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Textiles and textile products — Electrically conductive textiles — Determination of the linear electrical resistance of conductive tracks

bsi.

National foreword

This British Standard is the UK implementation of EN 16812:2016.

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A list of organizations represented on this committee can be obtained on request to its secretary.

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Textilien und textile Erzeugnisse - Elektrisch leitfähige Textilien - Bestimmung des linearen elektrischen Widerstands von Leiterbahnen

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European foreword

This document (EN 16812:2016) has been prepared by Technical Committee CEN/TC 248 “Textiles and textile products”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2016, and conflicting national standards shall be withdrawn at the latest by October 2016.

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1 Scope

This European Standard describes a test method for the determination of the linear electric resistance of conductive tracks for textile structures or intended for application in/ to textiles, e.g. yarns, printed or coated tracks, ropes, ribbons and webbing.

This European Standard is designed for materials showing ohmic behaviour.

This European Standard is designed for conductive tracks where electrical contact between the measurement electrodes and the conductive track is possible.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 12127, *Textiles — Fabrics — Determination of mass per unit area using small samples*

EN ISO 139, *Textiles — Standard atmospheres for conditioning and testing (ISO 139)*

3 Terms and definitions

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

3.1
textile-based electrically conductive track
electrically conductive part of the textile having a length to width ratio of minimum 10 to 1

Note 1 to entry: Examples for textile based electrically conductive tracks and how to determine their length (L) and width (w) are given in Figure 1

3.2
Ohmic behaviour
conductor's behaviour following Ohm's law

Note 1 to entry: Ohms law is a fundamental law of electricity, stating that the voltage at the terminals of an ideal resistor is proportional to the current in the resistor (voltage U across the terminals equals resistance R times current I) [www.electropedia.org IEV ref 131–15–08].

Note 2 to entry: In this standard 'U' is used for the measured voltage, according to the IEC electropedia (www.electropedia.org).

3.3
linear electrical resistance R_L
electrical resistance per unit length of a track, as determined in this standard (expressed in ohm/m)

3.4
wire
lead or measurement point used in the four point Kelvin method

3.5
electrode
contact between the measurement wire and the sample

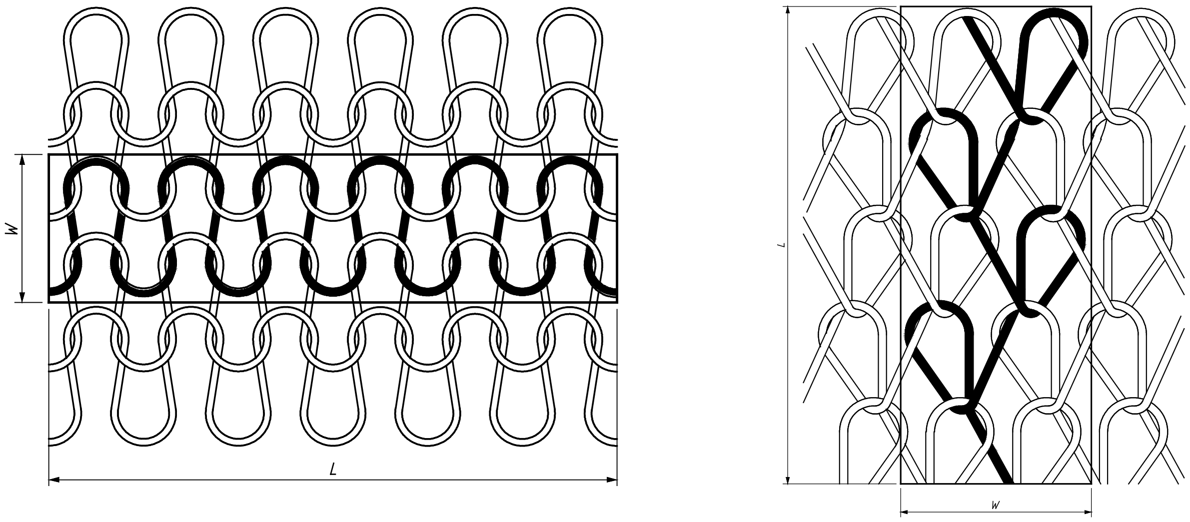


Figure 1 — Different types of conductive tracks, with indication on how to determine the width (W) and the length (L) of the track. Images adapted from EN ISO 8388

4 Principle of test

This test describes a procedure to measure the linear electrical resistance of textile based electrically conductive tracks using the measurement principle of the four wire (four point) Kelvin method and a DC current source.

