pulse-echo testing are a damping element, protective or matching layers, electrical matching circuits and the housing.

6.4.2.2 Piezo-electric transducer materials

Usually the piezo-electric transducer is a thin plate. The nominal frequency, f_n, of a transducer is determined by the thickness, d, of this plate:

$$f_n = \frac{c}{2d} \tag{3}$$

where c is the sound velocity (longitudinal wave) in the piezo-electric material.

Because the frequency is inverse proportional to the thickness of the transducer plate the required thickness decreases with increasing test frequency which in turn reduces the mechanical resistance of the plate.

The piezo-electric transducer in most cases is made from ceramic material. The most common ceramics is lead zirconate titanate (PZT), lead titanate ($PbTiO_3$) and lead metaniobate ($PbNb_2O_6$) are also used. These ceramics are used for test frequencies up to 30 MHz.

The energy transmitted into the test object is determined by this quantity, but also by the acoustic impedances of couplant and test object.

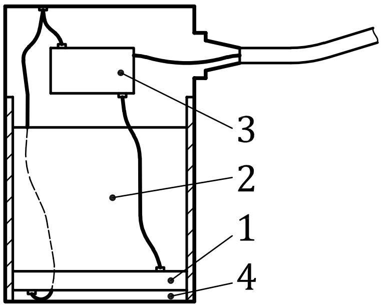
Piezo-electric foils made of polyvinylidene fluoride (PVDF) are also used as transducer material. Their low acoustic impedance provides efficient transmission, particularly for the immersion technique. These foils are rarely applied in the contact techniques. High frequencies can be achieved using PVDF foils. Due to their flexibility, curved focusing transducers can easily be produced. However, their disadvantage is their poor resistance to temperature (up to about 80 °C).

Composite piezo-materials are ceramic sticks or particles embedded in an epoxy resin matrix whose properties as transducers are determined by the structure and the ratio of the components ceramic and resin. They also exhibit low acoustic impedance, like foil transducers, but combined with the high efficiency of piezo-ceramics. However, they have poor resistance to mechanical load and poor resistance to temperature (up to about 100 °C).

6.4.2.3 Layout of piezo-electric probes

The transducer is coated with electrically conducting layers on both sides and basically offers a capacitive load. The transmitted and received signals are conducted via wires connected to these conductive layers.

There is usually a damping block (mass) behind the transducer which influences the vibrational behaviour and the bandwidth of the probe housing the transducer. Mechanically attached to the piezo-electric plate, the damping block also absorbs sound waves being emitted backwards. Interfering reflections from within the damping mass are suppressed by specific shaping of the damping block. When using piezo-electric materials with low acoustic impedances (foil transducers, composites, both in contact techniques) with a plastic delay line located in front of the transducer (delay-line probes, angle-beam probes with wedges, dual-element probes), damping blocks may be omitted.



Key

1	transducer	3	electrical matching circuit
2	transducer backing (damping block)	4	matching layer/protective layer

Figure 6 — Schematic of the set-up of a piezo-electric ultrasonic probe

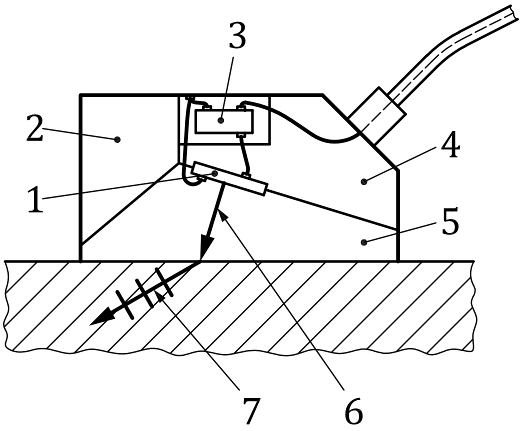
The exterior probe face provides mechanical protection and sometimes acoustic matching.

Electrical impedance can be included in the probe to provide matching to the transmission and receiving circuitry.

6.4.2.4 Probes for the contact technique

The simplest probe type is the normal-beam probe for the emission and reception of longitudinal waves in the axial direction of the probe (Figure 6).

Angle-beam probes contain a plastic wedge allowing by refraction the transmission of sound waves at a predetermined angle. The transducers of angle-beam probes very often are rectangular and usually generate transverse waves in the test object. Angle-beam probes are used for the detection of reflectors not detectable by a normal-beam probe. Weld testing is a typical field of application. The plastic wedges necessary for the refraction of waves are wear parts, so angle-beam probes are built to enable easy replacement of the wedge (Figure 7).



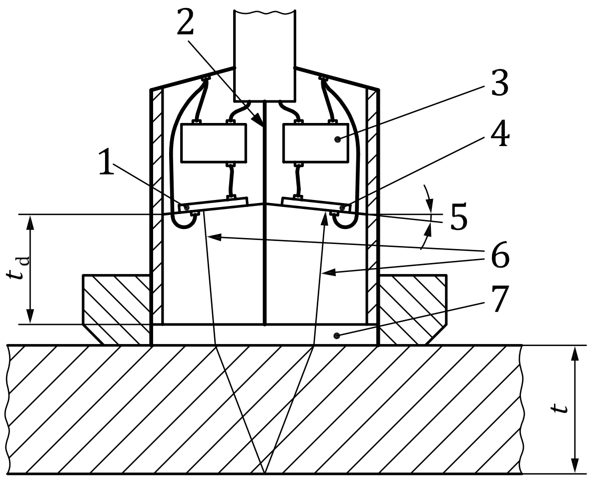
Key

1 transducer
2 absorber block
3 electrical matching circuit
4 damping block
5 wedge
6 longitudinal wave
7 refracted transverse wave

Figure 7 — Schematic of an ultrasonic angle-beam probe

Dual-transducer probes are designed with separate transducers for transmission and reception. Both transducers are electrically independent and are separated acoustically by a barrier and a delay line. This avoids cross-talk from transmitter to receiver. The transducers can be inclined towards one another (the interior angle is known as roof angle) to achieve a focusing effect and an improvement of resolution and signal-to-noise ratio in areas close to the surface of the test object. In any case dual-transducer probes can only be used for a limited depth range. When using dual-transducer probes the non-parallel sound paths shall be taken into account and suitable v-path corrections shall be made (Figure 8).

Normal-beam probes with delay block may be used, where the delay block enables to separate the transmission pulse and the usable received signal out of the test object.



Key

t	thickness of test object	4	receiving transducer
t_d	thickness of delay line	5	roof angle
1	transmitting transducer	6	delay paths
2	acoustical and electrical barrier	7	water layer
3	electrical matching circuit		

Figure 8 — Schematic of an ultrasonic dual-transducer probe

6.4.2.5 Probes for the immersion technique

For most applications of immersion testing normal-beam probes are used. The angle of incidence and/or wave type are controlled or adjusted by inclining the probe against the test object. The focusing of the sound beam is achieved by lenses or by curvature of the transducer.

Waterproof dual-transducer probes shall also be used for particular tests like automated testing of plates, billets and tubes with water gap coupling.

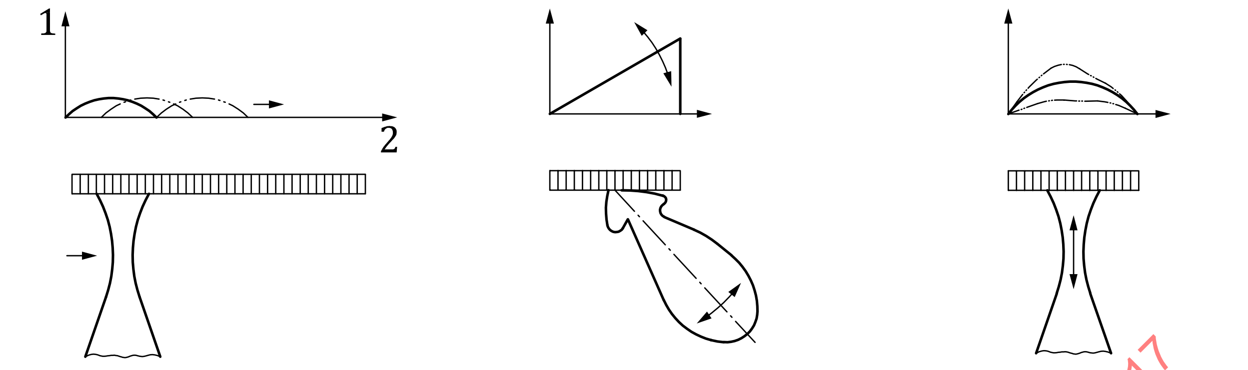
6.4.2.6 Special probe designs

Special tests may require special, individually designed or adapted probes.

Probe arrays with multiple transducers are usual for providing wide test tracks with constant testing sensitivity, e.g. when testing plates and tubes. The sound beams of the transducers overlap to an extent which enables a constant test sensitivity. Probe arrays with dual-transducer probes have been developed for the testing of plate material.

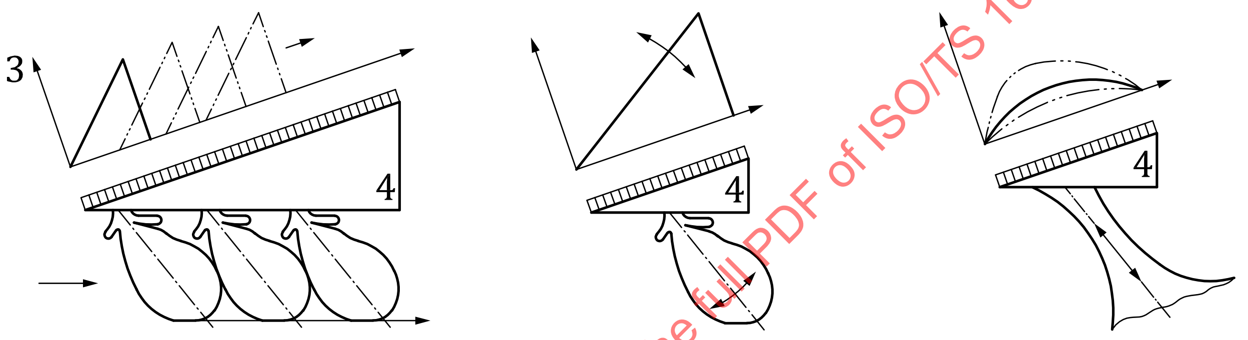
Probes bearing curved foil transducers with a linear focus have been developed for the testing of rods and tubes.

Modern test machines for semi-finished metal products use phased array probes, linear types or encircling ones if applicable. A phased array probe technique has been developed which allows control of focal point and beam direction. Phased array transducers consist of a multitude of small transducers (elements) being activated separately with electronically controlled delays during transmission and reception. Therefore, an appropriate electronic instrument and an especially adapted computer programs are needed (Figure 9).



a) Sound beam shifting b) Sound beam swivelling c) Sound beam focusing

a) Longitudinal waves



a) Sound beam shifting b) Sound beam swivelling c) Sound beam focusing

b) Transverse waves

Key

1 delay periods
2 transducer elements
3 delay periods
4 wedge

Figure 9 — Beam steering and focusing by an ultrasonic phased array system

A wheel probe is used predominantly for the testing of plates and tubes. The transducers are mounted radially in a flexible tyre filled with a liquid. The wave mode used for testing (longitudinal or transverse) is determined by the alignment of the transducer. The wheel probe can adapt to the surface of the test object due to the flexibility of the tyre. The main purpose of the application of this technique is to avoid the massive use of couplant, only a wetting of the surface of the test object may be necessary (6.3.6).

6.4.3 Electro-magnetic ultrasonic probes (EMAT)

The principle of the electro-magnetic sound generation is based on the interaction of a high frequency magnetic field with a static magnetic field which induces eddy currents in the test object which in turn produces sound waves. The ultrasonic wave is thus generated in the test object itself.

This technique can only be used in conducting materials. An electromagnetic-acoustic probe consists of one or more conductor coils residing in a magnetic field produced either by a permanent or an electro magnet. The wave modes generated are determined by the geometry of the conductor coil and the structure of the permanent magnetic field and can be:

a) horizontally polarized transverse waves;

b) vertically polarized transverse waves;

c) perpendicularly incident transverse waves;

d) surface waves;

e) plate waves.

The generated waves may also be polarized, focused and skewed to the test surface.

EMAT techniques need no couplant. This is advantageous for automated scanning, for instance for the testing of plates, tubes rods or wire. Welds on austenitic tubing may also be tested with this technique. Thin coatings on the test object can be penetrated by this technique. The electromagnetic-acoustic technique may also be used at elevated temperatures.

Electromagnetic-acoustic probes have relatively poor sensitivity, about 50 dB lower than piezo-electric probes, this can be a problem. In addition, a constant distance to the test object is necessary to maintain a constant test sensitivity. Inconsistencies in the electro-magnetic properties of the test object's surface influence the sensitivity of electromagnetic-acoustic testing. The frequency range is also limited to a maximum of 3 MHz.

6.4.4 Laser ultrasonics

Laser ultrasonics use different methods to generate and receive the ultrasonic signals, unlike piezo-electric and electro-magnetic methods. A combination of techniques is possible, e.g. transmission with a piezo-electric probe and reception with a laser.

Laser ultrasonics exploits thermo-elasticity within the test object. This is achieved by rapid localized heating or ablation (vapourising, plasmaforming) at the surface of the test object. Depending upon the excitation mechanism, different wave types and/or directional characteristics are possible.

A test object can be of complex geometry and difficult to access. Test locations can be reached by optical redirection of the laser beam. The impact angle of the laser beam is unimportant.

A laser interferometer may be used to receive the generated ultrasound signals. Here, a laser beam reflected from a surface excited by ultrasound optically interferes with a reference laser beam. The pulse repetition frequency of the interference signal corresponds to the frequency of the ultrasonic wave. Laser methods are technically more demanding than conventional techniques of ultrasonic testing. The equipment is delicate and usually difficult to transport. Any interference of the laser beam by vapour, smoke, optical streaks might handicap testing.

The following are the major advantages of laser ultrasonics:

a) the distance to the surface of the test object is of minor relevance;

b) couplants are unnecessary;

c) short, high frequency ultrasonic pulses can be generated, this offers high resolution, e.g. for the determination of wall thickness;

d) a laser beam offers testing at a small spot rather than over a relatively large integrated area as with conventional ultrasonic probes.

Possible areas of application are tests on hot objects and aircraft components (wings, rudder, etc.).

6.4.5 Special requirements for probes and cable connections

6.4.5.1 General

The probes and cable connections used for automated ultrasonic testing shall meet special requirements related to the environment at the location of the test, the coverage, and allow for easy service, maintenance and the replaceability.

6.4.5.2 Environmental conditions

The most important environmental parameters are:

a) environment and couplant;

b) temperature;

c) pressure;

d) electrical and magnetic fields;

e) radioactive radiation.

These parameters result in the following requirements to the probes and cable connections:

a) tightness and chemical resistance to environment and couplant;

b) the materials used for probe housing, transducers and cable connections shall be resistant to the relevant temperature, pressure and radiation;

c) shielding of cables and housings to ensure that electromagnetic fields, e.g. from motors and welding machines, do not reduce the signal-to-noise ratio below an acceptable level;

d) adequate earthing of components may further reduce the influence of disturbing fields;

e) ease of decontamination causing a health risk.

6.4.5.3 Test object

The geometrical shape of the test object may require special design of probes and probe holders, e.g. universal joints at probe holders or specially shaped housings. Normally, direct contact between probe and test object has to be avoided. The contact surfaces of the probe should be designed in such a way to avoid damage either to the probe or the test object. In addition, the build-up of deposits on the probe should also be avoided.

6.4.5.4 Efficiency of the test

In order to ensure an optimum performance of the testing of the probes, the mechanical parts and the controlling system shall be designed to cover the scope and extent of the testing. For the testing of plates, several transducers may be mounted in a single housing in order to cover a wide zone, or may be operated as a phased array. Similarly, the testing of tubes and pipes may be performed with multiple transducers in one single scan. Here also, phased array probes are increasingly used in order to be able to use less complicated mechanics and increase the test speed (6.4.2.5).

6.4.5.5 Service, maintenance and replaceability

In automated test systems, probes are considered consumables. In order to maintain the required test sensitivity level, it shall be necessary to replace them periodically. Changing the probes shall be a simple and a quick operation. This may also be required if the dimensions of the test object change or maintenance work has to be carried out. These conditions shall be considered during the design and construction of the test system, where an exchange should be kept within reasonable tolerances. It shall be possible to compensate for manufacturing tolerances through simple adjustments of probe positions, probe holders or housings.

6.5 Testing of electronics and signal digitization

6.5.1 Transmission and reception system

6.5.1.1 General

The essential components of the transmission and reception system of an ultrasonic instrument are

a) high voltage supply,

b) transmitter,

c) receiver,

d) amplifier, and

e) attenuator and filters

See also Figure 4.

6.5.1.2 Transmitter

The transmitter serves as a source of electric pulses (typically several hundreds of Volts) exciting the piezoelectric transducer to perform mechanical oscillations. Usual transmitter pulses are spike pulses, rectangular pulses, or bursts.

6.5.1.3 Receiver

The signals received from the probe, usually very low in the µV to mV range, are processed by the receiver electronics. The receiver contains an impedance matching circuit for matching to the impedance value of the probe plus probe cable, and also a low-noise preamplifier. Additional preamplifiers close to the probes may be utilized to compensate for long probe cables in analogue signal transmission.

In multi-channel test systems operating in parallel mode, multiple receivers shall be present according to the number of test channels.

6.5.1.4 Main amplifier and attenuator

To match the large dynamic range of the received ultrasonic signal to the signal processing system, a linear or logarithmic amplifier is necessary, which is controlled by an accurate attenuator (Table 2).

6.5.1.5 Filter

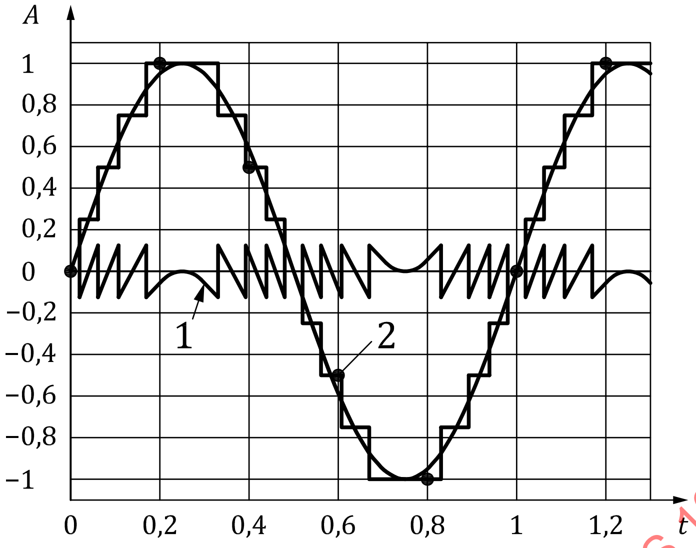
Filters are used to suppress unwanted frequency components of the received signal, thereby improving the signal-to-noise ratio. Filters can be analogue or digital.

6.5.2 Digitization

6.5.2.1 Analogue-to-digital conversion

After being processed by the receiver, the ultrasonic signal is digitized by an analogue-to-digital converter (ADC). The digitization of the receiver signals is a prerequisite for further signal processing and transfer to the data acquisition unit through an appropriate data interface (6.6.1).

At the output of the ADC, the digitized ultrasonic signal, is available as a sequence of integer values for the signal amplitude (Figure 10).



Key

1 quantization error

2 digitized values

A amplitude

T time

Figure 10 — Digitization of a sine wave signal and resulting quantization error

The amplitude resolution level depends upon the digitization accuracy of the used ADC. The higher the resolution of the converter, the lower the quantization error will be. The correlation between the digitization depth, the achievable dynamic range and the resolution of the amplitude values is shown in Table 2.

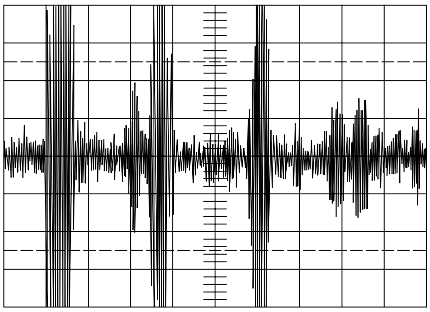
Table 2 — Correlation between digitization depth, dynamic range and resolution

Digitization depth bit	Dynamic range dB	Absolute resolution	Relative resolution %
8	48	1 in 256	0,391 3
10	60	1 in 1 024	0,097 7
12	72	1 in 4 096	0,024 4
14	84	1 in 16 384	0,006 1
16	96	1 in 65 536	0,001 5

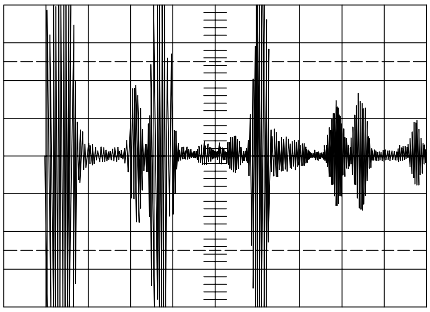
The conversion speed is another essential parameter of ADCs. Ultrasonic devices operate at frequencies between several hundreds of kHz up to about 20 MHz. The faster the analogue ultrasonic signal is scanned, the better it is represented by the amplitude function after digitization. This is an essential requirement when evaluating ultrasonic signals by the amplitude (see Figure 10).

6.5.2.2 Signal averaging

If the received ultrasonic signals contain electronic noise at considerable levels, a significant improvement of the signal-to-noise ratio (SNR) can be achieved by signal averaging (see Figure 11).



a) Without signal averaging



b) With signal averaging

Figure 11 — Improvement of the signal-to-noise ratio by signal averaging

One essential condition for the effectiveness of signal averaging is that the noise shall appear stochastically.

In some limited cases, local averaging can also be performed for reduction of structure-produced noise.

6.5.2.3 Time-of-flight measurement

The electronics of the time-of-flight counter has to operate at a sufficient digital depth, depending on the sound path length to be measured, in order to meet the requirement of accuracy of measurement for each particular task.

The significance of the digital depth of the time-of-flight counters is illustrated in Table 3.

Table 3 — Maximum achievable accuracy of a 100-mm thickness measurement

Digitization depth bit	Absolute resolution	Maximum achievable precision mm
8	1 in 256	0,391 3
10	1 in 1 024	0,097 7
12	1 in 4 096	0,024 4
14	1 in 16 384	0,006 1
16	1 in 65 536	0,001 5

Table 3 gives only the resolution of the electronic time conversion. The overall accuracy cannot be better than the values given in Table 3.