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INTERNATIONAL STANDARD

Piezoelectric sensors –
Part 1: Generic specifications

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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FOREWORD

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International Standard IEC 63041-1 has been prepared by IEC technical committee TC 49: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection.

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

CDV	Report on voting
49/1220/CDV	49/1249/RVC

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

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

A bilingual version of this publication may be issued at a later date.

PIEZOELECTRIC SENSORS –

Part 1: Generic specifications

1 Scope

This part of IEC 63041 applies to piezoelectric sensors of resonator, delay-line and non-acoustic types, which are used in physical and engineering sciences, chemistry and biochemistry, medical and environmental sciences, etc.

The purpose of this document is to specify the terms and definitions for the piezoelectric sensors, and to make sure from a technological perspective that users understand the state-of-art piezoelectric sensors and how to use them correctly.

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 60050-561:2014, *International Electrotechnical Vocabulary – Part 561: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection*

IEC 60122-2-1, *Quartz crystal units for frequency control and selection – Part 2: Guide to the use of quartz crystal units for frequency control and selection – Section One: Quartz crystal units for microprocessor clock supply*

IEC 60444-9, *Measurement of quartz crystal unit parameters – Part 9: Measurement of spurious resonances of piezoelectric crystal units*

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

ISO 2859-1:1999, *Sampling procedures for inspection by attributes – Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

ISO 80000-1:2009, *Quantities and units – Part 1: General*

3 Terms and definitions

3.1 General

For the purpose of this document, the following terms and definitions 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

Units, letter symbols and terminology shall, wherever possible, be taken from the following standards: IEC 60027, IEC 60050-561, IEC 60617, and ISO 80000-1.

NOTE Piezoelectric sensors covered herein are those used for the detection and measurement of physical quantities, chemical substances or biological molecules.

3.2 Piezoelectric sensors

3.2.1
piezoelectric sensor element
electronic component which is able to detect physical quantities as a change in its frequency, phase, delay, electrical charge, resistance, Q-value, bandwidth, etc.

Note 1 to entry: For chemical and biochemical sensor applications, the piezoelectric sensor element includes a sensitive or receptive layer (target recognition material).

3.2.2
resonator type sensor element
piezoelectric sensor component using acoustic resonances

3.2.3
delay line type sensor element
piezoelectric sensor component using a surface acoustic wave (SAW) delay-line of transversal type

3.2.4
non-acoustic type sensor element
piezoelectric sensor component using the electrical charge induced by a quasi-static force, torque or the like

Note 1 to entry: Here, the term, "non-acoustic", represents "quasi-static piezoelectric". Accordingly, the (piezoelectric) non-acoustic type sensor element means a sensor element using the quasi-static piezoelectric effect.

3.2.5
piezoelectric sensor cell
sensor element equipped with necessary mechanical accessories and attachments to correctly detect the parameters to be measured

3.2.6
piezoelectric sensor module
sensor element or cell equipped with electronic accessories for interfacing to external data acquisitions

3.2.7
piezoelectric sensor
generic term that includes a sensor element, cell and module

3.2.8
QCM
quartz crystal microbalance
one of the families of chemical and biochemical sensors using crystal resonators

Note 1 to entry: A thickness share mode (TSM) sensor is identical with a QCM.

3.3 Types of chemical sensors

3.3.1
piezoelectric chemical sensor element
piezoelectric sensor component including a sensitive layer (target recognition material), which is necessary for the practical measurement of simple non-biological molecules in quantity, and which works and detects chemical substances mainly in the gas phase

Note 1 to entry: A gas sensor element is one of the chemical sensor elements.

3.3.2
piezoelectric biochemical sensor element
piezoelectric sensor component including a receptive layer (target recognition material), which is necessary for the practical measurement of complex biological molecules in quantity, and which works mainly in aqueous media and detects biomolecules therein

3.4 Types of physical sensors

3.4.1
piezoelectric force sensor element
piezoelectric sensor component whose resonance frequency, delay or electrical charge/voltage is used for force measurement

3.4.2
piezoelectric pressure sensor element
piezoelectric sensor component whose resonance frequency, delay or electrical charge/voltage is used for pressure measurement

3.4.3
piezoelectric torque sensor element
piezoelectric sensor component whose resonance frequency, delay or electrical charge/voltage is used for torque measurement

3.4.4
piezoelectric viscosity sensor element
piezoelectric sensor component whose resonance frequency, delay or insertion loss/gain is used for viscosity measurement

3.4.5
piezoelectric temperature sensor element
piezoelectric sensor component whose resonance frequency or delay is used for temperature measurement

3.4.6
piezoelectric film-thickness sensor element
piezoelectric sensor component whose resonance frequency is used for film-thickness measurement

4 Symbols of sensor elements

4.1 General

Figures 1 to 6 show the conceptual diagrams and defined symbols for sensor elements of bulk acoustic wave (BAW) resonator, SAW resonator and SAW delay-line types. The symbols are essentially the same as those given in IEC 60122-1, IEC 61019-1 and IEC 60862-1.

