INTERNATIONAL STANDARD

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Non-destructive testing — Ultrasonic inspection — Characterization of search unit and sound field

Essais non destructifs — Contrôle par ultrasons — Caractérisation des traducteurs et des champs acoustiques

Reference number
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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.

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

International Standard ISO 10375 was prepared by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 3, *Acoustical methods*.

Introduction

In ultrasonic non-destructive testing, sound pulses are used for detecting and evaluating imperfections or flaws in a material. To obtain reproducible flaw information, the generation, production and reception of the ultrasonic pulses must be properly specified, controlled and characterized. To ensure the accuracy and repeatability of the ultrasonic examination, a knowledge of the characteristics of the search unit or probe (also known as the transducer), as well as the associated sound field and the testing procedures used, is required.

For a complete description or proper selection of an ultrasonic search unit or probe, a commonly accepted set of characteristics of the search unit must be specified. This standard establishes techniques to be used in the laboratory for characterizing ultrasonic search units with parameters such as centre frequency, bandwidth, near-field length, half-angle of beam spread, depth of field, beam diameter and focal length. This standard specifies means for measuring the characteristics of both immersion and contact search units used for the inspection of materials. This standard also provides guides for obtaining parameters measured in the free field and by pulse-echo measurement. Examples of calculations of these parameters are given.

This standard provides techniques and procedures to achieve the following objectives:

a) to select and specify search unit or probe characteristics;

b) to check and ensure consistency of search unit performance over its life span;

c) to facilitate selection of identical search units or equivalent alternatives;

d) to provide a base for the comparison of results obtained using different instruments, equipment settings, operators, operating times and periods.

Non-destructive testing — Ultrasonic inspection — Characterization of search unit and sound field

1 Scope

This International Standard establishes procedures for specifying certain ultrasonic search unit characteristics and for measuring the associated sound field. The aim is to establish uniformity of testing techniques, to form a basis for the interpretation of results obtained by different laboratories and at different times. Note that this International Standard establishes no acceptance criteria; however, it does establish the technical basis for criteria that may be defined by user parties.

ISO 2400 describes a calibration block used in weld inspection for checking the performance of the ultrasonic instrument and search unit. To further enhance the general ultrasonic inspection capability, information concerning the search unit's time domain response, frequency response (also referred to as frequency spectrum, frequency analysis, spectrum analysis and signature analysis) and sound field must be known before reliable detection and characterization of flaws can be achieved.

The search units discussed herein are straight-beam and angle-beam search units with a nominal ultrasonic frequency from 0,5 MHz to 15 MHz. Surface wave search units are not included in this standard. This standard provides procedures for specifying sound field parameters as well as methods of measurement in immersion tests. This standard does not address sound field measurement in contact tests.

This International Standard describes measurement procedures for evaluating characteristics of ultrasonic search units and describes techniques used for obtaining sound field data produced by electrically pulse-excited search units used in the field or in the laboratory. The characteristic parameters discussed in this standard are the upper, lower and centre frequencies, the wavelength, the bandwidth, the time domain and frequency domain responses, the near-field length, the half-angle of beam spread for search units of different shapes in free field, echo sound measurements, beam profiles, the impedance and the relative sensitivity. Formats for specifying both flat-face and focused search units are given.

To provide baseline information and to check possible performance degradation, the electrical properties of the search unit are measured independently of the ultrasonic instrument. The electrical impedance and sensitivity are measured at specific frequencies selected for each search unit. The electrical impedance corresponds to the complex input impedance of the search unit and the sensitivity of the search unit is a measure of the electroacoustic efficiency of the unit. These procedures are described in 4.6 and 4.7, respectively.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2400:1972, *Welds in steel — Reference block for the calibration of equipment for ultrasonic examination.*

3 Symbols

B_W Bandwidth, in percent

C_N Number of cycles

D Effective diameter, in millimetres, of the transducer element of the search unit

d_{FL} Beam diameter, in millimetres, at focal length

F_D Depth of field (also known as length of focal area), in millimetres

F_L Focal length (also known as focal distance), in millimetres

f Frequency, in megahertz, of the search unit

f_l Lower frequency (–3 dB for free field, –6 dB for echo, from peak amplitude), in megahertz

f_u Upper frequency (–3 dB for free field, –6 dB for echo, from peak amplitude), in megahertz

f_c Centre frequency, in megahertz

f_p Peak frequency, in megahertz

l_1, l_2 Effective dimensions, in millimetres, of a rectangular search unit

N_0 Near-field length, in millimetres

P_N Number of peaks

S_r Relative sensitivity, in decibels

T_k Thickness of the medium, i.e. the distance between the search unit and reflector, in millimetres

