Janusz Zięba,
Michał Frydrysiak,
Magdalena Tokarska

Technical University of Lodz,
Faculty of Material Technologies and Textile Design,
Department of Clothing Technology and Textronics,
ul. Żeromskiego 116, 90-924 Łódź, Poland
E-mail: michal.frydrysiak@p.lodz.pl

Research of Textile Electrodes for Electrotheraphy

Abstract
A textile electrode, which can be used for medicinal applications, especially in electrotherapy, can be an example of a textronic product. This paper presents initial research on textile electroconductive materials which can be used as textile electrodes for muscle electrostimulation. Measurement results for the volume and surface resistance of selected electroconductive materials are presented. Dual and multipoint probes were used for the measurements. The surfer program and interpolation methods based on the Kriging interpolation algorithm were used to visualise the results received. For an inaccuracy assessment of the resistance determination, the procedures described in the 'guide to the expression of uncertainty in measurement' were used.

Key words: *textronics, textile electrodes, electro-conductive textile, surface resistance, volume resistence.*

Introduction

Electro-conductive textiles, due to their numerous potential applications, are currently under investigation by many researchers. Such textiles may occur in measuring systems in the form of textile sensors, as conductive paths connecting the sensor to the power system, transmission lines, or systems monitoring physiological parameters. The interest in electro-conductive textiles results from the development of textronics [1, 2], which is a new branch of knowledge combining electronics and computer science with textile technologies. An example of a textronic product can be a textile electrode. Electrodes used in medicine, especially in electrotherapy [3 - 5] should not cause any allergic reaction in the patient. Another important property of a good electrode is the skin-electrode contact. Textile electrodes should be elastic and flexible products. While investigating the contact between the electrode and human skin, one should pay special attention to natural changes in the skin (changes of humidity, temperature, structure).

A small value of surface resistance of the electrode is the main parameter of a proper electro stimulation process. For manufacturing textile electrodes it is important to use, for example, yarns characterised by high conductivity, for instance silver polyamide yarns or cotton yarns wrapped round by stainless steel [6]. Textile electrodes can also be made of carbon and metallic yarns [5].

It should be emphasised here that electric volume resistivity is a physical parameter of a material, which is the same for a textile electrode and does not depend on its shape or dimensions. It does depend, however, on the type of fiber or yarn the electrode is made of and on other electroconductive elements used. However, in this paper we analysed the values of electrical resistance which depend on the dimensions of the sample and measuring electrodes. For the volume resistance, decisive is the distance between the measuring electrodes. On the other hand, considering the surface resistance, for the purpose of this paper, the authors introduced a definition according to which the surface resistance at a given point is the surface resistance of a surface determined by the measurement configuration of the electrodes (relating to a small area) referring to an arbitrally chosen point on the surface of the sample (textile electrode) determined by the measuring electrodes.

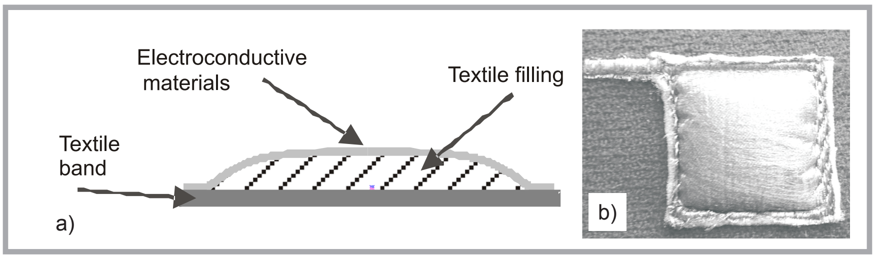

Figure 1. Scheme of a textile composite electrode for electrostimulation (a), real photo of the structure (b).

Producers of medical generators recommend that the surface resistance between any point on the electrode should not exceed 300 Ω, in order to ensure good electro-conductive properties of the electrode. Should the electrode have larger resistance, the current flowing could cause high temperature on the surface of the electrode, which could be dangerous and burn the skin.

Methods described in the standards devoted to textiles [7, 8] define the equivalent resistance of sheets of textile material. These methods make it possible to determine the resistance of textiles of a relatively large surface. Textronic applications, including electrodes used for muscle stimulation, are products of relatively small dimensions, therefore traditional methods could not be used for our purpose. It was important to determine the resistance distribution on a small sheet, as local resistance values are very significant for the application discussed. The first information on this subject is presented in paper [9], describing initial research.