Figure 7 and Figure 8 show the conceptual diagram and defined symbol for sensor elements of non-acoustic type.

NOTE 1 The diagonal line in Figure 2, Figure 4, Figure 6 and Figure 8 shows an emblem expressing changes in objects to be measured.

NOTE 2 Letter symbols (see 4.6) showing the types of sensors are put in the circle at the upper right corner in Figure 2, Figure 4, Figure 6 and Figure 8.

4.2 Symbol for sensor elements of BAW resonator type

Figure 1 shows the conceptual diagrams for sensor elements of BAW resonator type from which a mounting portion is omitted. Figure 2 shows the symbol for sensor elements of BAW resonator type.

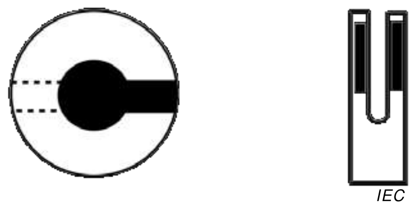

Figure 1 – Conceptual diagrams for sensor elements of BAW resonator type

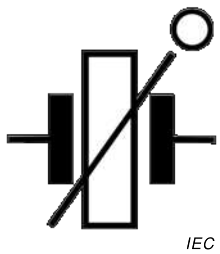

Figure 2 – Symbol for sensor elements of BAW resonator type

4.3 Symbol for sensor elements of SAW resonator type

Figure 3 and Figure 4 show, respectively, the conceptual diagram and symbol for sensor elements of SAW resonator type.

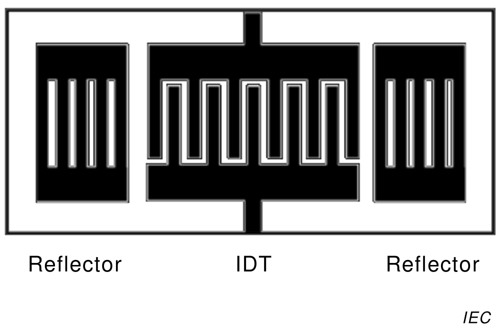

Figure 3 – Conceptual diagram of sensor elements of SAW resonator type

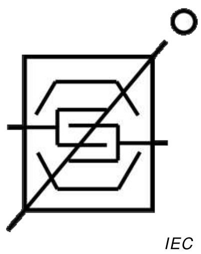

Figure 4 – Symbol for sensor elements of SAW resonator type

4.4 Symbol for sensor elements of SAW delay-line type

Figure 5 and Figure 6 show, respectively, the conceptual diagram and symbol for sensor elements of SAW delay-line type.

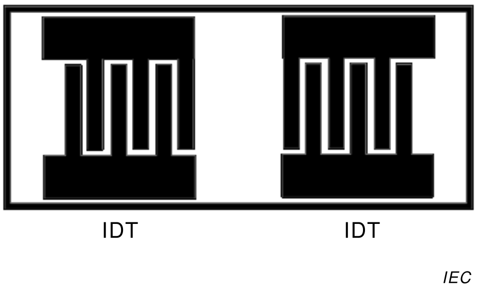

Figure 5 – Conceptual diagram for sensor elements of SAW delay-line type

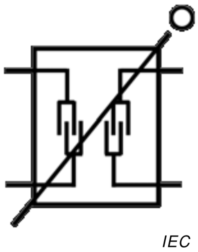

Figure 6 – Symbol for sensor elements of SAW delay-line type

4.5 Symbol for sensor elements of non-acoustic type

Figure 7 shows the conceptual diagrams for sensor elements of non-acoustic type from which a mounting portion is omitted. Figure 8 shows the symbol for sensor elements of non-acoustic type.

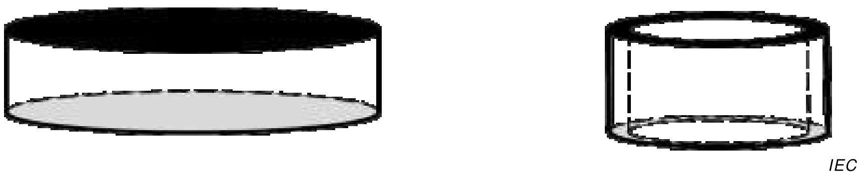

Figure 7 – Conceptual diagrams for sensor elements of non-acoustic type

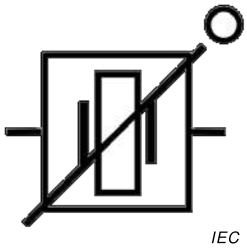

Figure 8 – Symbol for sensor elements of non-acoustic type

4.6 Symbols

The symbols put in the circle at the upper right corner in Figure 2, Figure 4, Figure 6 and Figure 8 are defined below (see ISO 80000 all parts):

a) film-thickness: d;
b) force: F;
c) mass: m;
d) density: ρ;
e) pressure: P;
f) temperature: T;
g) torque: τ;
h) viscosity: υ.

