ICS 31.020 SLOVENSKÁ TECHNICKÁ NORMA Február 2024

STN	**Nositeľné elektronické zariadenia a technológie Časť 401-1: Prístroje a systémy Funkčné prvky Metóda hodnotenia pružných odporových snímačov tlaku**	**STN EN IEC 63203-401-1** 35 9350

Wearable electronic devices and technologies - Part 401-1: Devices and systems: functional elements - Evaluation method of the stretchable resistive strain sensor

Táto norma obsahuje anglickú verziu európskej normy.
This standard includes the English version of the European Standard.

Táto norma bola oznámená vo Vestníku ÚNMS SR č. 01/24

Obsahuje: EN IEC 63203-401-1:2023, IEC 63203-401-1:2023

obsahuje farebné strany

138042

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN IEC 63203-401-1

November 2023

ICS 31.020

English Version

Wearable electronic devices and technologies - Part 401-1: Devices and systems: functional elements - Evaluation method of the stretchable resistive strain sensor (IEC 63203-401-1:2023)

Technologies et dispositifs électroniques prêt-à-porter - Partie 401-1 : Dispositifs et systèmes: éléments de fonctionnement - Méthode d'évaluation de la jauge de contrainte extensible de type résistif (IEC 63203-401-1:2023)

Tragbare elektronische Geräte und Technologien - Teil 401-1: Produkte und Systeme - Funktionselemente - Bewertungsverfahren für dehnbare Widerstandssensoren (IEC 63203-401-1:2023)

This European Standard was approved by CENELEC on 2023-11-13. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and the United Kingdom.

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

Ref. No. EN IEC 63203-401-1:2023 E

European foreword

The text of document 124/223/FDIS, future edition 1 of IEC 63203-401-1, prepared by IEC/TC 124 "Wearable electronic devices and technologies" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN IEC 63203-401-1:2023.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2024-08-13
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2026-11-13

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC shall not be held responsible for identifying any or all such patent rights.

Any feedback and questions on this document should be directed to the users' national committee. A complete listing of these bodies can be found on the CENELEC website.

Endorsement notice

The text of the International Standard IEC 63203-401-1:2023 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standard indicated:

IEC 63203-101-1:2021	NOTE	Approved as EN IEC 63203-101-1:2021 (not modified)
IEC 62047-22:2014	NOTE	Approved as EN 62047-22:2014 (not modified)
IEC 62047-2:2006	NOTE	Approved as EN 62047-2:2006 (not modified)

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cencenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 62899-202-4	2021	Printed electronics - Part 202-4: Materials - Conductive ink - Measurement methods for properties of stretchable printed layers (conductive and insulating)	-	-
ISO 291	2008	Plastics - Standard atmospheres for conditioning and testing	EN ISO 291	2008
ISO/TS 12901-2	2014	Nanotechnologies - Occupational risk management applied to engineered nanomaterials - Part 2: Use of the control banding approach	-	-

IEC 63203-401-1

Edition 1.0 2023-10

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Wearable electronic devices and technologies – Part 401-1: Devices and systems: functional elements – Evaluation method of the stretchable resistive strain sensor

Technologies et dispositifs électroniques prêt-à-porter – Partie 401-1: Dispositifs et systèmes: éléments de fonctionnement – Méthode d’évaluation de la jauge de contrainte extensible de type résistif

IEC 63203-401-1:2023-10(en-fr)

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

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

IEC 63203-401-1

Edition 1.0 2023-10

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Wearable electronic devices and technologies – Part 401-1: Devices and systems: functional elements – Evaluation method of the stretchable resistive strain sensor

Technologies et dispositifs électroniques prêt-à-porter – Partie 401-1: Dispositifs et systèmes: éléments de fonctionnement – Méthode d'évaluation de la jauge de contrainte extensible de type résistif

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 31.020 ISBN 978-2-8322-7558-0

Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WEARABLE ELECTRONIC DEVICES AND TECHNOLOGIES –

Part 401-1: Devices and systems: functional elements – Evaluation method of the stretchable resistive strain sensor

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

IEC 63203-401-1 has been prepared by IEC technical committee 124: Wearable electronic devices and technologies. It is an International Standard.

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

Draft	Report on voting
124/223/FDIS	124/239/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 www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 63203 series, published under the general title *Wearable electronic devices and technologies*, 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.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

WEARABLE ELECTRONIC DEVICES AND TECHNOLOGIES –

Part 401-1: Devices and systems: functional elements – Evaluation method of the stretchable resistive strain sensor

1 Scope

This part of IEC 63203-401 specifies a measurement method of tensile strain for stretchable, resistive strain sensors. This document describes characterization procedures for evaluation of the gauge factor, linearity, response characteristics, and hysteresis of unimodal tension sensors but is not appropriate for assessment of the physical properties of the sensor material such as the elastic modulus, elastic limit, and Poisson's ratio.

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 62899-202-4:2021, *Printed electronics – Part 202-4: Materials – Conductive ink – Measurement methods for properties of stretchable printed layers (conductive and insulating)*

ISO 291:2008, *Plastics – Standard atmospheres for conditioning and testing*

ISO/TS 12901-2:2014, *Nanotechnologies – Occupational risk management applied to engineered nanomaterials – Part 2: Use of the control banding approach*

3 Terms and definitions

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1
stretchable substrate
stretchable material
substrate or material able to recover original size and shape immediately after the removal of the extending force causing deformation

Note 1 to entry: In this document, the notion of "stretchability" is based on the elasticity of the substrate.

[SOURCE: IEC 63203-101-1:2021, 3.10 [1]]

3.1.2
gauge factor
G_F
ratio of the change in electrical resistance divided by the original resistance (R_O, resistance in the undeformed configuration) to engineering strain (e) along the axis of the stretching

Note 1 to entry: Gauge factor is expressed as $G_F = \frac{(R - R_O) / R_O}{e}$, where R_O is the initial resistance in the undeformed configuration, R is the electrical resistance in the deformed configuration, and e is the tensile strain.