In the article the authors suggest the application of methods for measuring the resistance of textile materials which could be an alternative for the methods commonly used. In this way it is possible to determine whether a textile product is suitable for constructing textile electrodes as a part of a textronic product. From literature and the market different kinds of textile electrodes are known that have different shapes and structures, some of which are made using knitting technology [5] or consist of an elastic

Zięba J., Frydrysiak M., Tokarska M.; Research of Textile Electrodes for Electrotheraphy.
FIBRES & TEXTILES in Eastern Europe 2011, Vol. 19, No. 5 (88) pp. 70-74.

fabric [4]. An alternative for these solutions can be a unique electrode, the construction of which is described below.

Often the design of a textile electrode is based on a multilayered structure use of materials with good conductivity. An example is presented in ***Figure 1***. In this case an elastic bandage was used as a textile base and polyurethane foam of 3 mm thickness was the filling. The size of the electrode was 35 mm × 35 mm, and the active electro-stimulating surface was 30 mm × 30 mm. The area of the electrode can change depending on the patient's body. The peripheries of the electrode were made of electro-conductive yarns.

This kind of electrode can be used in textronic systems for electro-stimulation in the form of a textile knee brace or elbow band. This system can be useful for muscle hardening when cramps occur as a result of the immobilisation of a limb (broken arm, leg) and also as a training device. We assumed that for the construction of textile electrodes, the electro-conductive materials used should be widely available on the market and not too expensive; however, the most important selection criterion was the resistance of the fabric. During initial selection, the authors also took into consideration the use of solid electro-conductive textile materials be characterised by good elastic properties, and good fitting to the skin and shape of particular parts of the human body, which could make the electro-stimulation process more effecient.

The aim of this study was to determine which of the materials selected were suitable to be used as textile electrodes in

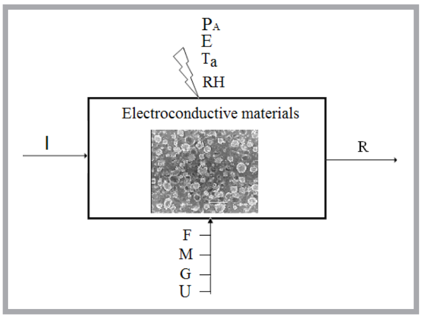

Figure 3. *Qualitative model of resistance measurementof a textile electrode; I – current, R - resistance; F - pressure force, M - kind of material, G - geometrical size of a textile electrode, U - measuring voltage, PA - atmospheric pressure, E- electromagnetic interference, Ta - ambient temperature, RH - relative humidity.*

Table 1. *Characteristics of the electro-conductive materials investigated.*

Kind of material	Aerial density, g/m2	Thickness, mm	Electro-conductive materials
Silicone foil	410	0.95	silver particles
Woven fabric plain weave	95	0.74	Nitril Static yarns
Nonwoven	65	0.64	graphite

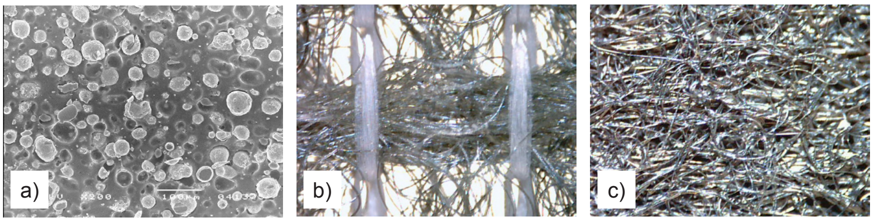

Figure 2. *Microscopic photos of electroconductive materials tested; a) silicone foil, b) Woven fabric plain weave, c) nonwoven.*

electrotherapy considering the electric properties.

Materials

Other features were not taken into account while carrying out the tests. Three types of materials were selected for the tests:

- electro-conductive silicone foil with silver particles,
- electro-conductive woven fabric made of Nitril Static yarns, and
- a graphite nonwoven.

The basic parameters of the test materials and their microscopic photos are presented in ***Table 1*** and ***Figure 2***.