In chemical, biochemical and gas sensor applications, antigen-antibody or chemical reaction occurs between the sensitive or receptive layer and target substances, which is detected as a change in mass density, viscosity or shear modulus of the sensitive or receptive layer. Accordingly, the following specific symbols are defined for biochemical, chemical and gas sensor elements:

i) biochemical: Bi;
j) chemical: Ch;
k) gas: Ga.

5 Specifications

5.1 Sensor elements

5.1.1 General

In consideration of the target sensitivity, dynamic range or the like, the specifications of sensor elements and cells shall be determined. They should be defined clearly in the contract to be concluded between the manufacturer and customers.

Subclauses 5.1.2 and 5.1.3 present key points to be described in the specifications. These elements should be specified numerically unless confidential technological information is concerned.

5.1.2 Sensor elements of resonator and delay-line types

Sensor elements of resonator and delay-line types include the following:

a) range of measurand;
b) sensitivity of output signal with respect to measurand;
c) nominal frequency;
d) frequency tolerance;
e) parameters of equivalent circuit;
f) operating temperature range;
g) unwanted response;
h) level of drive or input power;
i) insertion loss/gain;
j) delay time (for sensor elements of SAW delay-line type);
k) phase response;
l) piezoelectric material, cut angle, or the like;
m) electrode material, dimension, shape, structure or the like;
n) mounting material, dimension, shape, structure or the like;

o) dimensions of enclosure, or name, model number or the like corresponding thereto;
p) category of environmental test;
q) others.

5.1.3 Sensor elements of non-acoustic type

Sensor elements of non-acoustic type include the following:

a) operating temperature range;
b) piezoelectric material, cut angle, dimension, shape, structure or the like;
c) electrode material, dimension, shape, structure or the like;
d) mounting material, dimension, shape, structure or the like;
e) dimensions of enclosure, or name, model number or the like corresponding thereto;
f) category of environmental test;
g) others.

5.2 Frequency ranges

The frequency range applied herein should be 10 kHz to 10 GHz.

When one of the higher-order overtones is used or the frequency deviates from the specified range, the manufacturer and customer shall consult, and the results shall clearly be defined in the contract.

NOTE The frequency ranges for sensor elements of non-acoustic type are not defined.

5.3 Level of drive or input power

For sensor elements and cells, the level of drive or input power shall be limited so that an influence of "heat generation" or a "non-linear effect" does not deteriorate their performance.

NOTE The level of drive or input power for non-acoustic type sensor elements is not defined.

5.4 Unwanted response

Unwanted responses shall be measured based on IEC 60444-9. This rule shall be applied only to sensor elements of BAW resonator type.

According to IEC 60122-2-1, the ratio of the motional resistance R_N for the unwanted response to R_1 for the main response (N=R_N/R_1) shall be two and a half times or more.

NOTE Conceptually, the sensitivity increases with an increase in the electrode area, which reduces the ratio of R_N / R_1. Under this situation, unwanted responses affect the main response, and sensor elements of BAW resonator type occasionally oscillate, caused by the unwanted response.

5.5 Analysis of measurements

Electronic circuits and measuring instruments are generally used in sensor systems. The output signals such as frequency, phase, insertion loss/gain, electrical charge / voltage, etc., and their response functions and graphs are obtained as system data.

The rule on how to apply this system data to data analyses shall clearly be defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

NOTE The response function based on the linear response theory is effective in the analysis of acoustic wave sensor elements and cells of resonator and delay-line types. For example, it is possible for the frequency response to predict the resonant response levels of the acoustic wave sensor.

5.6 Enclosure

Holder specifications shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

5.7 Performance confirmation

The basic performance of sensor elements and cells such as the minimum and maximum detection limits, dynamic range, sensitivity, etc. should be specified.

5.8 Long-term and short-term stabilities

At the time of the measurement, attention should be paid to long-term stability as well as to short-term stability affected by a background noise such as an electronic and/or foreign noise.

The specifications for long-term and short-term stabilities shall clearly be defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

NOTE The long-term and short-term stabilities for sensor elements of non-acoustic type are not defined.