[SOURCE: IEC 62047-22:2014, 3.1.1 [2] modified – "along the axis of the stretching" has been added to the definition, and, in the note to entry, "where R is the electrical resistance in the deformed configuration" has been replaced with "where R_O is the initial resistance in the undeformed configuration, R is the electrical resistance in the deformed configuration, and e is the tensile strain".]

3.1.3
gauge length
length of the strain-sensitive section of a stretchable strain sensor in the direction of the measurement axis

3.2 Symbols and abbreviated terms

Symbol	Unit	Description
a	mm	Width of the resistive thin film
h	µm	Thickness of the resistive thin film
l_0	mm	Gauge length of the sensor
l_1	mm	Length of the stretchable resistive thin film

4 Test environments

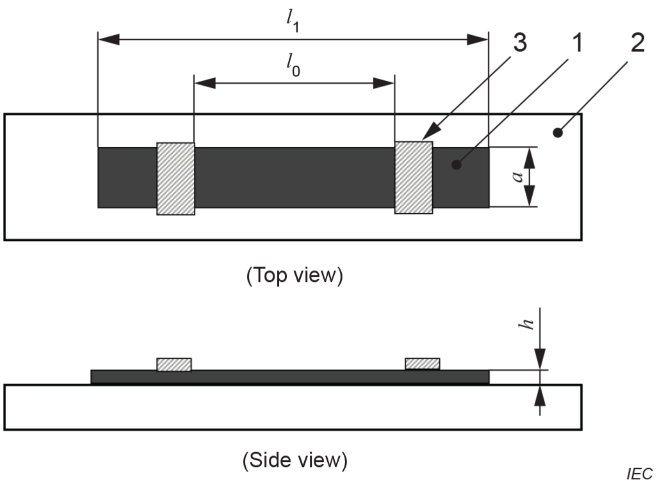
The tests shall be performed under constant temperature and humidity conditions. As environmental conditions, including temperature and humidity, can affect the electrical and mechanical properties of resistive materials and substrates, the testing temperature and humidity shall be monitored during testing. Fluctuations in temperature during a test shall be kept to less than ±2 °C. Thus, when testing such materials, the change in relative humidity (RH) in the testing laboratory shall be kept to less than ±10 % RH. The recommended temperature and relative humidity are 23 °C ± 2 °C and relative humidity of 50 ± 10 %, respectively, conforming to standard atmosphere class 2 specified in ISO 291. Whenever testing is conducted, the environmental conditions shall be recorded.

5 Test specimen

5.1 Shape of the test specimen of the stretchable strain sensor

The shape of the stretchable strain sensor to be tested shall be rectangular or square. The test specimen has a stretchable substrate, and the resistive thin film is deposited on this stretchable substrate or on a single layer of resistive composite materials. Figure 1 presents the basic shape of the test specimen including pads or metal layer for electrical connection. For the pad, the thin metal film or coating is deposited or fabricated on the resistive sensor layer. The film materials with low stiffness are fabricated as thin as possible (for example, less than a few micrometers in thickness) so that the stretching of the resistive sensor material is not restricted due to the pad material. Some resistive composite sensor materials can be sensitive to the deposition process. Thus, there will be a possibility that the resistive sensor materials can be damaged during the deposition process. In this case, metal clips can be used for electrical connection instead of metal pads. The length of the stretchable resistive thin film l_1 can be the same as the length of the stretchable substrate. The width of stretchable substrate is more than or equal to the width of the resistive thin film.

For uniform strain distribution, a rectangular strip shape is recommended. Since the change in electrical resistance is related to the strain, the electrical resistance is measured in a region of nearly uniform strain within the gauge length. The gauge length is chosen as the region where the strain of the stretchable sensor layer is uniform over the cross-sectional area.



Key

1 Stretchable strain sensor material

2 Stretchable substrate

3 Pad for electrical connection

Figure 1 – Shape of a test specimen of the stretchable strain sensor

5.2 Measurement of dimensions

The length of the stretchable strain sensor, in particular the gauge length of the sensor shall be measured accurately, because the dimension of the length can be used to determine the mechanical and electrical properties of the strain sensor. Each test specimen should be measured directly. The test specimens' dimensions shall be specified within the maximum error of ±5 %.

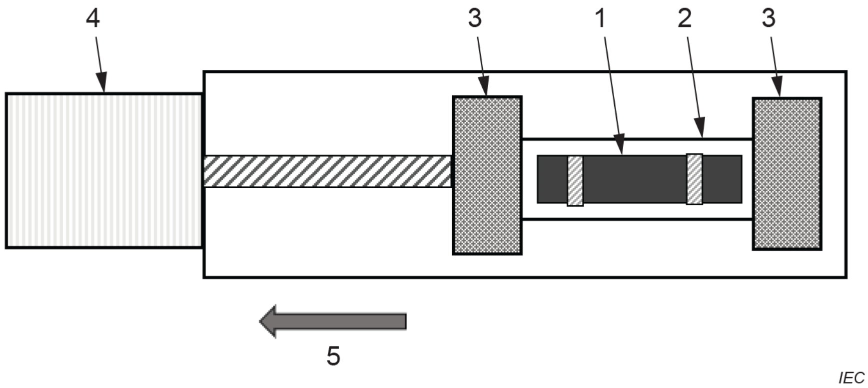
6 Test method and test apparatus

6.1 General

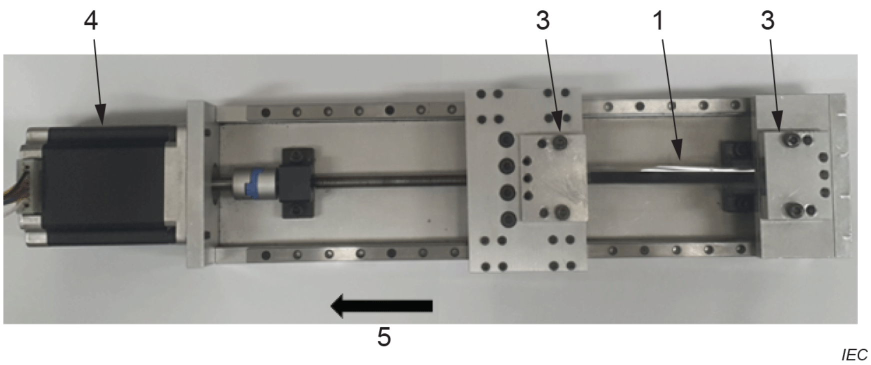
The test is performed by applying a tensile load to a test specimen. The tensile strain induced by the tensile load shall be uniform in a pre-defined gauge section in the elastic region of the substrate or the thin resistive material. To measure the change in electrical resistance along with the change in mechanical strain, the section of gauge shall be selected carefully. The gauge section used to measure the mechanical strain shall be coincident with or scalable to the section used to measure the electrical resistance.