This test method can be performed as “four electrode - four wire method” or “two electrode - four wire method”.

By using four electrodes the contact resistances between the electrodes and the sample are compensated. As a result this method requires less measurements and calculations as compared to the “two electrode – four wire method”. This is why the “four electrode - four wire method” is preferred.

In cases where it is not feasible to prepare the necessary four contacts for the electrodes, “the two electrode – four wire method” can be used.

5 Test equipment

The test equipment shall consist of:

— an electrical current source able to deliver a stable DC current in the range necessary for the measurement;

— a volt-meter capable of measuring voltages in the range necessary for the measurement.

NOTE An Ohm meter in accordance with EN 60051–6, suitable for four wire measurements, can also be used.

— Contacting electrodes, which shall be clean, oxide free and undamaged, and suitable for low-resistance measurements e.g. made of chrome or gold finished copper. The electrodes shall be suitable for soft materials e.g. have a flat contact surface.

— A calibrated ruler to measure the distance between the voltage electrodes (edge to edge), with the resolution of at least 3 significant digits in relation to the sample length. The ruler should preferably be integrated in the clamping device.

— An insulating surface on which the specimen is placed. An insulating surface has a surface resistance of > 10^9 Ω reduced to a square, also commonly expressed as Ω /☐ or Ω/sq. Alternatively the specimen can also be suspended in air.

6 Test specimens

6.1 Number of test specimens

Five representative specimens per sample shall be tested.

NOTE Resistance may depend on the orientation of the sample taken out of the textile structure.

Additional specimens may be required as discussed in 8.5.

6.2 Dimensions of specimens

The specimen length shall be chosen such that:

— the distance d between the voltage electrodes is at least 10 times the width w of the conductive track; a recommended distance d is 50 cm, taking into account the requirements mentioned below.

— the part between the voltage electrodes represents the full structure of the conductive track

— the specimen fits into the measurement set-up, including clamping device and current electrodes.

6.3 Conditioning

Test specimens shall be stored for at least 24 h in standard atmosphere conditions (20 °C and 65 % RH in accordance with EN ISO 139).

6.4 Relaxation

Relaxation of the fabrics shall be performed according to EN 12127.

It is important to ensure that the fabrics are in the relaxed state prior to testing. The fabrics shall be kept in a flat tension free state for at least 24h, during conditioning. Knitted fabrics may require a longer relaxation treatment, as agreed upon between the interested parties.

7 Test set-up

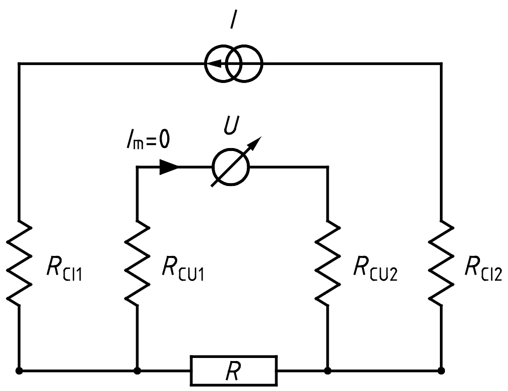
7.1 General

In the following the test set-up is described with the level of detail needed for implementing this standard. A more detailed description of the test set-up can be found in Annex A.

7.2 Test set-up for a "four electrode – four wire method"

This set-up is the preferred set-up, as discussed in Clause 4.