6 Measurement and detection methods

Required measurement and detection methods are shown in Annexes A and B.

7 Delivery conditions

7.1 Marking

The content to be marked should be selected at least out of the following items. Moreover, the marking shall be made at the place from which sensor elements and cells can easily be viewed to the greatest extent possible. If such a place is unavailable, the marking shall be made on a packing plane.

a) Type designation as defined in the detailed specifications
b) Year and week (four digits) of manufacture, or serial number
c) Factory identification code
d) Name of manufacturer or trade mark
e) Country of production
f) Mark of conformity (unless a certificate of conformity is used)

7.2 Wrapping

In the wrapping of sensor elements and cells, sealing is desirable. Moreover, vacuum wrapping must also be taken into consideration. This rule shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

7.3 Packaging

The packaging specifications shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

8 Quality and reliability

8.1 Reuse

Reuse of sensor elements and cells shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

8.2 Validity of release

Inspection before shipment and re-inspection when the products are stored for a predetermined period of time and then shipped, shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

8.3 Test procedures

Test procedures to be used shall be selected from this document. If any required test is not found, then it shall be defined in detailed individual specifications.

8.4 Screening requirements

Where screening by the customer is required for sensor elements and cells, this shall be defined in the detailed individual specifications.

8.5 Unchecked parameters

Only those parameters of sensor elements and cells which have been described in detailed specifications and which were subjected to testing can be assumed to be within the specified limits. It should not be assumed that any parameter not specified will remain unchanged from one sensor element and cells to another. Should it be necessary for further unchecked parameters to be controlled, then new, more extensive and detailed specifications should be prepared. The additional test method(s) shall be fully described with appropriate limits, AQLs and inspection levels specified (see ISO 2859-1).

9 Test and measurement procedures

9.1 General

9.1.1 Classification of tests

The tests are classified into tests for shipping products, and mechanical and environmental tests for confirming the reliability of products.

9.1.2 Shipping test

The test is conducted to confirm whether sensor elements and cells maintain the state satisfying the contract between the manufacturer and customer when unsealed sensor elements are shipped. The following shall be clearly defined in the contract between the manufacturer and customer, or individual specifications.

a) When the specifications can presumably be sufficiently ensured, no inspection or sampling inspection shall be allowed.
b) When inspections are required, all sensor elements and cells shall be inspected.

9.1.3 Mechanical and environmental test

9.1.3.1 General

Tests should be conducted to confirm whether or not sensor elements and cells have predetermined performances. Regarding test samples, those sealed into enclosures shall be used. When no sealing is required, however, such samples may also be used.

9.1.3.2 Test samples

With regard to all test samples, the sensor elements and cells which maintain the state meeting the contract between the manufacturer and customer shall be used. Selection of the test sample shall be clearly defined in the contract between the manufacturer and customer, or in individual specifications.

9.1.3.3 Test items

Test items such as vibration, shock, thermal shock, heat resistance, bump, salt fog, ageing, bending of enclosure and the like are strongly dependent upon the requirement specifications of sensor elements and cells. Therefore, the test items shall be discussed between the manufacturer and customer, and shall be settled by the contract.

9.2 Test and measurement conditions

9.2.1 Standard conditions for testing

Unless otherwise specified, all of electrical tests shall be conducted under the following conditions:

– temperature 15 °C to 35 °C;
– relative humidity 45 % to 75 %;
– atmosphere 86 kPa to 106 kPa (860 mbar to 1 060 mbar).

If any doubt arises, the following conditions shall be applied:

– temperature 25 °C ± 2 °C;
– relative humidity 48 % to 52 %;

Before starting the measurement, the test samples shall be stored at the measurement (inspection) temperature for a period of time enough to reach the thermal equilibrium state. The ambient temperature during the measurement shall be recorded in the test report.

9.2.2 Equilibrium state

Unless otherwise specified, all of the electrical tests shall be conducted under an equilibrium state. In the case where the test state causes significant time dependence on the measurement of characteristics, a means for compensating such dependence shall be specified.

9.2.3 Power supply

When the oscillation method (see Clause A.3) is employed, a direct current power supply to be used for testing samples should have no ripples which influence the measurement accuracies required. An alternate current power supply shall have no transient response characteristics. When the ripples and transient response characteristics influence the measurement, such an influence shall clearly be described in individual standards.

9.2.4 Alternative test system

Measurement shall be conducted according to specified methods as much as possible. If there is no doubt, another method by which equivalent results are expected may be applied.

NOTE “Equivalent” means that the measured values obtained by the alternative test method are correlated to the specified method.