Research method

The resistance value is one of the most important parameters of textile materials used as a textile electrode for muscle electro-stimulation. There are many ways of determining the resistance or resistivity of electro-conductive textile materials. The standard [7] includes a method of determining the electrical resistivity of textiles. A method of testing the surface resistivity of protective clothing is described in standard [8]. The method of determining the resistance of textile materials most commonly used is the four point measurement technique [9, 10]. Another way of sheet resistance measurement is the Van der Pauw method [9]. Therefore it is important to clearly define measurements. For this purpose, a well-defined qualitative model of the research object is needed. The authors initially define the factors which influence resistance in textronic applications [2, 11].

Figure 3 presents a qualitative model of the resistance distribution on a textile electrode. The set of input quantities includes the value of current measurement *I*; the set of output quantities is the resistance measured *R*, and its distribution; the set of constant quantities contains the pressure force *F*, kind of material *M*, geometrical size *G* of the textile electrode and the measurement voltage *U*. In the group of disturbances there are the following: atmospheric pressure P_A, electromagnetic interference *E*, ambient temperature T_a, and relative humidity *RH*.

The dimensions of the electro-conductive material investigated were 60mm×60mm. Measurements of the resistance on the surface of the electrode were carried out by means of two types of testing probes, placed on each of the two neighbouring measuring fields on the electro-conductive materials, creating a matrix of the resistance distribution. The first method is based on measuring the resistance on the surface using two measuring probes of circular cross section (***Figure 4***). The average diameter of the measuring probe was 8 mm. The textile material tested

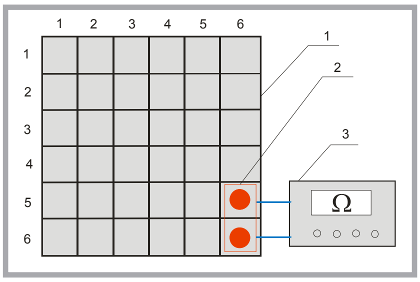

Figure 4. *Simplified scheme of a stand for measuring surface resistance; 1 – textile electrode, 2 – dual point probes, 3 – Agilent 6.5 Digits Mullimeter.*

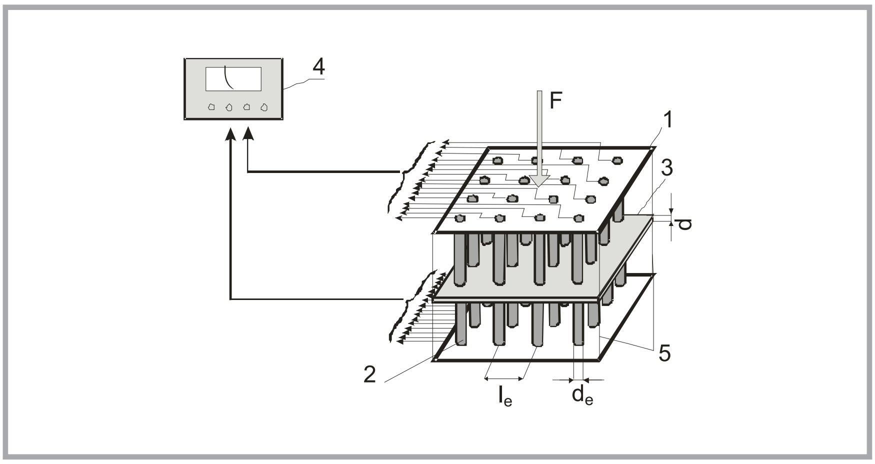

***Figure 5.** Simplified scheme of the volume resistance measurement stand, 1 – upper multipoint measurement probe, 2 – lower multipoint measurement probe, 3 – textile electrode, 4 – Agillent 6.5 Digits Mullimeter, 5 – crossrails, F – preasurre force*

was divided into measuring sectors, creating a matrix of 6 × 6 measuring fields.

A scheme of the measuring stand is presented in ***Figure 4***. Two measuring electrodes (2) were connected to an Agilent 34401A Digital Multimeter (3) with a reading inaccuracy of 0.010% and range inaccuracy of 0.001%. The multimeter was used to read resistance values of the samples investigated.