The electrodes shall be arranged as shown in Figure 2 and shall cover the whole width of the conductive track.



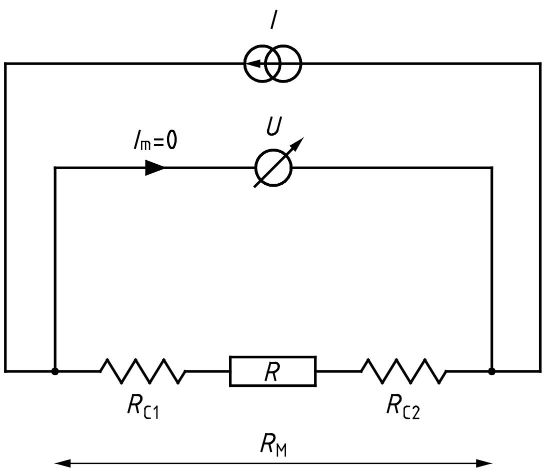
Key

I	the applied current, in amperes
U	the measured voltage, in volts
I_m	the current in the voltage measurement circuit (equivalent to zero)
R_{CI1}, R_{CI2}	the contact resistances in the current circuit, in ohms
R_{CU1}, R_{CU2}	the contact resistances in the voltage circuit, in ohms
R	the resistance of the sample in ohms, identical to the measured resistance: $R = U/I$

Figure 2 — Schematic test set-up for a four electrode - four wire measurement

7.3 Test set-up for a "two electrode – four wire method"

This set-up shall be used for tracks where the application of the "four electrode - four wire method" is not possible.



Key

I	the applied current, in amperes
U	the measured voltage, in volts
I_m	the current in the voltage measurement circuit (equivalent to zero)
R_{C1}	the contact resistance at electrode 1, in ohms
R_{C2}	the contact resistance at electrode 2, in ohms
R	the resistance of the sample in ohms
R_M	the measured resistance in ohms, with $R_M = R_{C1}+R+R_{C2} = U/I$

Figure 3 — Schematic test set-up for a “two electrode - four wire measurement”

8 Test procedure

8.1 General

Testing shall be performed in the same conditions as described in 6.3.

It is advised to verify the test set-up and measurement principle by using a well characterized sample.

8.2 Preparation of conductive track contact points

Any insulating cover or coating shall be removed from the conductive track points that will be contacted by the electrodes.

The conductive track contact points shall be cleaned to remove materials (e.g. oils, varnish) that can disturb the electrical contact between the electrodes and track contact points.

If mechanical clamping does not yield the necessary measurement stability (as described in 8.5), the contacting needs to be improved.

For a yarn this may be done by:

— using a crimp connector (commercially available crimp connectors for electronic components are usually suitable).

For a track in or on a textile substrate this may be done by:

— gluing a metal plate/foil to the track using a conductive glue (using as little glue as necessary); or

— applying an electrode (in paste form) using a mask with well-defined dimensions (including thickness); or

— soldering a contact to the track.

Important for gluing and soldering is that the method used is compatible with the materials in the substrate and in the conductive track. The properties of the conductive track shall not be affected.

NOTE Silver and gold are suitable materials for this purpose, with gold being preferred as it does not corrode. Copper can also be used, but it should be cleaned before the measurement, e.g. by ultrasonic pre-treatment or mechanical abrasion. The supplier of the conductive track/ yarn could also be able to provide the necessary information concerning temperature resistance and suitable material for soldering.

8.3 Tensioning

8.3.1 General

Tensioning of the specimen, in order to flatten and straighten it, is necessary for determining accurately the distance.

8.3.2 Yarns

Yarns may be straightened by applying a weight to one extremity of the yarn. A pre-tensioning of 0,5 cN/tex is recommended, but other values can be agreed upon by the interested parties or in function of the tensile properties of the yarn. This can be important for yarns containing high amounts of metal.

8.3.3 Fabrics

8.3.3.1 General

For pre-tensioning of fabrics, it is recommended to use the guidelines given in EN ISO 13934-1.