9.2.5 Visual inspection

9.2.5.1 General

Unless otherwise specified, external visual examination shall be performed under normal factory lighting and visual conditions.

9.2.5.2 Visual test A

The test samples shall visually be examined to ensure that the condition, workmanship and finish are satisfactory. The marking shall be legible.

9.2.5.3 Visual test B

The test samples should visually be examined under the lighting condition of ten times the normal condition. There shall be no cracks in the glass (base, cover, etc.) or damages to the terminations. Minute flaking around the feather edge of a meniscus shall not be considered a crack.

9.2.5.4 Visual test C

The test samples shall visually be examined. There shall be no corrosion or other deterioration likely to impair satisfactory operation. The marking shall be legible.

9.3 Test conditions for shipment

9.3.1 Temperature dependence of frequency, phase, insertion loss/gain, motional resistance, and electric charge / voltage

The performance of the test samples shall be measured under stepwise changing temperature over the specified range.

The shipment test shall be conducted either at ordinary temperature or according to the specification settled in the contract to be concluded between the manufacturer and customer.

9.3.2 Unwanted response

The measurement of unwanted response shall be applied to sensor elements and cells of quartz crystal BAW resonator type (see 5.4).

9.3.3 Shunt capacitance

The shunt capacitance C_0 should be measured at a frequency far below the fundamental resonance frequency at which sensor elements are not badly affected by acoustic responses.

NOTE The shunt capacitance for sensor elements of non-acoustic type is not defined.

9.3.4 Insulation resistance

The insulation resistance measurement using DC voltage and its conditions shall be discussed between the manufacturer and customer, and shall be settled by the contract.

The insulation resistance shall be larger than the value specified in the relevant detailed specification.

Annex A
(normative)

Measurement methods

A.1 General

Annex A applies to measurement methods and systems for quality management of piezoelectric sensor elements and cells.

A.2 Measurement methods using reflection and transmission characteristics

Figures A.1 to A.3 show the measurement methods using the reflection and transmission characteristics, respectively, for sensor elements and cells of BAW and SAW resonator types, and SAW delay-line type. The methods are basically defined in IEC 60444-1, 60444-5, 61019-1.

NOTE The part surrounded by the broken line in Figures A.1 to A.3 represents the test fixture.

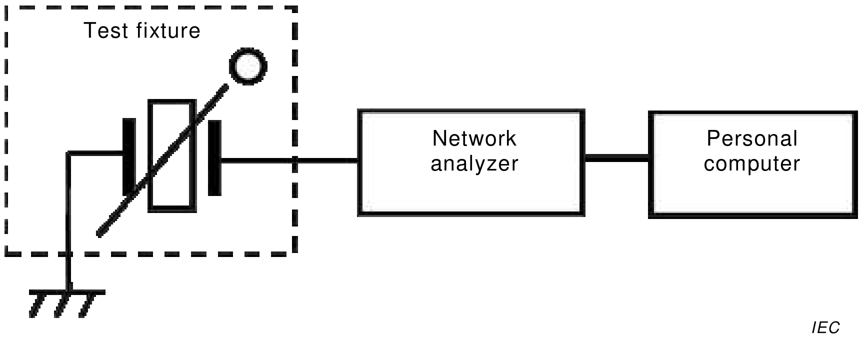

Figure A.1 – Measurement method using reflection characteristics of BAW resonator type sensor elements and cells

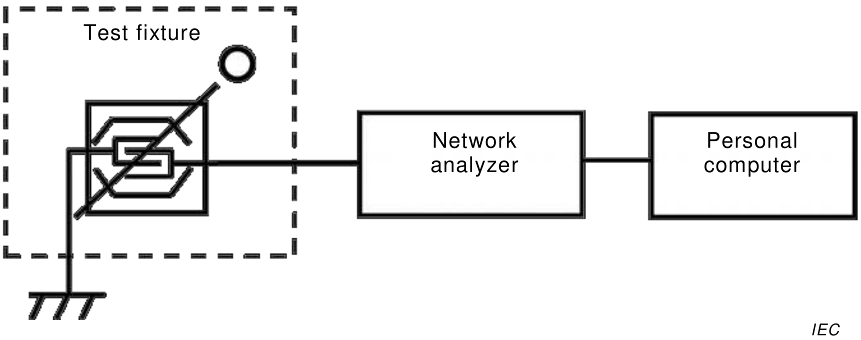

Figure A.2 – Measurement method using reflection characteristics of SAW resonator type sensor elements and cells