6.2 Test apparatus and measurement

The stretching test machine includes the grips to hold a test sample, the actuating motor which regulates moving distance and moving speed while testing. Stretching shall be applied along the tensile axis of the test sample to avoid the bending or twisting of the test piece. An example of a stretching test machine is shown in Figure 2.



(a) Schematic drawing of stretching test machine (top view)



(b) Photograph of example of a stretching test machine (top view)

Key

1 Stretchable strain sensor

2 Stretchable substrate

3 Grip

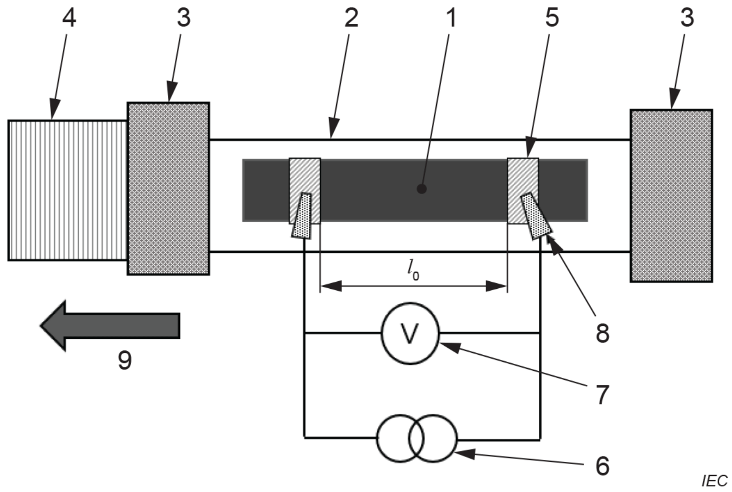
4 Actuating motor

5 Actuating direction

Figure 2 – Example of stretching test machine

A vertical stretching test machine can be used if the deformation of the stretchable sensor due to its own weight can be ignored. The electrical measurement circuit can use two-wire or four-wire methods depending on the magnitude of the electrical resistance of the sensor. For a sensor that has an electrical resistance greater than 1 kΩ, a two-wire method can be used for ease of measurement. For a sensor that has an electrical resistance 1 kΩ or less, the four-wire method shall be used to eliminate contact- and lead-wire resistance.

Figure 3 shows the schematic drawing of the two-wire method and test machine setup. The test machine consists of grips, load cell (or strain measurement sensor), motor or actuator. Prepare a stretchable specimen with a gauge length longer than the distance between the grips. The resistance measurement setup consists of a constant-current source, a voltmeter, metal clips or electrodes. The clips that are made of rust-resistant metal or that have a surface treatment (such as gold plating) to prevent rust shall be used.



Key

1 Stretchable sensor material
2 Stretchable substrate
3 Grip
4 Motor or actuator
5 Pad
6 Constant current source
7 Voltmeter
8 Metal electrode (or metal clip)
9 Actuating direction

Figure 3 – Schematic drawing of a stretching test machine and two-wire measurement method

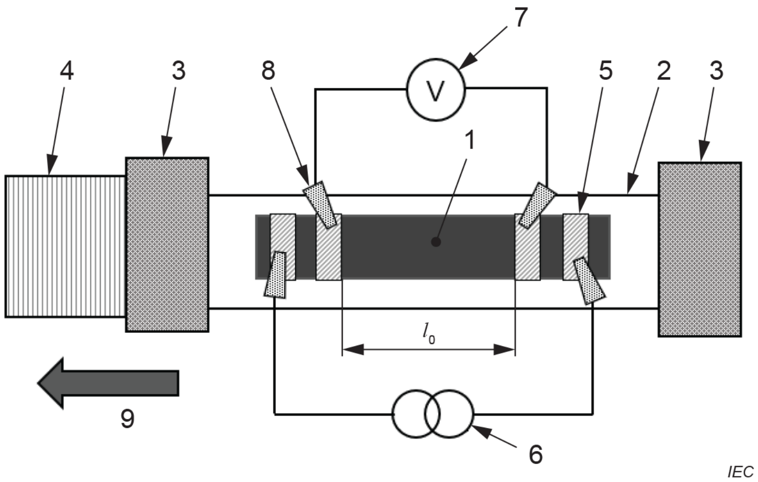
Figure 4 shows the schematic drawing of the four-wire method and test machine setup. The resistance measurement setup consists of a constant-current source, a voltmeter, metal electrodes or metal clips (voltage electrode), and metal electrodes (current electrode). Therefore, the constant-current source pad and voltmeter pad for electrical connection are required at each side of the sample. The fabrication of pads is explained in 5.1. Figure 4 a) illustrates the initial test setup, and Figure 4 b) illustrates the test setup during stretching. The examples of sensor resistance or changes in resistance during stretching test are illustrated in Annex A.

The quality-certified rulers or mechanical extensometer are used to measure the stretched gauge length (l_s). Several optical methods using laser, interference light, camera, and image systems such as digital image correlation (DIC) systems can be utilized to measure the stretched gauge length. Several methods are available to measure resistance changes of the sensor with sufficient resolution and accuracy.

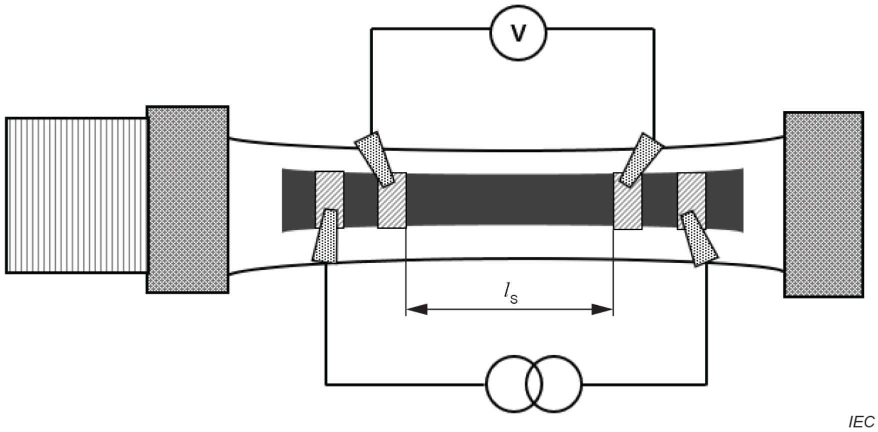
During stretching, there will be slippage or friction between the pad and metal electrode or metal clip which will cause the distortion of the electrical resistance value of the sensor. In this case, more stable electrical connection such as soldering of electrical wire to the pad shall be used. In particular, the continuous cyclic stretching test shall require stable electrical connection. Figure 4 c) illustrates an example of the test setup during stretching.

Figure 4 d) illustrates another example of test setup. This test setup and test method are described in detail and shall be as described in IEC 62899-202-4:2021. When this test method is used, it is noted that the stress is not relatively uniform across the sample in lateral direction.

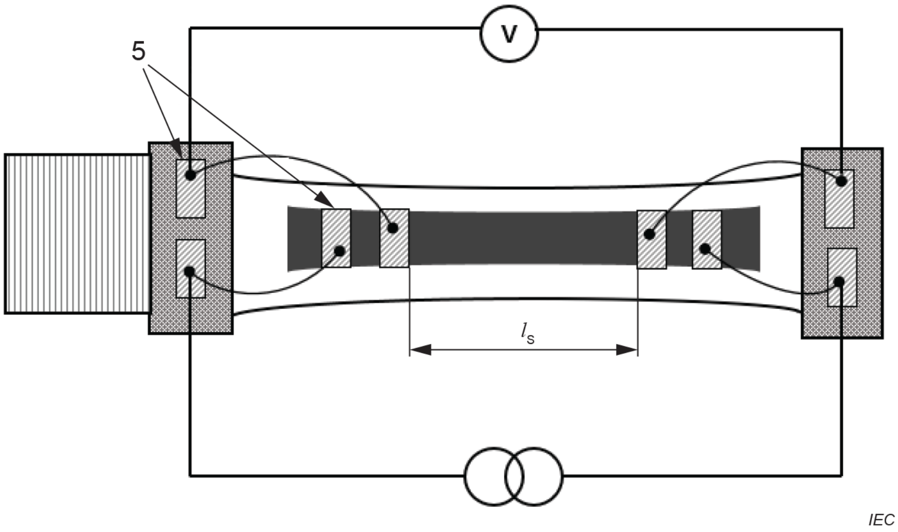
The test machine shall use the gripping system which holds the test sample evenly and firmly to avoid the slippage of the sample during the stretching test. The gripping system shall not cause premature damage, failure and scratch in the sample. For highly stretchable samples, including elastomers, over-tightening of the gripping is also to be avoided to prevent concentrating the local stress, scratching, or damaging the substrate in the area that is clamped. The sample shall not twist or bend during stretching.



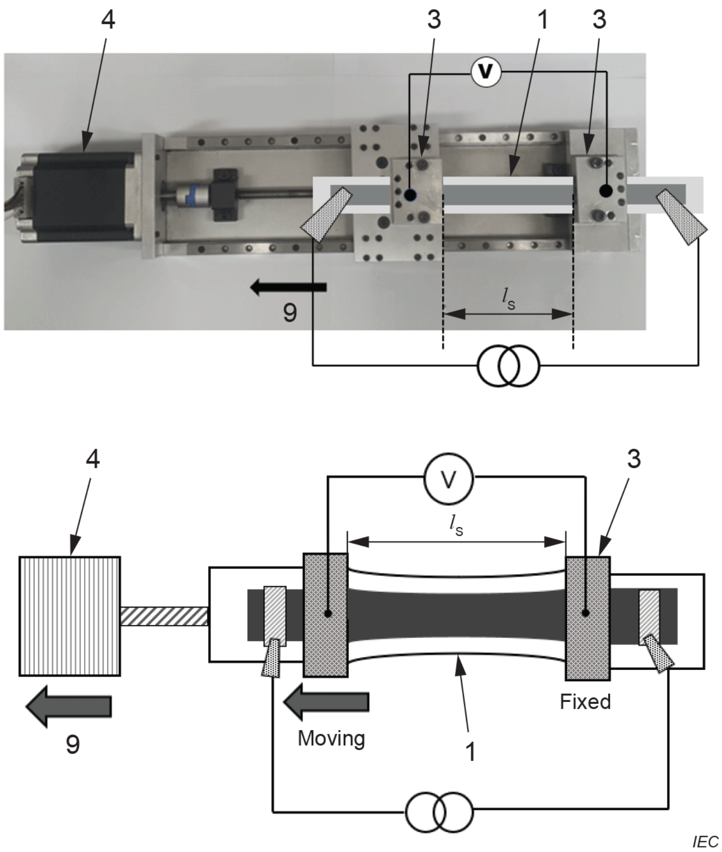
a) Initial test setup using four-wire method



b) Test setup during stretching using four-wire method



c) Example of test setup during stretching using four-wire method and stable electrical connection



d) Other example of test setup during stretching using four-wire method and stable electrical connection

Key

1	Stretchable sensor material	2	Stretchable substrate
3	Grip	4	Motor or actuator
5	Pad	6	Constant current source
7	Voltmeter	8	Metal electrode (or metal clip)
9	Actuating direction	l_s	Stretched gauge length

Figure 4 – Schematic drawing of a stretching test machine and four-wire measurement method

7 Test procedure

The test procedure is as follows.

1) Mount the sensor to be tested on the test apparatus. Centre the sensor symmetrically on the constant-stress area and align it with the longitudinal centre line of the actuating direction of the test apparatus.
2) Measure the initial electrical resistance of the sensor.
3) The sensor is stretched with the increasing tensile strain to a designated tensile strain. Then, the sensor's electrical resistance is measured simultaneously with no time delay. Record the strain and electrical resistance.
4) The test is performed under a constant strain speed that depends on the material of the sensor and the sensor's actual application. The strain rate will range from 0,01 min^{-1} to 1 min^{-1} to avoid the possible external effects on the sensor performances caused by stretching speed or strain-rate, depending on the sensor material and the actual usage condition of the strain sensor. The examples of the relative resistance change of the strain sensors at different strain rates are illustrated in Annex B in which the strain rate affects the sensor performances. When the speed is not specified, use the lowest speed.
5) This operation is repeated, increasing the tensile strain until the resistance value reaches a level that is unacceptable in the actual usage condition of the strain sensor. The test will be stopped at this point.
6) Unload the sensor when electrical failure occurs in the sensor or when fracture or damage occurs in the resistive thin film or the substrate. The test will also be terminated when electrical failure occurs in the sensor or when fracture or damage occurs in the resistive thin film or the substrate.

8 Measurement of sensor performance and endurance

8.1 Gauge factor

8.1.1 General

The gauge factor is the ratio of relative change in electrical resistance to the mechanical strain. It is determined from the average of the slope of the straight line between the measurement points in the graph of relative change in electrical resistance to nominal tensile strain. The measurement of the gauge factor of the stretchable strain sensor can be similar to that of the conventional metal-foil strain gauge except for the amount of strain applied. The gauge factor may vary with the strain due to the nonlinear characteristics of the resistive material and the elastomer. In addition, it should be noted that the change in resistance with strain is not due solely to the dimensional changes in the resistive sensor but that the resistivity of the resistive material also changes with the strain. In this case, the characteristics of the gauge factor with the strain shall be reported.

NOTE Details on measuring the thermal characteristics of the strain sensor can be found in ASTM E251-92 [3][1].

8.1.2 Purpose

The purpose of this method is to measure the gauge factor of the stretchable strain sensor.

---

1 Numbers in square brackets refer to the Bibliography.

8.1.3 Test procedure

The test procedure to measure the gauge factor of the strain sensor is basically the same as the test procedure described in 6.1 and 7 except that the strain sensor is stretched up to a designated operating strain range of the stretchable strain sensor. The gauge factor can be calculated as the ratio of the change in electrical resistance of the strain sensor to the change in length (strain) along the axis of the stretching.

8.2 Linearity

8.2.1 Purpose

Linearity of the stretchable strain sensor refers to the relationship between the relative change of the electrical signal, such as electrical resistance, and applied strain as shown in Figure 5. The closeness of the calibration curve to a specified straight line shows the linearity of a sensor. Its degree of resemblance to a straight line describes how linear a sensor's output is. A stretchable sensor with good linearity can reliably produce sensor signals even without rigorous calibration over a wide range of tensile strain.

8.2.2 Test procedure

Measure the electrical resistance outputs when the stretchable strain sensor is stretched within measuring stretchability range including end-point. Five measurements at least should be taken throughout the possible range of measurement. These points are then recorded on a graph as shown in Figure 5. An attempt is made to fit a straight line through these points. The point which deviates most from the simple straight line will be used to specify the "linearity" of the stretchable strain sensor. The degree to which the points lie away from the straight line of best fit is called the linearity error of the strain sensor.

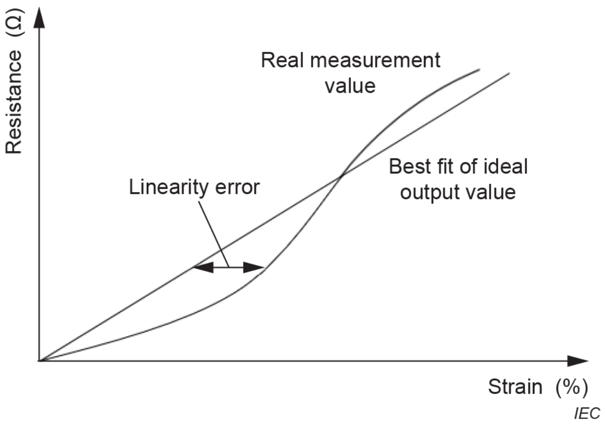


Figure 5 – Linearity measurement of the stretchable strain sensor

8.3 Response characteristics

8.3.1 General

The response time is how fast the sensor responds to external strain. Response characteristics determine how quickly the stretchable strain sensor moves toward a steady-state response. The response characteristics of the stretchable strain sensor are important when the strain sensor is used to monitor human motion or activity. Since a response delay exists in all elastomer-based stretchable strain sensors due to the viscoelastic nature of elastomers, measuring the stretchable sensor's response time is recommended. The response time required for a stretchable sensor is dependent on the sensor's application.

8.3.2 Purpose

The purpose of this method is to measure the response characteristics of the stretchable strain sensor.

8.3.3 Test procedure

a) The response time of the stretchable sensor is calculated as the time span between stretching and the point in time when the sensor output signal rises to the 90 % of maximum response to the applied strain. Therefore, the exact definition of the response time used should be defined and reported. Examples of the measurement of the response time for various stretchable strain sensors are illustrated in Annex C.

b) As the stretchable strain sensor is stretched, the corresponding transient electrical signals, such as electrical resistances of the strain sensor over time, are continuously recorded.

c) To measure the response time of the strain sensor, the resistance measurement methods with the data acquisition systems and computer are used. Various data acquisition systems and instruments such as high-speed digital oscilloscope and digital multimeter also can be used.

d) While the sensor is at rest, the strain is increased to the lowest possible strain level with a maximum speed and then released back to the initial state. The time required for the stretch/release process is different because the stretch/release process is a quasi-transient process that requires more time for large elongations, which means that with increasing elongations, the residual time also increases. It is appropriate to set the minimum satisfactory elongation with maximum speed (for example, 1 mm deformation length and 100 mm/min strain rate). It is recommended to determine the stretching elongation or strain within a range in which the non-linearity and hysteresis characteristics of the sensor are minimized. The stretching strain and speed can be dependent on the sensor's application.

8.4 Hysteresis

8.4.1 General

Hysteresis and recovery become important when stretchable strain sensors are used to sense dynamic load application, including in skin-mountable and wearable applications. Hysteresis represents the history dependence of the stretchable sensor under mechanical deformation. Large hysteresis behaviour in the sensors leads to the sensing performance of the sensors being irreversible upon dynamic loadings. Typically, nanocomposite-based strain sensors that use metallic particles, Ag nanowire, carbon-based materials, and elastomer composite are known to exhibit longer recovery times due to the friction force between the fillers and the elastomer matrices. Therefore, the measurement of the hysteresis and the recovery characteristics of the stretchable sensors is recommended. When handling nano-materials such as nanoparticles, nanopowders, nanofibers, nanotubes, and nanowires, the risks associated with occupational exposure to nano-material or prevention of any possible adverse effects on workers' health shall be controlled in accordance with ISO/TS 12901-2:2014.

8.4.2 Purpose

The purpose of this method is to measure the hysteresis of the stretchable strain sensor.

8.4.3 Test procedure

a) To characterize the hysteresis behaviour of the stretchable strain sensor, the strain sensor is subjected to a stretching-releasing cycle with a targeted maximum strain.

b) Place the stretchable strain sensor in the tensile-testing machine.

c) Stretch the strain sensor to a designated strain and record the electrical resistance value and applied strain. The stretching speed or strain rate is described in Clause 7.

d) Repeat the increment of strain with continuous measurement of the electrical resistance up to a targeted maximum strain.

e) After the strain sensor is stretched to a maximum strain, release the strain sensor to a designated strain. Repeat the reduction of the strain down to 0 % strain, that is, initial state.

f) There can be several methods to calculate the hysteresis value. Therefore, the designated strain and the exact definition of the hysteresis value used should be defined and described in the test reports. Examples of hysteresis calculation and hysteresis behaviour of various stretchable strain sensors are illustrated in Annex D.

9 Test report

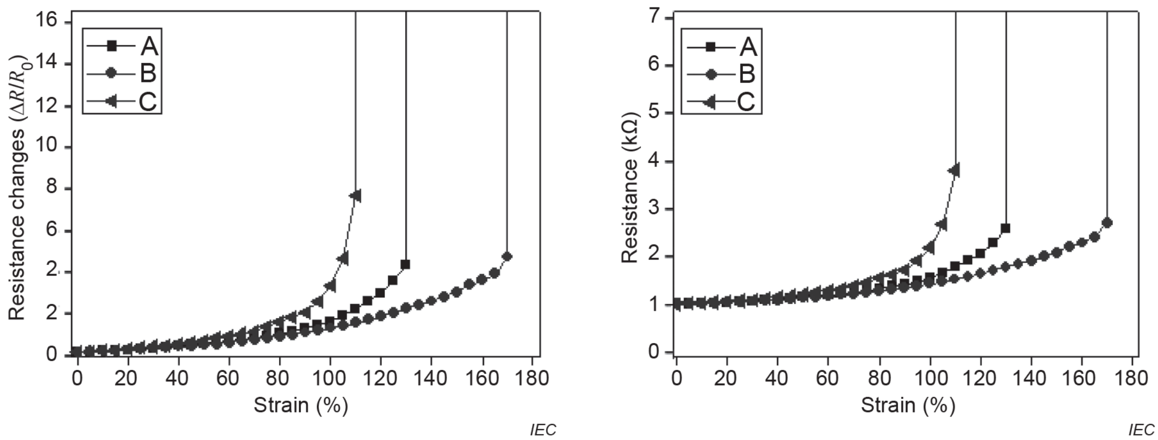
The test report shall contain the following information.

1) Sensor material and substrate material
2) Sensor dimensions and the method used to measure them
3) Number of sensors tested
4) Description of the testing apparatus
5) Strain rate applied
6) Sensor performance, including
   - Stretchability or maximum allowable amount of strain
   - Gauge factor and linearity
   - Response and hysteresis characteristics
   - Definition and measurement methods of the response time and hysteresis value

Annex A
(informative)

Strain sensor resistance measurement

Figure A.1 shows examples of stretchability test results of a stretchable resistive strain sensor using a tensile test machine. The stretchable strain sensor was made of Ag flakes and a polymer binder and printed on the polyurethane stretchable substrate. The stretching test was performed using a tensile test at a low speed of 0,1 mm/s. The change in the electrical resistance of the strain sensor was measured during the test using the two-wire method. Three kinds of the resistive strain sensor were evaluated and compared. In Figure A.1 b), the change in the resistance of the strain sensor was expressed as ΔR (= $R - R_{\text{o}}$)/R_{o}, where R_{o} and R are the resistances of the strain sensor before and after testing, respectively. The electrical resistance of the sensors gradually increases as tensile strain increases, and then at a certain point, the resistance increases sharply for some sensors.



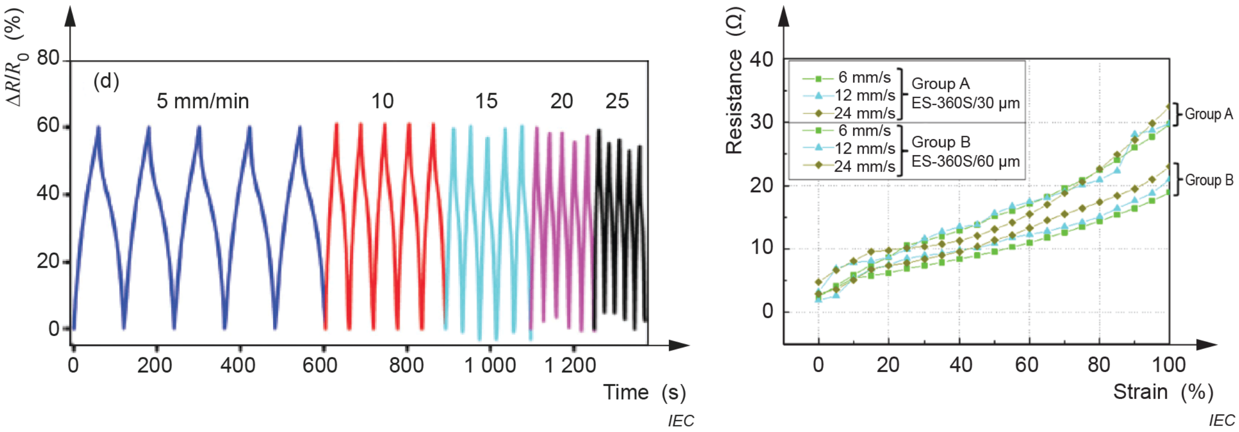
a) b)

Figure A.1 – Changes in electrical resistances when the strain sensor is stretched

Annex B
(informative)

Effects of strain rate on performances of the stretchable strain sensor

Figure B.1 shows two examples of the resistance change of the stretchable strain sensor for different strain rates. Figure B.1 a) shows the relative resistance change of the stretchable strain sensor for different strain rates with a strain of 50 %. The applied rate was in the range of 5 mm/min to 25 mm/min [4]. The relative resistance ΔR (= $R - R_o$)/R_o was measured where R_o and R are the resistances of the strain sensor before and after testing, respectively. As the strain rate increases from 5 mm/min to 20 mm/min, the resistance of the strain sensor reduces. Figure B.1 b) also shows the effect of the strain rate on performances of the stretchable strain sensor [5]. For different strain rates, the stretchable strain sensor shows the different resistance behaviour during stretching.



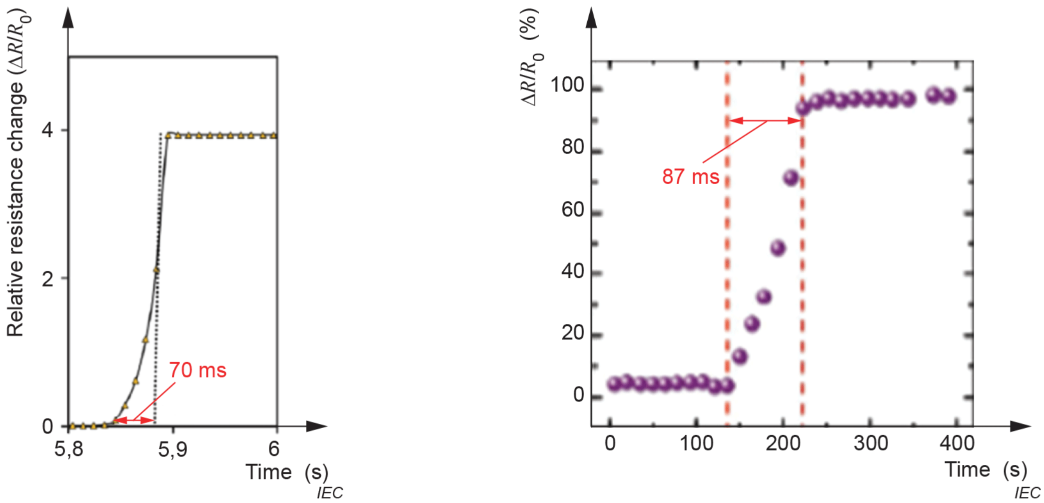
a) b)

Figure B.1 – Examples of the effects of strain rate on performances of the stretchable strain sensor

Annex C
(informative)

Measurement of response time of the stretchable strain sensor

Figure C.1 shows two examples of the response time of the stretchable resistive strain sensor tested using a tensile test machine. The stretchable strain sensor in Figure C.1 a) was made of Ag ink and polymer binder [6]. The relative resistance ΔR (= $R - R_o$)/R_o was measured with time where R_o and R are the resistances of the strain sensor before and after testing, respectively. The response time of this strain sensor is 70 ms. Figure C.1 b) shows another example of the response time of the stretchable strain sensor made of the carbon nanotube and polydimethylsiloxane (PDMS) binder [7]. The response time of this strain sensor is 87 ms. Obviously, the sensor with the faster response time is better.



a) b)

Figure C.1 – Examples of the response time of the stretchable strain sensors

Annex D
(normative)

Examples of hysteresis calculations

There can be several methods to calculate the hysteresis behaviour of the sensors. Figure D.1 shows an example of the hysteresis behaviour of a stretchable resistive strain sensor.

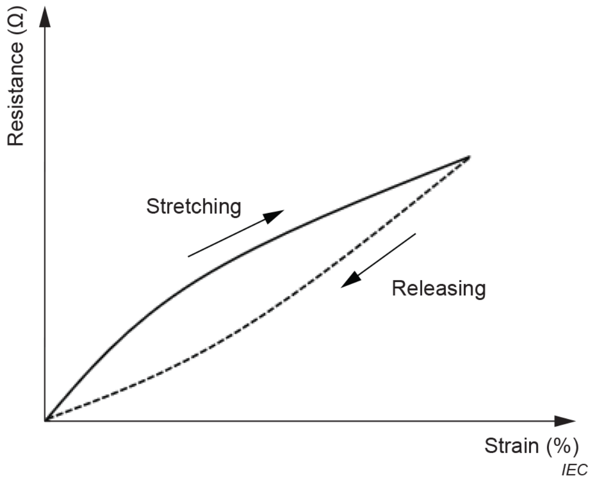


Figure D.1 – Example of the hysteresis behaviour of a stretchable strain sensor

In many cases, the main portion of the hysteresis curve is not a simple straight line. Non-linearity and sampling error tend to make the line less than ideal in Figure D.2.

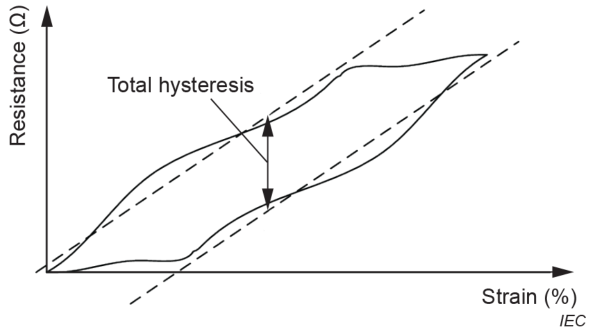


Figure D.2 – Example calculation of hysteresis behaviour

The calculation of the hysteresis occurs at the midpoint of the curve shown in Figure D.3. This point can be located with the following formula. X in the formula represents strain and Y represents resistance.

$$X_{\text{m}} = \left(\frac{X_{\text{max}} - X_{\text{min}}}{2} \right) + X_{\text{min}}$$

$$Hysteresis\ \% = \left| \frac{\left(Y_{\text{mn}} - Y_{\text{mp}} \right)}{\left(Y_{\text{max}} - Y_{\text{min}} \right)} \right| \times 100\ \%$$

Once the midpoint has been located, the two Y values (positive and negative going) can be obtained and the hysteresis can be calculated from the above equation.

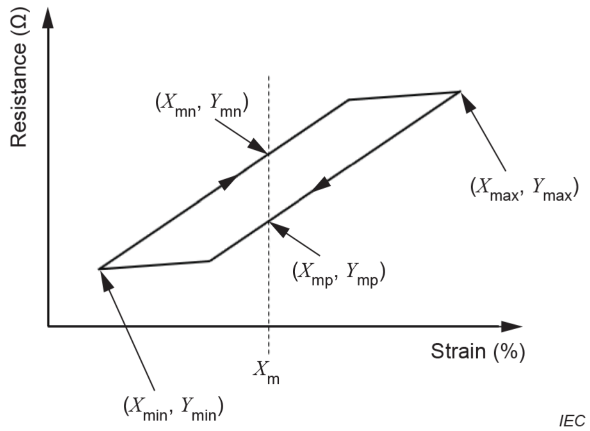


Figure D.3 – Calculation of hysteresis behaviour of the stretchable strain sensor

The hysteresis magnitude of the stretchable sensor can also be evaluated by quantifying the areal ratio of the loading and unloading curves [8]. In Figure D.4, the degree of hysteresis (DH) can be calculated as follows:

$$DH = \frac{A_s - A_R}{A_s} \times 100\ \%$$

where A_s and A_R are the areas of stretching and releasing curves, respectively.

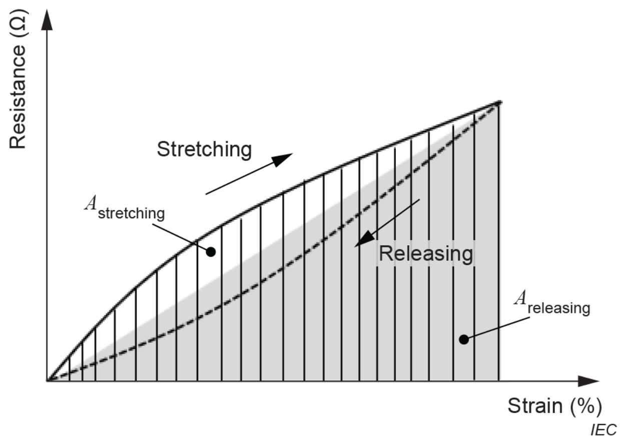


Figure D.4 – Example of calculation of the degree of hysteresis

Bibliography

[1] IEC 63203-101-1:2021, *Wearable electronic devices and technologies – Part 101-1: Terminology*

[2] IEC 62047-22:2014, *Semiconductor devices – Micro-electromechanical devices – Part 22: Electromechanical tensile test method for conductive thin films on flexible substrates*

[3] ASTM E251-92, *Standard test methods for performance characteristics of metallic bonded resistance strain gages*

[4] Y. Li, B. Zhou, G. Zheng, X. Liu, T. Li, C. Yan, C. Cheng, K. Dai, C. Liu, C. Shena and Z. Guo, *Continuously prepared highly conductive and stretchable SWNT/MWNT synergistically composited electrospun thermoplastic polyurethane yarns for wearable sensing*, Journal of Materials Chemistry C, 6. 2258-2269, 2018

[5] C. G. Lee, B. S. Kwon, H. M. Nam, D. M. Seo, J. Park, H. Hwangbo, L. S. Park, S. Y. Nam, *Stretchable Strain Sensors Fabricated by Screen Printing of Silver Paste on the Surface Modified Transparent Elastomeric Polyurethane Films*, Materials Sciences and Applications, 9, 1008-1020, 2018

[6] J. Tolvanen, J. Hannu, H. Jantunen, *Stretchable and Washable Strain Sensor Based on Cracking Structure for Human Motion Monitoring*, Scientific Reports, 8, 13241, 2018

[7] C. Li, D. Zhang, C. Deng, P. Wang, Y. Hu, Y. Bin, Z, Fan, and L. Pan, *High performance strain sensor based on buckypaper for full-range detection of human motions*, Nanoscale, 10, 14966, 2018

[8] S. G. Yoon, H.-J. Koo, and S. T. Chang, *Highly Stretchable and Transparent Microfluidic Strain Sensors for Monitoring Human Body Motions*, ACS Appl. Mater. Interfaces, 7, 27562−27570, 2015

[9] T.Q. Trung and N.-E. Lee, *Flexible and Stretchable Physical Sensor Integrated Platforms for Wearable Human-Activity Monitoring and Personal Healthcare,* Advanced Functional Materials, 28, 4338–4372, 2016

[10] M. Amjadi, K.-U. Kyung, I. Park, and M. Sitti, *Stretchable, Skin-Mountable, and Wearable Strain Sensors and Their Potential Applications: A Review, Advanced Functional Materials, 26,* 1678–1698, 2016

[11] IEC 62047-2:2006, *Semiconductor devices – Micro-electromechanical devices – Part 2: Tensile testing method of thin film materials*

[12] ASTM D2653-07, *Standard Test Method for Tensile Properties of Elastomeric Yarns (CRE Type Tensile Testing Machines)*

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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

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