In the second case, the measurement of volume resistance was carried out by means of two specially constructed multi-point probes, between which a textile electrode was placed (***Figure 5***). The distance l_e between the measuring probes was 10 mm one from the other, the diameter d_e of the measurement probes - 10 mm, and the thickness of the sample measured (textile electrode) d was chosen as about 1 mm.

In order to precisely position the measuring electrodes and secure a constant pressing force, four crossrails were used, placed in the corners of the measuring device. The measurements were carried out at a constant pressure of 2725 Pa

The ends of the individual coaxial upper and lower probes of the measuring electrodes (2) & (1) were connected to the Agilent 34401A Digital Multimeter (4).

Results of meareements

Measurements of the surface and volume resistance were conducted in the following conditions: ambient temperature T_a = 24.5 ± 2 °C, and relative humidity RH = 45 ± 3%.

As a result of the resistance measurements, the surface and volume resistance distribution on the textile material were obtained. Local resistance values were calculated on the basis of nine measurements. In the case of silicone foil with silver particles, the surface resistance changed in the range of 0.30 Ω to 0.63 Ω. In the case of woven fabric made of Nitril Static yarn, it changed in the range of

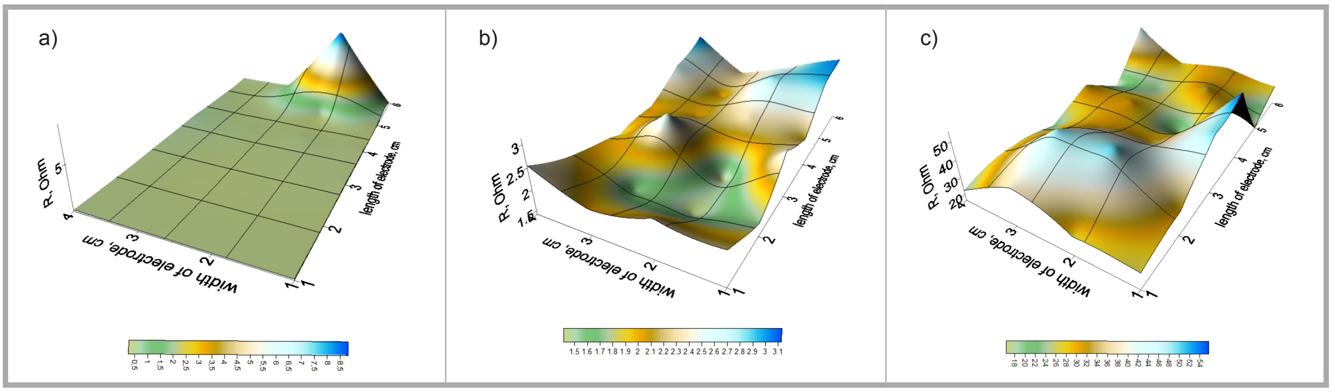

***Figure 6.** Example of the surface resistance distribution on a textile electrode: 1 – electro-conductive silicone foil with silver particles, 2 – woven fabric made of Nitril Static yarn, 3 – graphite nonwoven.*