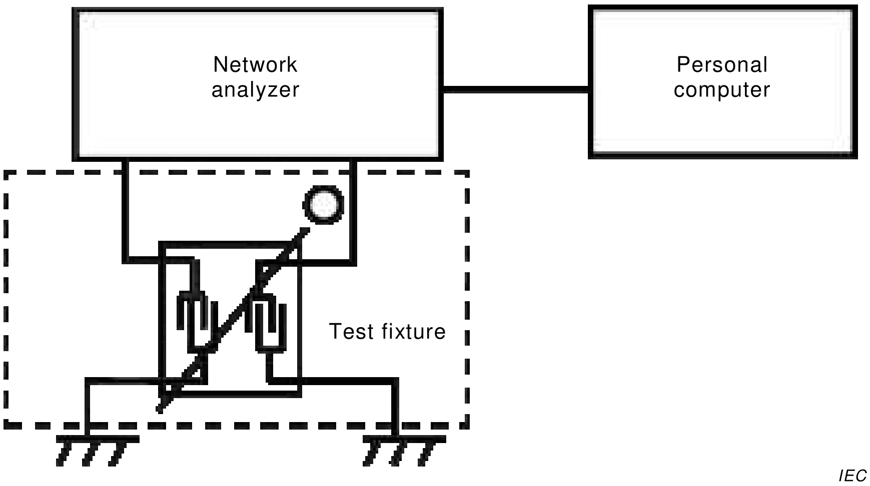

Figure A.3 – Measurement method using transmission characteristics of SAW delay-line type sensor elements and cells

A.3 Measurement methods using oscillation circuits

For a simplified measurement of frequency, the block diagrams of the oscillation method are shown in Figures A.4 to A.6.

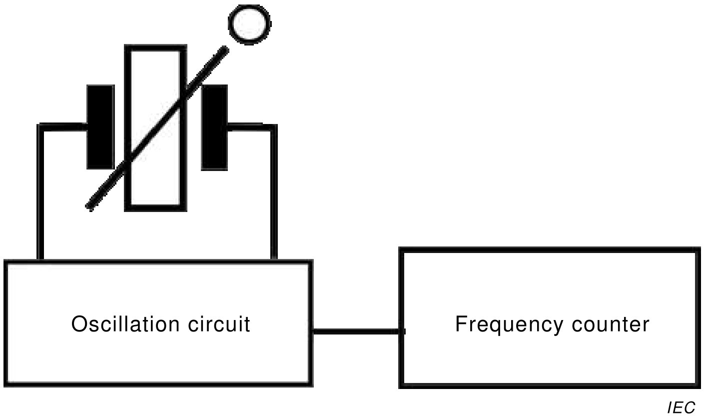

Figure A.4 – Measurement method using oscillation circuit consisting of BAW resonator type sensor elements and cells

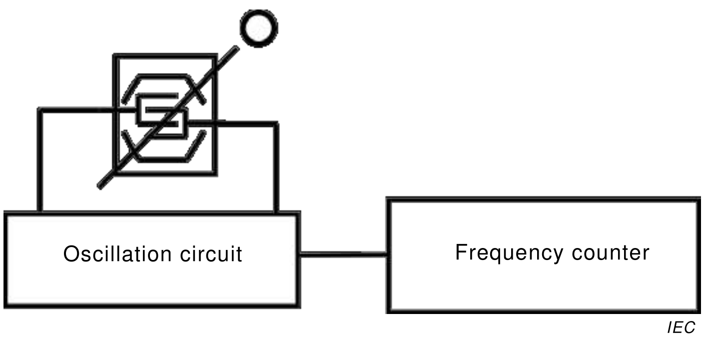

Figure A.5 – Measurement method using oscillation circuit consisting of SAW resonator type sensor elements and cells

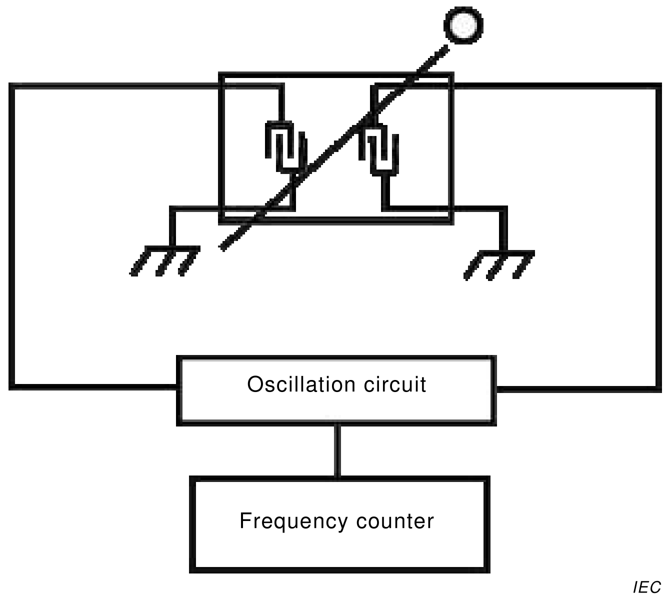

Figure A.6 – Measurement method using oscillation circuit consisting of SAW delay-line type sensor elements and cells

A.4 Measurement method of non-acoustic type sensor elements and cells

The block diagram for a simplified measurement of electric charge/voltage is shown in Figure A.7.