T_{PD} Pulse duration time, in microseconds

v Wave velocity, in kilometres per second, in the test medium

V_{in} Peak-to-peak input, or excitation, voltage signal amplitude, in volts

V_{out} Peak-to-peak output voltage signal amplitude, in volts

x Longitudinal direction of the search unit

z Axial distance, in millimetres, normal to the search unit front surface

λ Wavelength, in millimetres, in the test medium

α Incident angle, in degrees

β Refraction angle, in degrees

γ Skew (or squint) angle, in degrees

Ω Impedance, in ohms

θ Half-angle of the beam spread, in degrees

4 Techniques and procedures

Characteristics of an ultrasonic search unit are determined by a combination of its own parameters and the physical properties of the medium to which the search unit is coupled. The ultrasonic search unit is characterized by parameters such as the wavelength, the centre frequency, the time domain response, the frequency and the fractional bandwidth. The wavelength, the frequency of the search unit and the velocity of a wave propagating through a medium have the following relationship:

$$\lambda = \frac{v}{f} \quad \ldots (1)$$

where

v is the wave velocity, in kilometres per second, in the test medium;

λ is the wavelength, in millimetres, of the search unit;

f is the frequency, in megahertz, of the search unit.

EXAMPLE 1

a) Consider a straight-beam search unit of 5 MHz, in contact test on steel. The longitudinal wavelength of the pulse in steel is determined as follows:

$$f = 5\ \text{MHz} = 5 \times 10^6\ \text{Hz}$$

The longitudinal-wave velocity in steel is given by:

$$v_{long} = 5{,}92\ \text{km/s} = 5{,}92 \times 10^6\ \text{mm/s}$$

$$\therefore \lambda_{long} = \frac{5{,}92 \times 10^6}{5 \times 10^6} = 1{,}18\ \text{mm} \quad \text{(longitudinal wavelength)}$$

b) Consider an angle-beam (transverse-wave) search unit of 5 MHz, in contact test on steel. The transverse wavelength of the pulse in steel is determined as follows:

$$f = 5\ \text{MHz} = 5 \times 10^6\ \text{Hz}$$

The transverse-wave velocity in steel is given by:

$$v_{trans} = 3{,}26\ \text{km/s} = 3{,}26 \times 10^6\ \text{mm/s}$$

$$\therefore \lambda_{trans} = \frac{3{,}26 \times 10^6}{5 \times 10^6} = 0{,}65\ \text{mm} \quad \text{(transverse wavelength)}$$

These parameters are measured in a pulse-echo procedure described herein. The echo is gated by a stepless gate to eliminate non-relevant signals. The gated echo acts as input to both an oscilloscope for analysis of its time domain response and to a frequency analyser for analysis of the frequency response. The electrical spike pulse applied to the search unit produces a spectrum of energy broad enough to permit the evaluation of the response of the search unit. The pulse level of the excitation, the types of target used for each test and the distance from the search unit shall be recorded.

4.1 Test set-up

Figure 1 presents a schematic illustration of the test set-up for an electrical spike pulse technique commonly used in ultrasonic pulse-echo testing. The system consists of a pulser, receiver, gate (or ultrasonic echo instrument having an output terminal for a gated echo signal), oscilloscope, frequency analyser and search unit. The oscilloscope and frequency analyser shall have a frequency range of no less than 50 MHz. Coaxial cables of 50 Ω shall be used for the measurement, and the cable input to the oscilloscope and the frequency analyser shall be matched with a 50 Ω terminator. An excitation pulse is applied to the search unit and the echo from a specific target is analysed.

For immersion tests, the search unit shall be oriented to provide maximum signal amplitude from the target surface. Targets commonly used in immersion tests are a small stainless-steel ball or a steel wire, which are used for sound field measurements, or a flat reflector, such as a glass block, which is used for the analyses of the echo waveform. The standard diameter of the sphere is 4 mm and that of the steel wire is 2,5 mm. Upon agreement between user parties, different-sized spheres and targets may also be used. To avoid tank reflections, the distance of the ball or wire target from the bottom of the tank shall be at least 50 mm. Figure 2 shows an immersion test with a stainless-steel ball or the cross-section of a steel wire and a glass block target.