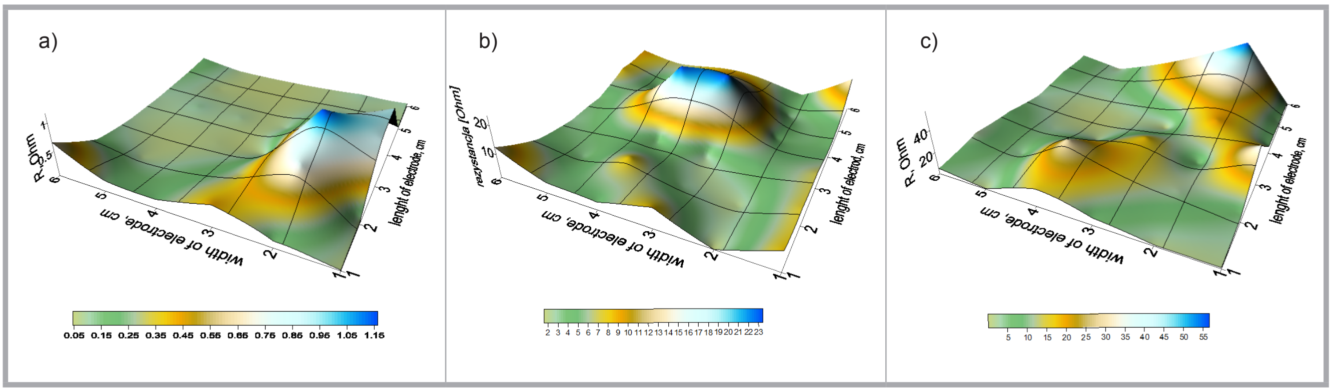

***Figure 7.** Example of the volume resistance distribution on a textile electrode: 1 – electro-conductive silicone foilwith silver particles, 2 – woven fabric, made of Nitril Static yarn, 3 – graphite nonwoven.*

Table 2. Uncertainty budget of the surface resistance measurement.

Kind of material	Estimated input quantity, Ω	Standard uncertainty of Type A, Ω	Standard uncertainty of Type B, Ω	Combined uncertainty square, Ω^2	Complex uncertainty, Ω	Relative complex uncertainty, %
Silicone foil with silver particles	0.40	$1.5 \cdot 10^{-2}$	$5.8 \cdot 10^{-5}$	$2.4 \cdot 10^{-4}$	0.03	7.5
Woven fabric made from Nitril Static yarn	2.09	$9.8 \cdot 10^{-2}$	$5.8 \cdot 10^{-5}$	$9.6 \cdot 10^{-3}$	0.20	9.6
Graphite nonwoven	55.99	6.88	$5.8 \cdot 10^{-5}$	47.39	13.77	24.6

Table 3. Uncertainty budget of the volume resistance.

Kind of material	Estimated input quantity, Ω	Standard uncertainty of Type A, Ω	Standard uncertainty of Type B, Ω	Combined uncertainty square, Ω^2	Complex uncertainty, Ω	Relative complex uncertainty, %
Silicone foil with silver particles	0.21	$2.5 \cdot 10^{-2}$	$5.8 \cdot 10^{-5}$	$6.5 \cdot 10^{-4}$	0.05	23.8
Woven fabric made from Nitril Static yarn	4.39	0.73	$5.8 \cdot 10^{-5}$	0.53	1.45	33.0
Graphite nonwoven	15.98	1.70	$5.8 \cdot 10^{-5}$	2.90	3.41	21.3

1.39 Ω to 3.13Ω. As for graphite nonwoven, it was from 15.99 Ω to 55.99 Ω.

The volume resistances changed as follows: in the case of silicone foil with silver particles - in the range of 0.05 Ω to 1.18 Ω, in the case of woven fabric made from Nitril Static yarns - in the range of 1.52 Ω to 23.70 Ω, and in the case of graphite nonwoven - from 0.07 Ω to 56.82 Ω. For both measurement results mentioned above, an analysis of inaccuracy was conducted.

Figures 6 and ***7*** present examples of the surface resistance and volume resistance distribution, respectively, on the materials investigated. The figures show the average results of ten measurements for each textile sample.

The Surfer program was used to visualise the results received. The software uses an interpolation method based on the algorithm of multidimensional Kriging interpolation. The algorithm was used because of the fact that there is some connection between the measuring points (the so-called significant autocorrelation), and on the basis of the adjacent points it is possible to determine the value of the intermediate points, although the value of an unknown point is not fully dependent on the values of the adjacent measuring points.

Assessment of the inaccuracy of the resistance measurements

An analysis of the inaccuracy of determining the resistance R was carried out on the basis of the uncertainty theory [12]. Complex uncertainty is defined by the formula below:

$$U(R) = k\, u_c(R) \qquad (1)$$

where:

k - the coefficient of expansion ($k = 2$ for the confidence level of 0.95),

$u_c(R)$ - the combined standard uncertainty of the estimate R.

The relative uncertainty of the measurement is determined by the following formula:

$$U_{rel}(R) = \frac{U(R)}{R} 100\% \qquad (2)$$

An inaccuracy analysis of the surface and volume resistance of the electro-conductive materials investigated was conducted. Calculations of the standard uncertainties were made using the B type method with an assumption of the uniform distribution of possible values within the interval. In ***Table 2*** a budget of the uncertainty of the surface resistance for a selected point is shown. An estimate of the input quantity value was calculated on the basis of nine repeated measurements.

In ***Table 3*** a budget of the uncertainty of the volume resistance R_v for a selected point is shown.

In the case of surface resistances, the relative uncertainty changes from 4.6 to 75.9%. In the case of volume resistances the relative uncertainty changes from 0.2% to 54.1%. The variable relative uncertainty is connected with the heterogeneous structure of the electro-conductive materials investigated.

Discussion and conclusion

- The construction of textile electrodes is quite complex and consists of several stages. The most important seems to be the selection of proper textile electroconductive material. In order to choose it, it is necessary to properly measure the local resistances of electro-conductive textiles in small areas (high resolution).
- Measurements of the local surface and volume resistance of electro-conductive materials at selected ambient conditions are characterised by a varying, relatively high uncertainty.
- The results of the resistance measurements conducted have proven that the materials investigated can be applied as electrodes in electrotherapy, especially for muscle electro-stimulation.
- The resistance of the electrode was tested below the permissible value that producers of medical devices for electrotherapy recommend, i.e. the maximum resistance between every two points on the surface of the electrode should not exceed 300 Ω. In our case the maximum local surface resistance values do not exceed 60 Ω, and the volume resistance does not exceed 57 Ω (this case concerns graphite nonwoven).

Acknowledgment

- *This work is (partially) supported by Structural Funds within the framework of the project entitled "Textronic system for the electrical stimulation of muscles" financed by the Operational Programme Innovative Economy, 2007-2013, Sub-measure 1.1.2.*
- *This work is also (partially) supported by Structural Funds within the framework of the project entitled 'Development of a research infrastructure for innovative techniques and technologies of the textile*

clothing industry" CLO–2IN–TEX, financed by the Operational Programme Innovative Economy, 2007-2013, Action 2.1.

References

1. Gniotek K., Stempień Z., Zięba J.; Tekstronika - a new area of knowledge (in Polish), Przegląd - WOS, No. 2/2003, pp. 17-18.
2. Zięba J., Frydrysiak M., Textronics-electrical and electronic textiles. Sensors for breathing frequency measurement, Fibres & Textiles in EE, Vol. 14, No. 5(59), 2006, pp. 43-48.
3. Sylwanowicz W., Michalik A., Ramotowski W.; Human anatomy and physiology (in Polish), PZWL, Warsaw 2000.
4. Oh K.W., Park H.J., Kim S.H.; Stretchable conductive fabric for electrotherapy, Journal of Applied Polymer Science, Vol. 88, 2003, pp. 1225-1229.
5. Rente A., Salvado R., Araújo P.; Textile electrodes for cardiac monitoring, Proceedings of the International Scientific Conference Ambience: Smart Textiles – Technology and design, Boras, Szwecja, June 2-3 2008.
6. Beckmann L., Kim S., Leonhardt S.; Characterization of textile electrodes for bioimpedance spectroscopy, proceedings of the International Scientific Conference Ambience: Smart Textiles – Technology and Design, Boras, Sweden, June 2-3 2008.
7. Standard PN-91/P-04871.
8. Standard PN-EN 1149-1:2008.
9. Banaszczyk J., Schwarz A., De Mey G., Van Langenhove L.; The Van der Pauw method for sheet resistance measurements of polypyrrole-coated para-aramide woven fabrics, Journal of Applied Polymer Science, Vol. 117, Issue 5, 2010, pp. 2553–2558.
10. De Souza F.G. Jr., Soares B.G., Pinto J.C.; Electrical surface resistivity of conductive polymers – A non-Gaussian approach for determination of confidence intervals, European Polymer Journal, Vol. 44, Issue 11, 2008, pp. 3908-3914.
11. Gniotek K., Zięba J., Frydrysiak M.; Measurements of contact resistance of electroconductive threads (in Polish), PAK, Vol. 54, No. 9, 2008, pp. 653-657.
12. Guide to the Expression of Uncertainty in Measurement, ISO 1995.
13. Zięba J., Frydrysiak M., Tokarska M.; The initial research of textile electrode to electrostimulation, Texsci conference, Czech Republic 2010.
14. Zięba J., Frydrysiak M.; Textronic system with matrix electrode to selective muscles electrostimulation, Imtex conference 2009

Received 27.08.2010 Reviewed 13.05.2011