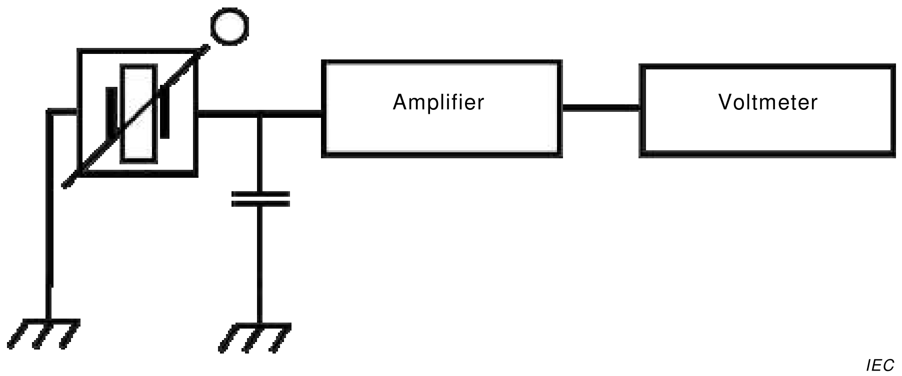

Figure A.7 – Measurement method using amplifier consisting of non-acoustic type sensor elements and cells

A.5 Other measurement methods

Other measurement methods shall clearly be defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

Annex B
(normative)

Detection methods

B.1 General

Annex B describes some basic methods of utilizing piezoelectric sensor elements and cells of resonator and delay-line types. The output of the sensor elements and cells is obtained as a change in their frequency, phase, delay, insertion loss/gain, etc. in response to detected physical quantities or chemical and biochemical reactions. Accordingly, the detection is conventionally carried out by the following methods.

B.2 Detection methods

B.2.1 Frequency difference measurement

The method measures a frequency difference between the two signals generated by the oscillation circuits employing the detecting and reference sensor elements and cells as shown in Figure B.1. A frequency synthesizer may be used as a source of the reference frequency as shown in Figure B.2.