8.3.3.2 Fabrics without stretch characteristics

A pre-tension according to the fabric mass per unit area is recommended, as given in Table 1.

Table 1 — Recommended fabric pre-tensioning for fabrics without stretch characteristics

Fabric mass per unit area (g/m^2)	Applied tension* (N)
≤ 200	2
> 200 and ≤ 500	5
> 500	10
*per 5 cm of width.	

8.3.3.3 Fabrics with stretch characteristics

A pre-tensioning with 0,5 N per 5 cm of width is recommended.

8.4 Contacting/ clamping of the specimen

Good contacting is important to reduce the contact resistance between conductive track and the measurement electrode, which influences the effectively measured resistance of the circuit and therefore falsifies the test result. Most important is the stability of the contact resistance.

Contacting is preferably done by mechanical clamping.

For the two electrode – four wire method it shall be verified that the contact is ohmic. This can be verified by determining whether there is a linear dependence of the measured Voltage on the applied current, also when reversing the current direction at the current source. If this is not the case, then the contacting and or clamping has to be improved.

8.5 Modus operandi and calculation of results

8.5.1 "Four electrode – four wire method"

Take five specimens.

a) For each specimen:

   1) Clamp the specimen into the test setup using the recommended tensioning (8.3).

   2) Determine the distance (*d*) between the voltage measurement electrodes.

   3) Apply a suitable current (*I*), and note the value. Avoid resistance heating of the track resulting from applying a too high current.

   4) Measure the voltage (*U*) five times at fixed intervals of time within one minute. If the values are stable (within to two significant digits), note the final value. If the values are not stable, discard the measurement and re-contact and re-measure again. If it is not possible to get a stable measurement after three re-measurements, discard the specimen.

   5) Re-clamp and repeat the measurement two times.

   6) Calculate for each measurement R and R_L, using Formulae (1) and (2) below:

$$R = U/I \tag{1}$$

$$R_L = R/d \tag{2}$$

   7) Calculate the mean value of R_L for all measurements of the same specimen, to 4 significant digits.

b) Perform the same measurements for the other four specimens. If any specimen is discarded more specimen(s) shall be measured such that the minimum number of successful specimens shall be five.

c) Calculate the mean value of R_L and standard deviation for the sample, to three significant digits.

8.5.2 "Two electrode - four wire measurement"

Take five specimens.

a) For each specimen the measurement shall be performed at four different distances d between the voltage measurement electrodes. The differences in distance should be as large as possible (preferably a factor of five between the smallest and the largest) . The distance should be varied by either clamping the specimen at four different lengths or by cutting the specimen into four parts, each with a different length.

   1) For each length of specimen

      i) Determine the distance (*d*) between the voltage measurement electrodes.

ii) Apply a suitable current (I), and note the value. Avoid resistance heating of the track resulting from applying a too high current.

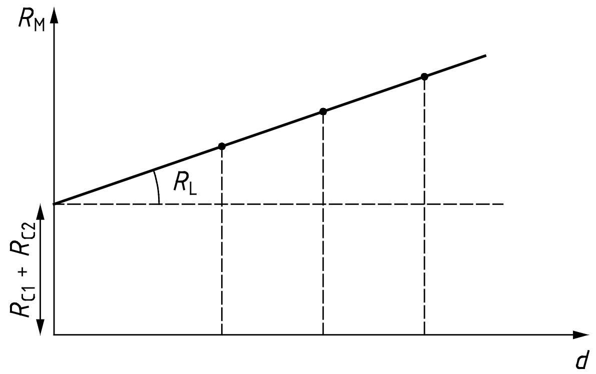
iii) Measure the voltage (U) five times at fixed intervals of time within one minute. If the values are stable (within to two significant digits), note the final value. If the values are not stable, discard the measurement and re-contact and re-measure again. If it is not possible to get a stable measurement after three, discard the specimen.

2) Repeat the measurement for the three other lengths of the same specimen.

3) Perform a linear regression on the measurement data per specimen, plotting for each length of specimen the measured resistance against the distance between the electrodes (Figure 4). Calculate the slope of the curve, which is equivalent to the linear resistance R_L of the specimen, to four significant digits. Calculate also the correlation factor of the regression curve. If the correlation factor is below 0,9, discard the specimen.

b) Perform the same measurements for the other four specimens. If any specimen is discarded more specimen(s) shall be measured such that the minimum number of successful specimens shall be five.

c) Calculate the mean value of the linear resistance R_L and the standard deviation for the sample, to three significant digits.



Key

R_{C1} the contact resistances at electrode 1, in ohms

R_{C2} the contact resistances at electrode 2, in ohms

R_M the measured resistance in ohms, with $R_M = R_{C1} + R + R_{C2}$, *with:* R the resistance of the sample in ohms

d the electrode spacing, in metres

R_L the linear resistance of the specimen, in ohm/m

Figure 4 — Schematic for determining the linear resistance R_L of the specimen by linear regression

9 Test report

The test report shall contain the following elements:

a) Identification of the test lab

b) Identification of the sample and the material (fibre, yarn, fabric, etc.), including the direction of the track with respect to the fabric structure, if applicable

c) Type, manufacturer and specifications of the equipment used (voltage meter and current supply).

d) Test conditions

   1) reference of standard textile-based electrically conductive track, if used for verification

   2) date

   3) description of test set-up

   4) type of clamping used and preparation of the contact ends on the specimen

   5) measurement method used (four electrode – four wire method or two electrode – four wire method)

   6) applied current

   7) length of specimen (four electrode – four wire method), different lengths of specimen (two electrode – 4 wire method)

e) Linear resistance R_L in ohm per metre:

   1) average test results per specimen

   2) average per sample

   3) standard deviation between specimens

f) Any deviations from this standard

g) Other remarks and observations

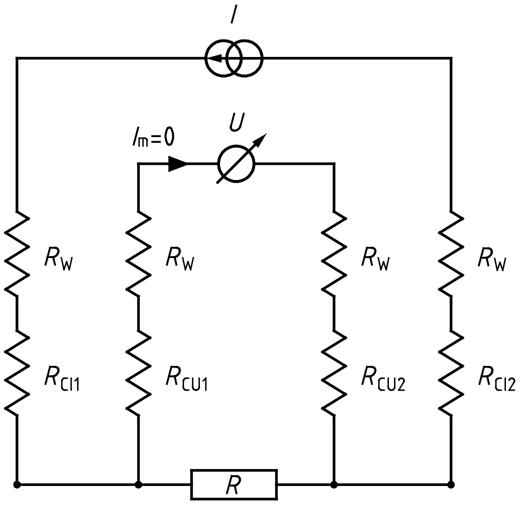
The test report may include the following elements:

h) clamping force, with specified clamping geometry

Annex A
(informative)

Four point (wire) Kelvin method

A.1 “Four electrode – four wire method”



Key

I	the applied current, in amperes
U	the measured voltage, in volts
I_m	the current in the voltage measurement circuit (equivalent to zero)
R	the resistance of sample (function of electrode spacing d) = R_L x d, in ohm
R_{CI1} and R_{CI2}	the contact resistances in current circuit, in ohms
R_{CU1} and R_{CU2}	the contact resistance in voltage circuit, in ohms
R_W	the wire resistance, in ohms

Figure A.1 — Detailed scheme for the “four electrode – four wire method”; the four electrodes (contacts) are visualized by the four nodes indicated in the scheme

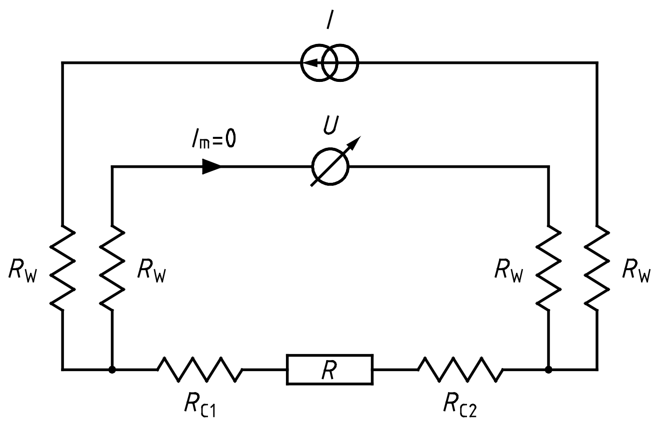
R_{CI}, R_{CV} and R_W can be excluded due to the “four electrode - four wire measurement”, so that the resistance of the specimen can be calculated by the simple formula

$$R = U/I$$

The linear resistance R_L, in ohm/m, is then calculated as

$$R_L = R/d$$

A.2 "Two electrode – four wire method"



Key

I	the applied current, in amperes
U	the measured voltage, in volts
I_m	the current in the voltage measurement circuit (equivalent to zero)
R	the resistance of sample (function of electrode spacing d) = $R_L \cdot d$, in ohms
R_{C1}	the contact resistance at electrode 1, in ohms
R_{C2}	the contact resistance at electrode 2, in ohms
R_W	the wire resistance, in ohms

Figure A.2 — Detailed scheme for the "two electrode – four wire method"; the two electrodes (contacts) are visualized by the two nodes indicated in the scheme

Here only R_W can be excluded due to the four- wire measurement, so that the resistance R of the specimen needs to be calculated by the more complex formula:

$$R_M = R_{C1} + R + R_{C2} = U/i$$

The contact resistances R_{C1} and R_{C2} are usually not known. Assuming that the contact resistances are independent of the specimen length (i.e. only related to the nature of the specimen and the measurement set-up) it is possible to determine the resistance for different specimen lengths (d, in m) and then calculate by linear regression the linear resistance, R_L, in Ohm/m, of the specimen, using the equation:

$$R_M\,(d) = (R_{C1} + R_{C2}) + R(d) = (R_{C1} + R_{C2}) + R_L \cdot d$$

By taking into account that:

$$R_L = R(d)/d$$

Bibliography

In this bibliography some standards are referenced that are currently used for determining electronic or electrostatic properties of textile substrates but which are not suitable for determining the linear electrical resistance of textile-based electrically conductive tracks.

[1] www.electropedia.org

[2] www.electropedia.org, IEV ref 131-15-08

Also standards, which can be used for assessing the characteristics of yarns and fabrics are listed.

[3] EN 50286, *Electrical insulating protective clothing for low-voltage installations*

[4] EN 60601-1, *Medical electrical equipment — Part 1: General requirements for basic safety and essential performance (IEC 60601-1)*

[5] EN ISO 2060, *Textiles — Yarn from packages — Determination of linear density (mass per unit length) by the skein method (ISO 2060)*

[6] EN ISO 2062, *Textiles — Yarns from packages — Determination of single-end breaking force and elongation at break using constant rate of extension (CRE) tester (ISO 2062)*

[7] EN ISO 5084, *Textiles — Determination of thickness of textiles and textile products (ISO 5084)*

[8] EN ISO 8388, *Knitted fabrics — Types — Vocabulary (ISO 8388)*

[9] EN 61340-5-1, *Electrostatics — Part 5-1: Protection of electronic devices from electrostatic phenomena — General requirements (IEC 61340-5-1)*

[10] EN 60228, *Conductors of insulated cables (IEC 60228)*

[11] EN 60051-6, *Direct acting indicating analogue electrical measuring instruments and their accessories — Part 6: Special requirements for ohmmeters (impedance meters) and conductance meters (IEC 60051-6)*

[12] EN ISO 13934-1, *Textiles — Tensile properties of fabrics — Part 1: Determination of maximum force and elongation at maximum force using the strip method (ISO 13934-1)*

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