In contact tests, both straight-beam and angle-beam search units are used. For straight-beam contact tests, either single-element in pulse-echo mode or dual-element in pitch-catch (or transmit-receive) mode and a reference block of multiple-thickness steps is used. A suitable couplant, such as mineral oil or glycerin, shall be used, and a uniform pressure maintained between the search unit and the contact surface. The block shall have a thickness greater than the spatial duration of the excitation pulse used. Both the flatness and parallelism of the reference block shall be better than 0,02 mm. The surface finish of the front and back surface of the reference block shall be between 1,6 µm and 3,2 µm. Figure 3 shows a contact test on a step calibration block.

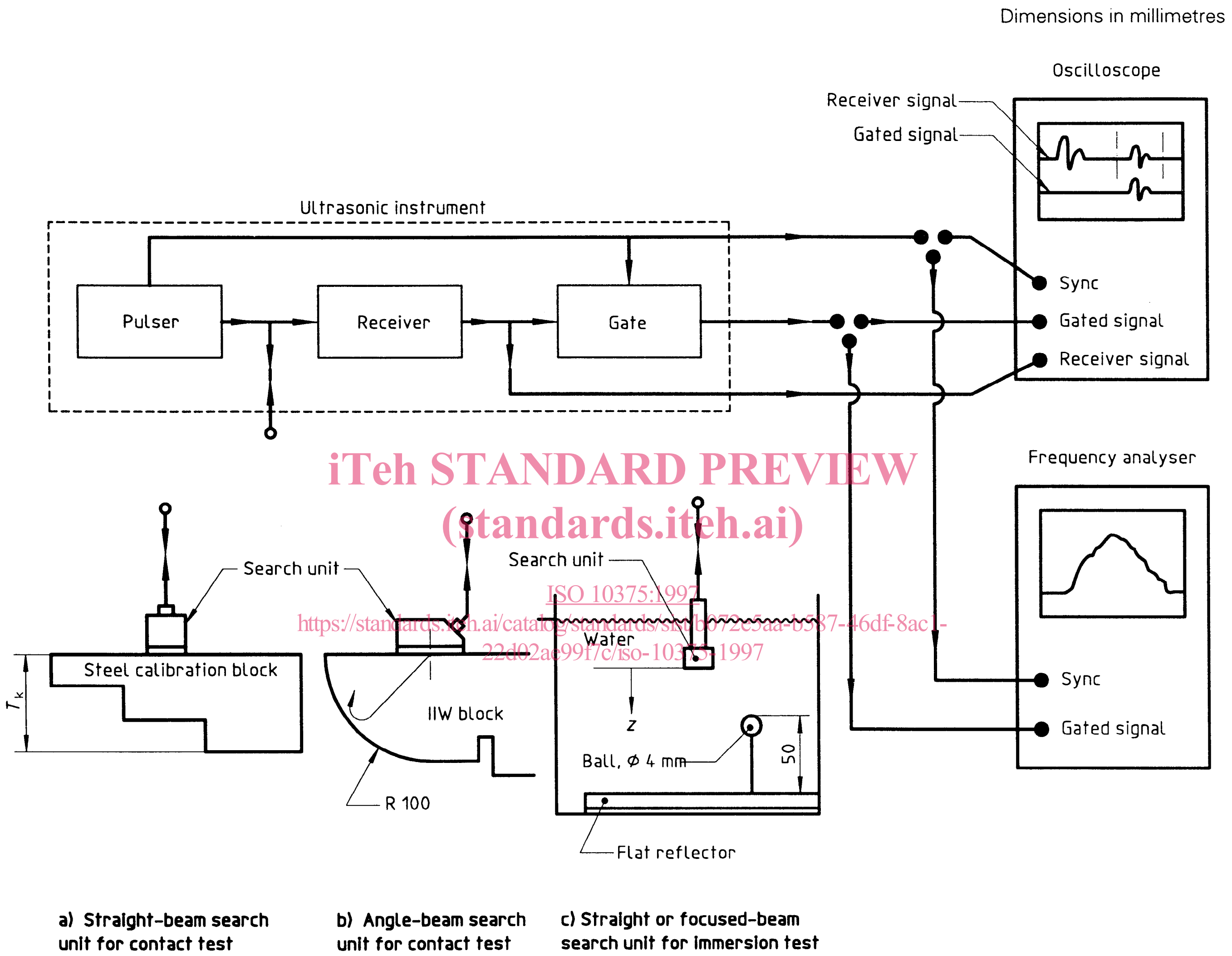
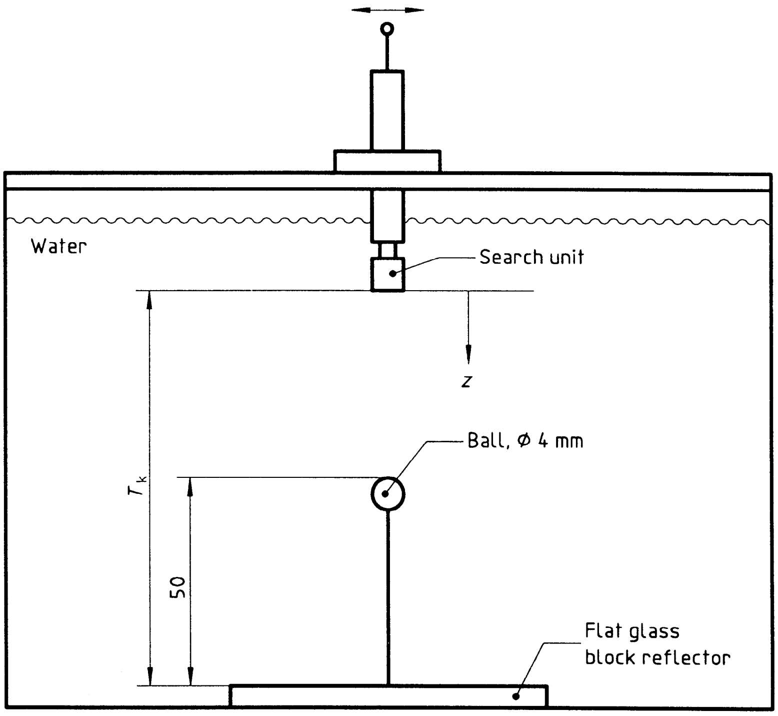


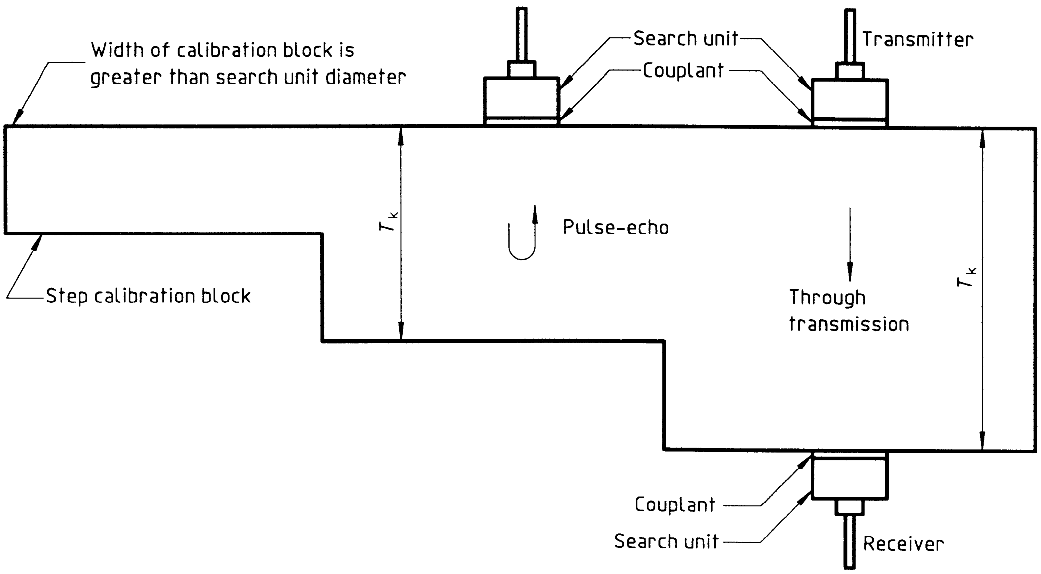
Figure 1 — Arrangement for ultrasonic pulse-echo testing using electric-shock excitation
(T_k = 0,75N_0 to 1,5N_0; N_0 = near-field length)

Dimensions in millimetres



T_k = near-field length for straight-beam search unit
= focal length for focused-beam search unit

Figure 2 — Immersion test with search unit positioned above a ball target or a flat reflector
(Flat reflector is for frequency response measurement; ball target is for sound field measurement)



T_k = thickness
N_0 = near-field length

Figure 3 — Arrangement for contact test with straight-beam search unit
(For pulse-echo test, $T_k = 0{,}75N_0$ to $1{,}5N_0$; for through-transmission test, $T_k > N_0$)

The angle beam is produced with a transducer element built at an angle to the probe z-axis, defined as the incident angle α, or using a wedge on a straight-beam search unit, to produce a sound beam refracted at an angle into the test material. The angle beam transmitted into the material can be a refracted longitudinal or a refracted transverse wave.

For angle-beam search units used in contact tests, the International Institute of Welding (IIW) block shall be used as the calibration block, as described in ISO 2400. The angle-beam search unit shall be set to transmit its ultrasonic beam in the direction of the 100 mm radius section. With proper positioning of the search unit to maximize the received echo, the search unit index, i.e. the ultrasonic-beam exit point of the search unit, is marked on the search unit at the centre point of the 100 mm radius section of the IIW block.

After the search unit index has been determined, the search unit refraction angle β, i.e. the angle between the direction of the transmitted beam and the normal to the test surface, can be measured as follows. For a refraction angle between 40° and 75°, by setting the transmitted beam towards the 50 mm diameter through-hole, the angle marked in degrees on the IIW block corresponding to the search unit index is the refraction angle of the search unit. For refraction angles of about 80°, the transmitted beam is set towards the 1,5 mm diameter through-hole. By positioning the search unit so that the maximum echo is obtained, the angle marked in degrees on the IIW block corresponding to the search unit index is the refraction angle of the search unit. The skew (also known as squint) angle γ is the angular deviation of the transmitted-beam direction from its longitudinal direction x.

The echo reflected from the 100 mm radius surface of the IIW block is used for the waveform analysis. For two angle-beam search units placed in a pitch-catch (transmit-receive) mode, the peak amplitude signal reflected from the flat side of the IIW block is used for the waveform analysis.

Figure 4 shows the angle-beam search unit and the IIW block for contact tests. For a wide-angle angle-beam search unit, the reflector shall be at least as wide as the diameter of the transducer element of the search unit.

For waveform analyses, the gated echo from the back surface of the reference block, i.e. from an infinite reflector, is characterized in terms of its time domain response and frequency response.

4.2 Time domain response

The time domain response of an echo signal is recorded for the specific target chosen for the type of test and the type of search unit under evaluation, i.e. an immersion test or contact test, a straight-beam or angle-beam search unit. The duration of the echo signal provides a measure of the damping characteristics of the search unit. The waveform of the pulse is characterized by the peak number P_N, which is defined as the number of half-cycles having amplitudes greater than or equal to 20 % (–14 dB) of the peak half-wave amplitude. The time from the start of the first peak to the end of the last peak is defined as the pulse duration time T_{PD}, which is measured in microseconds. The waveform shown in figure 5 has a peak number of 7. Also, the time domain response may be expressed as a number of cycles C_N, which is half the peak number.

4.3 Frequency response

Using a frequency (or spectrum) analyser, the echo response from a given target can be measured in terms of the signal amplitude as a function of frequency. The target shall be a flat reflector set as close to the near-field distance N_0, or to the focal length F_L, as possible. The signals can be analysed with a spectrum analyser with filters or by using a full digitization of the signal, followed by a fast Fourier transform. This response is used as the basis for establishing other parameters such as peak frequency, centre frequency and bandwidth. The peak frequency f_p is the frequency at which the peak amplitude occurs in the frequency response. The lower and upper frequencies f_l and f_u, respectively, are defined as the frequencies at which the echo amplitude is 50 % down (–6 dB) from the peak amplitude of the pulse-echo measurement, as shown in figure 6. The centre frequency is defined as

$$f_c = \frac{f_u + f_l}{2} \qquad \ldots (2)$$

The peak amplitude may or may not occur at the centre frequency. The bandwidth B_W, in percent, of the echo signal is defined as

$$B_W = \frac{f_u - f_l}{f_c} \times 100 \qquad \ldots (3)$$

In addition to B_W, the absolute value of the bandwidth, $f_u - f_l$, in megahertz, may also be noted.