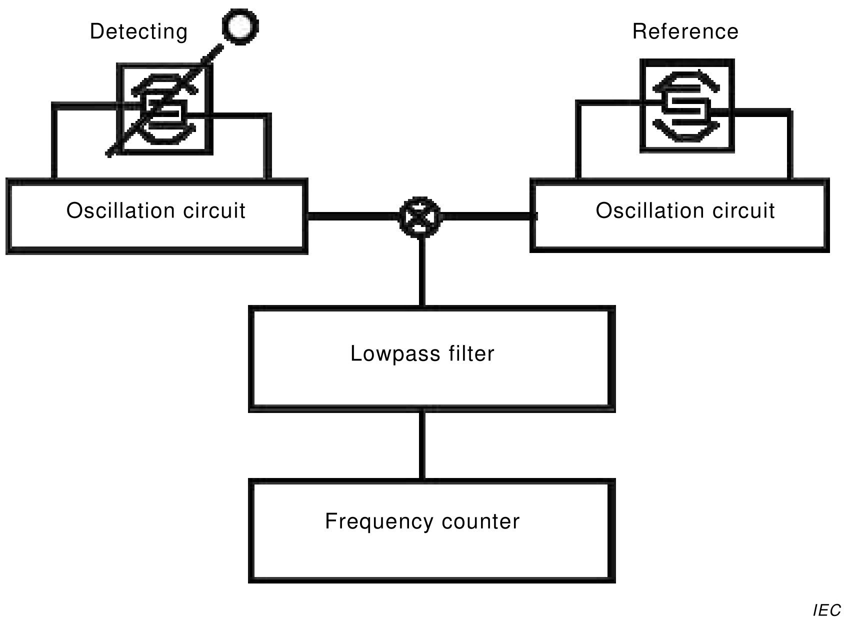

Figure B.1 – Measurement of frequency difference using two oscillation circuits

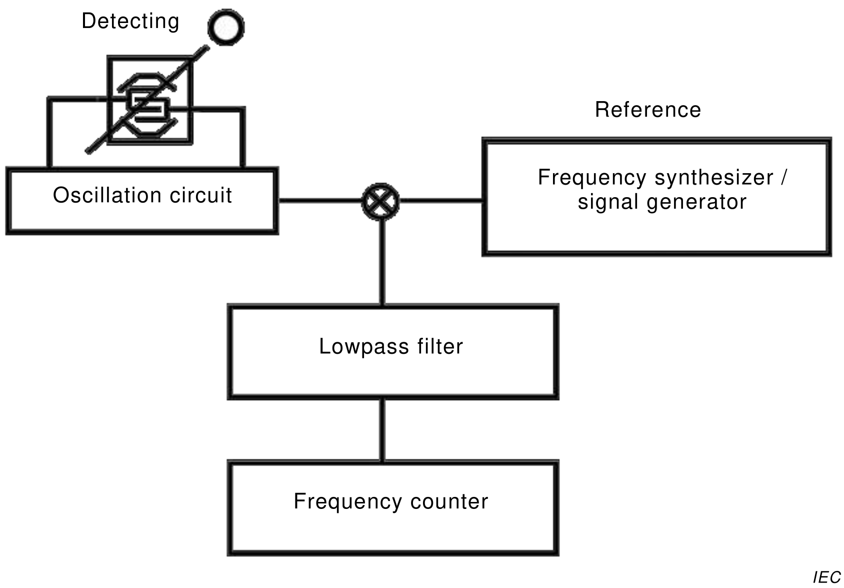

Figure B.2 – Measurement of frequency difference using an oscillation circuit and frequency synthesizer

B.2.2 Insertion loss/gain measurement

If an automatic gain control circuit is added, then the measurement of a change in insertion loss/gain is made possible for the oscillation signal of the detecting sensor elements and cells (see Figure B.3).

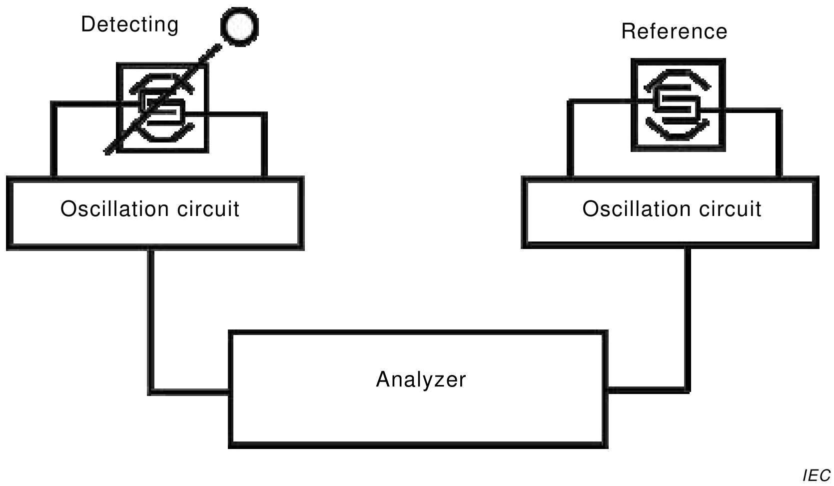

Figure B.3 – Measurement of insertion loss/gain difference using two oscillation circuits

B.2.3 Phase difference measurement

For delay-line type sensor elements and cells, a phase difference between the input and output signals is measured, as shown in Figure B.4.

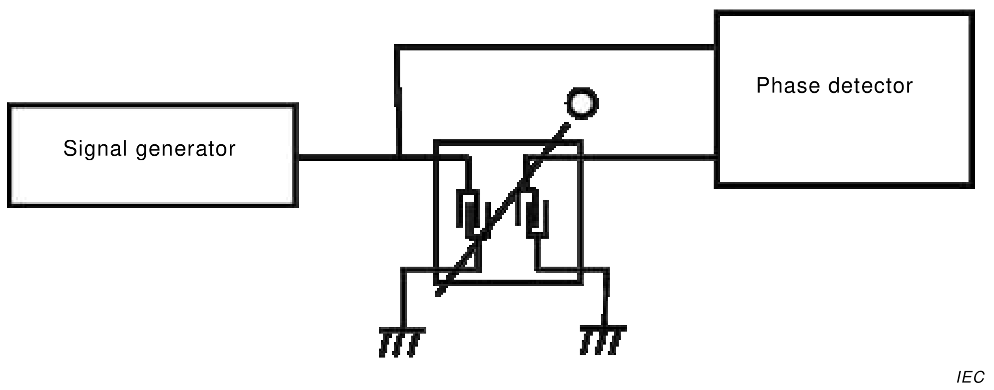

Figure B.4 – Measurement of phase difference using signal generator and phase detector

B.2.4 Other detection methods

The measurement methods shown in Figures A.1 to A.7 may be also used as detection methods.

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch