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Part 3: Physical sensors

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Piezoelectric sensors -
Part 3: Physical sensors

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC 63041-3:2020. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IEC 63041-3 has been prepared by IEC technical committee TC 49: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection. It is an International Standard.

This second edition cancels and replaces the first edition published in 2020. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Some terms in Clause 3 have been updated to be consistent with IEC TS 61994-5:2023 [1].

The text of International Standard is based on the following documents:

Draft	Report on voting
49/1526/FDIS	49/1530/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English .

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at http://www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at http://www.iec.ch/publications.

A list of all parts in the IEC 63041 series, published under the general title *Piezoelectric sensors*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

– reconfirmed,
– withdrawn, or
– revised.

1 Scope

This part of IEC 63041 is applicable to piezoelectric physical sensors mainly used in the field of process control, wireless monitoring, dynamics, thermodynamics, vacuum engineering, and environmental sciences. This document provides users with technical guidelines as well as basic knowledge of common physical sensors.

Piezoelectric sensors covered herein are those applied to the detection and measurement of physical quantities such as force, pressure, torque, viscosity, temperature, film thickness, acceleration, vibration, and tilt angle.

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.

IEC 60027 (all parts), *Letter symbols to be used in electrical technology*

IEC 60050–561, *International electrotechnical vocabulary – Part 561: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection*

IEC 60617:2012, *Graphical symbols for diagrams* (database available at http://std.iec.ch/iec60617)

IEC 63041-1:2017, *Piezoelectric sensors - Part 1: Generic specifications*

IEC 63041-2, *Piezoelectric sensors - Part 2: Chemical and biochemical sensors*

ISO 80000–1, *Quantities and units – Part 1: General*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60027 (all parts), IEC 60050–561, IEC 60617:2012, IEC 63041-1, IEC 63041-2, and ISO 80000–1 and the following apply.

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

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

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

3.1.1
piezoelectric acceleration sensor element
piezoelectric sensor component whose resonance frequency or delay time is used to measure the change in velocity of an object with time

3.1.2
piezoelectric humidity sensor element
piezoelectric sensor component whose resonance frequency or delay time is used for dew point and moisture detection

3.1.3
piezoelectric tilt angle sensor element
piezoelectric sensor component whose resonance frequency or delay time is used to measure tilt angles, elevation, or depression of an object with respect to gravity's detection

3.1.4
piezoelectric vibration sensor element
piezoelectric sensor component whose resonance frequency or delay time is used for measurement of vibration

3.1.5
dual mode sensor
piezoelectric sensor which is able to detect physical quantities from a change in resonance frequencies of two independent modes on a single piezoelectric plate

Note 1 to entry: In order to achieve improved precision and/or to eliminate undesired influence factors, sensor solutions are employed that utilize two or more modes. By evaluation of combinations of these modes' sensitivities to various ambient conditions, on the one hand, improved detection sensitivity can be achieved, while, on the other hand, undesirable sensitivities can be reduced or eliminated.

3.1.6
differential sensor
piezoelectric sensor which is able to detect physical quantities from a change in resonance frequencies or ~~delays~~ delay times of two independent and same micro-acoustic structures assembled on the same or different piezoelectric plates

3.1.7
multi-measurand sensor
piezoelectric sensor element that ~~is able to~~ can detect two or more different physical quantities from an analysis of different sensor responses

[SOURCE: IEC TS 61994-5:2023 [1], 3.6]

3.2 Symbols and units

The symbols and units given in IEC 63041-1 apply.

4 Specifications

4.1 General

Key points of the specification are identified in IEC 63041-1~~:2017~~, Clause 5.

4.2 Conceptual diagrams of sensor types

4.2.1 General

~~In addition to the sensor types listed in IEC 63041-1:2017, Clause 4, specific realizations are common for surface acoustic wave (SAW) sensors.~~

In addition to the sensors defined in Clause 4 of IEC 63041-1, piezoelectric acceleration sensor element, piezoelectric humidity sensor element, piezoelectric tilt angle sensor element and piezoelectric vibration sensor element are also in practical use as physical sensors.

In addition, dual mode sensor, differential sensor and multi-measurand sensor are used as sensor configuration.

4.2.2 Conceptual diagram for sensor elements of SAW resonator type

Figure 1 and Figure 2 show conceptual diagrams for resonator type SAW sensors. Figure 1 provides one resonance which is sensitive to undesirable influence factors such as frequency pulling. In the case of Figure 2, comprising e.g. a parallel connection of two resonators at different resonance frequencies, the sensor will be designed to have similar sensitivities of both resonators to such undesired effects and is therefore suitable to achieve higher accuracy with respect to the target measurand due to this compensation technique.

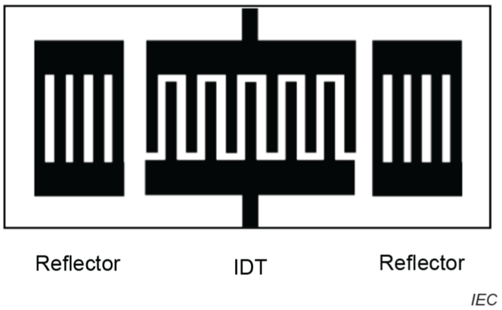

Figure 1 – Conceptual diagram for SAW single resonator type

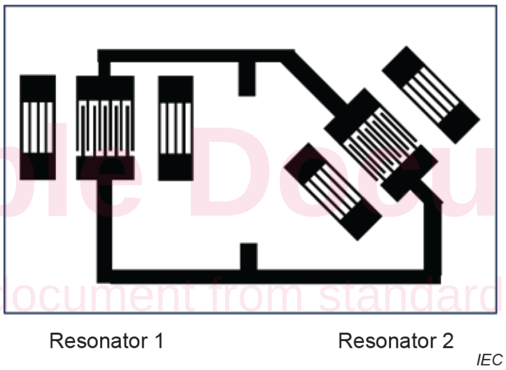

Figure 2 – Conceptual diagram for SAW differential resonator type

4.2.3 Conceptual diagram for sensor elements of SAW delay-line type

Figure 3 shows a transmission type (two-port) and Figure 4 shows a reflective type (one-port).

Reflective delay lines use the SAW propagation path which is evaluated for delay and attenuation changes twice for incident and reflected wave, and therefore can be designed as smaller realizations. Reflective delay-line sensors can be designed to feature a unique sensor identification, in combination with their sensor capabilities, by using several SAW reflector structures resulting in a characteristic pattern of the reflected signal which can be distinguished from other sensors using the same frequency range.

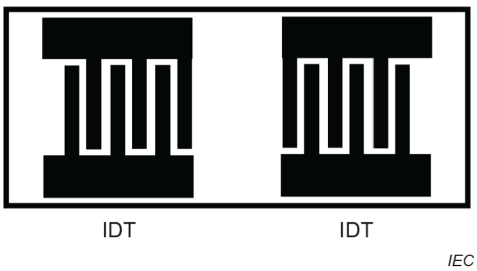

Figure 3 – Conceptual diagram for SAW transmission (two-port) delay-line type

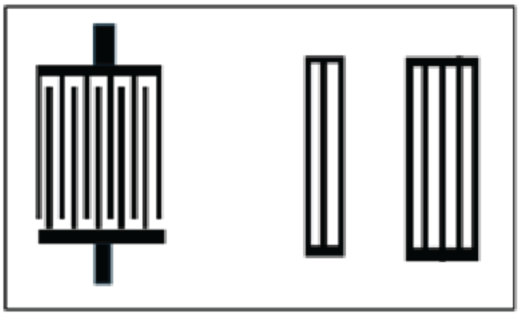

Figure 4 – Conceptual diagram for SAW reflective (one-port) delay-line type

4.3 Technical documents

The physical reaction in sensor cell and detection methods are defined in Annex A.

The following 4.3, list item a) to 4.3, list item f) shall clearly be defined in the specifications to be concluded between the manufacturer and customers:

a) avoidance of coupling of main and unwanted vibration modes;
b) detection direction of sensor element;
c) hysteresis of sensor elements;
d) linearity between sensor outputs and physical quantities to be detected;
e) overload characteristics by excessive physical quantities to be detected;
f) response time of sensor elements.

5 Delivery conditions

Clause 7 of IEC 63041-1~~:2017~~ applies.

6 Quality and reliability

Clause 8 of IEC 63041-1~~:2017~~ applies.

7 Test and measurement procedures

Annexes A and B of IEC 63041-1~~:2017~~ apply.

Annex A
(informative)

Physical reaction in sensor cell and detection method

A.1 Detection and measurement

Generally, detection and measurement items are Clause A.1, list item a) to Clause A.1, list item d):

a) resonance frequency, delay time, and electrical charged and voltage covered herein are applied to the detection and measurement of force, pressure, torque, vibration, acceleration, etc.;

b) resonance frequency, delay time or insertion loss / gain covered herein are applied to the detection and measurement of viscosity;

c) resonance frequency or delay time is applied to the detection and measurement of temperature;

d) resonance frequency is applied to the detection and measurement of film thickness.

NOTE An electrical charged and voltage is measured by non-acoustic type piezoelectric ceramic and quartz crystal sensors.

~~For these specifications, the manufacturer and customer shall have detailed discussions, the discrepancies shall be eliminated, and the results shall clearly be described in the contract clause, the requirements specifications of the customer, the delivery specifications thereof or the like, and shall be settled as one of the contracts with the customer.~~

For Formula (A.1) to Formula (A.6), the manufacturer and customer can have discussions to resolve discrepancies and note them in the relevant contract clause of the customer's specifications

A.2 Typical formulae for detection methods of physical quantity

A.2.1 General

Formula (A.1) to Formula (A.6) presented as below are typical examples applied to physical sensor elements and cells. ~~For these formulae, the manufacturer and customer shall have detailed discussions, the discrepancies shall be eliminated, and the results shall be described clearly in the contract clause.~~

A.2.2 Non-acoustic type

A.2.2.1 Piezoelectric ceramics

When a sensor element is made of piezoelectric ceramics, and is working under g_{33} mode, Formula (A.1) applies:

$$V = g_{33} l \frac{F}{S} \tag{A.1}$$

where

V is the voltage generated across the piezoelectric ceramic (V);

g_{33} is the piezoelectric voltage coefficient that quantifies the electric field generated per unit of mechanical stress (V·m/N);

l is the length of the piezoelectric ceramics element and is the direction in which force is applied to the one (mm);

F is the force applied to the piezoelectric ceramic element and cell (N);

S is the electrode area and is formed in a direction in which a force is applied to the piezoelectric ceramic element and cell (m²).

A.2.2.2 X-cut quartz crystal

When sensor element is X-cut quartz crystal, Formula (A.2) applies:

$$V = g_{11} t \frac{F}{S} \tag{A.2}$$

where

g_{11} is the piezoelectric voltage coefficient (V·m/N);

t is the thickness of quartz crystal (mm).

A.2.3 Acoustic type

A.2.3.1 Resonator type

For resonator-type piezoelectric sensors, the change of one or more resonance frequencies related to the effect of the measurand is interpreted to quantify the measurand. Typical measuring range transform function is defined by polynomials as

$$y = g(\Delta f_r) = \sum_{i=0}^{N} a_i f_r^i$$

$$y = g(\Delta f_r) = \sum_{i=0}^{N} a_i f_r^i \tag{A.3}$$

where

y is the measurand (e.g. temperature, pressure, film thickness, etc.);

Δf_r is the change of resonance frequency under the influence of the measurand (Hz);

a_i are transform coefficients, determined by design and material system.

The unit used to measure "y" varies depending on the object being measured, for example, temperature is measured in kelvins (K), pressure in pascals (Pa)", Δf_r in hertz (Hz). a_i is an arbitrary unit which changes depending on the input amount. For example, in the case of measuring temperature, the unit of a_i is K/Hz.

A biunique transform function is generally desirable. Hence, the order of the polynomial ~~should~~ will be kept low, ideally $N = 1$.

A.2.3.2 Differential resonator type

For differential resonator type sensors, it is common to evaluate two resonances with different sensitivities to the measurand in order to eliminate undesired frequency pulling effects (e.g. from load pulling effects in wireless piezoelectric sensor systems), such as

$$y = g(\Delta f_{r1} - \Delta f_{r2}) = \sum_{i=0}^{N} b_i (\Delta f_{r1} - \Delta f_{r2})^i$$

$$y = g(\Delta f_{r1} - \Delta f_{r2}) = \sum_{i=0}^{N} b_i (\Delta f_{r1} - \Delta f_{r2})^i \qquad \text{(A.4)}$$

where

Δf_{r1}, Δf_{r2} are resonance frequencies of two resonators or resonant modes with different sensitivities with respect to the measurand, but preferably similar sensitivities with respect to undesired influence actors (Hz);

b_i are transform coefficients, determined by design and material system.

A.2.3.3 Multi-measurand resonator type

Evaluation of two or more resonators and their resonance frequencies, having arbitrary sensitivities with respect to the measurands to be quantified, can be transformed by

$$\begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ \cdot \\ y_K \end{bmatrix} = \begin{bmatrix} a_{1,0} & a_{1,1} & \cdot & \cdot & \cdot & a_{1,N} \\ a_{2,0} & a_{2,1} & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ a_{K,0} & a_{K,0} & \cdot & \cdot & \cdot & a_{K,N} \end{bmatrix} \begin{bmatrix} 1 \\ \Delta f_1 \\ \Delta f_2 \\ \cdot \\ \cdot \\ \cdot \\ \Delta f_N \end{bmatrix} \qquad \text{(A.5)}$$

where

$y_1 \ldots y_K$ are a range of measurands, and the units used to measure them vary depending on the measurement object. For example, the unit for temperature is K and the unit for pressure is Pa;

$a_{K,N}$ is the coefficient of the transformation matrix, and its units are determined by the relationship between $y$and Δf. For example, if 'y' represents temperature, the unit of a is K/Hz;

$\Delta f_1 \ldots \Delta f_N$ are the changes in resonance frequencies obtained for N resonators of the piezoelectric sensor (Hz);

$K < N$ ~~to allow for determination of multiple measurands and compensation for undesired effects~~ are dimensionless constants;

j, n are the exponents of higher order polynomial transform functions and ~~should be~~ are kept minimum, e.g. $j, n \leq 2$.

or higher-order polynomials of $\Delta f_i^j \cdot \Delta f_m^n (i, m \in [1 \ldots N])$.