Dimensions in millimetres

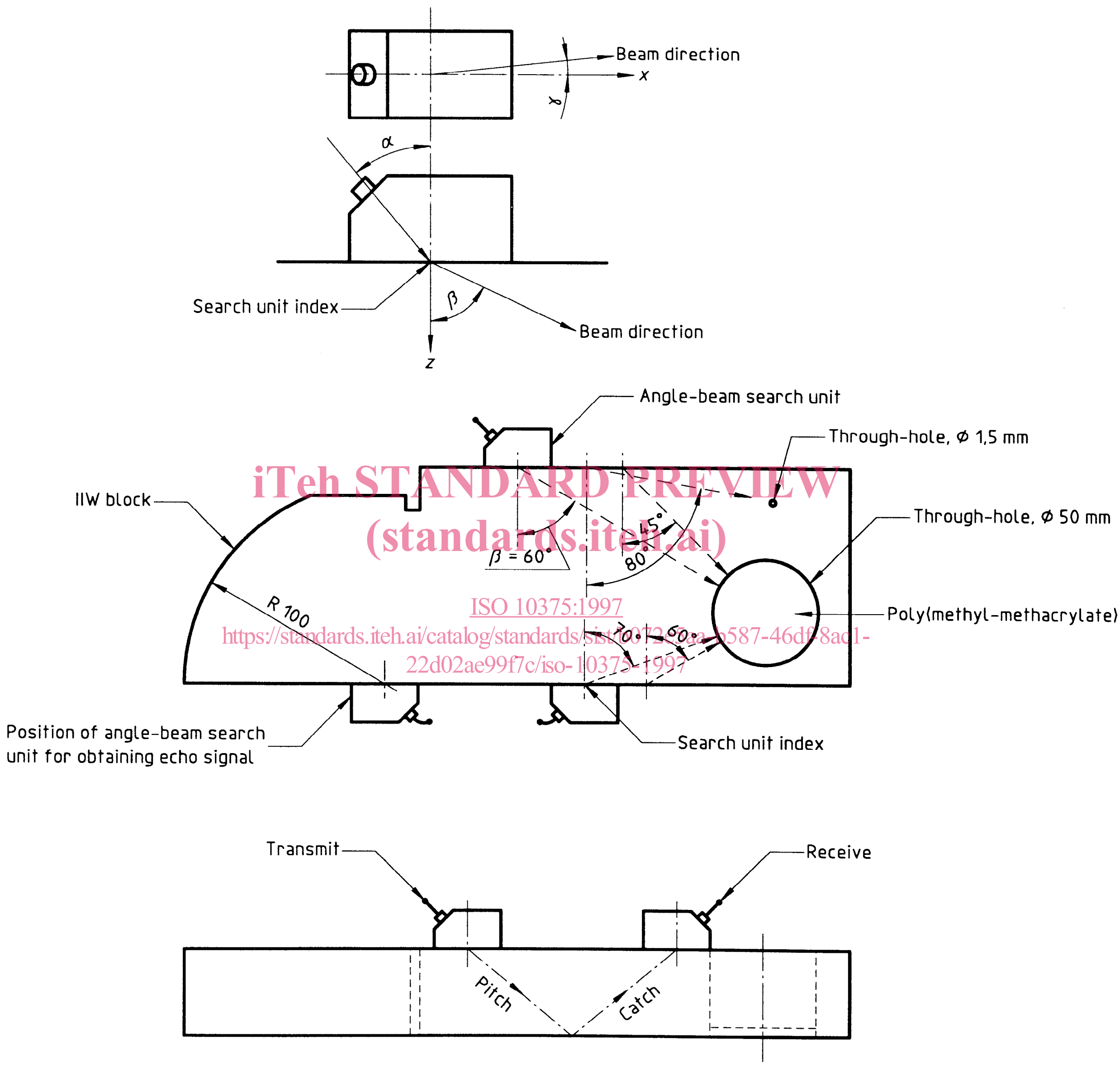


Figure 4 — Arrangements for contact test with angle beam search unit
(Search unit index is the beam exit point; x = longitudinal direction of search unit, z = normal to test surface, β = refraction angle, γ = skew angle)