THE INITIAL RESEARCH OF TEXTILE ELECTRODE TO ELECTROSTIMULATION

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Abstract
During the last several years increasing interest has been observed in electroconductive textiles. This interest results from the development of textronics which is a new branch of knowledge combining electronic and computer science technologies with textile ones. One of the example of textronic's product can be textiles electrodes. This electrodes can be use in medicine disciplines especially in electrotherapy. In the paper the initial research of textile electroconductive materials was presented. This kind of materials can be used as a textile electrodes to muscle electrostimulation. The measurement of volume and surface resistance results of selected electroconductive materials were presented. To the measurement it was used multipoints and dual points probes. To the visualization of received results was used Surfer program and an interpolation method based on the Kriging interpolation algorithm. For the assessment of inaccuracy in resistance determination, the procedures described in 'guide to the expression of uncertainty in measurement' are used.
Key words: textronic, electrodes, electroconductive textile

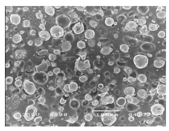
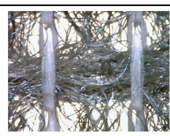
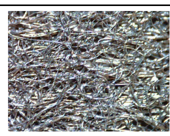
1. Introduction

During the last several years increasing interest has been observed in electroconductive textiles. This interest results from the development of textronics [1] which is a new branch of knowledge combining electronic and computer science technologies with textile ones. One of the example textronic's product can be textiles electrodes. This electrodes can be use in medicine disciplines especially in electrotherapy [2].
The small value of surface resistance of electrodes is the main parameter of proper electrostimulation process. The producers of medical generator equipment recommended that the surface resistance of electrodes of any point on the electrode should be smaller than 300Ω. This is connected with good electro conducted properties of electrodes. If the resistance has got biggest resistance, the current flow could be caused high temperature on the electrode. It could be dangerous and burn the skin.

2. Materials

As an electrode was used three kind of different materials: 1 – electroconductive silicone with silver particles, 2 – electroconductive woven, made from Nitril Static yarns, 3 – graphite nonwoven. The basic parameters of research materials and their microscopic photos presents Tab. 1.

Table 1. The characteristic parameters of electroconductive materials

Kind of material	Aerial density g/m^2	Thickness mm	Geometrical dimension mm × mm	Microscopic photo
1	410,0	0,95	60 × 60	
2	95,3	0,74	60 × 60	
3	64,9	0,64	60 × 60	

3. Measurements

The resistance value is one of the most important parameter of textile materials which can be use as a textile electrode to muscle electrostimulation. The authors have provisionally defined the factors which influence on resistance in textronic applications [3]. Fig. 1 presents the qualitative model of resistance distribution on textile electrode.

The set of input quantities includes real value of resistance R_r; the set of output quantities: measured resistance R; the set of constant quantities: pressure force F, kind of material M and geometrical size G of electrode. In the group of disturbances there are: ambient temperature T_a and humidity RH.

Measurements of surface and volume resistance were conducted at ambient conditions and additionally measurements of volume resistance - in environmental chamber for choosing temperatures.

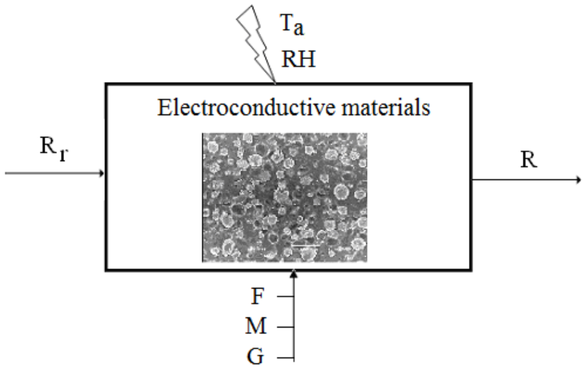
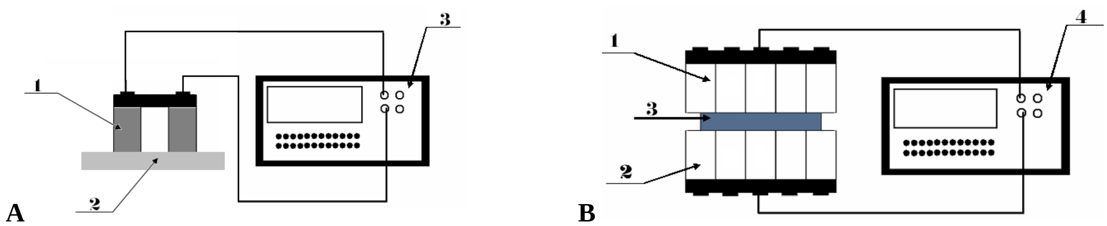


Figure 1. The qualitative model of resistance distribution on textile electrode

Measurements of resistance distribution on the electrodes surface were made by means of two types of testing probes. The first method is based on measuring resistance on the surface between two measuring probes situated 10 mm one from the other. A simplified diagram is presented in Fig. 2A. In the second case the measure of volume resistance was carried out by means of two specially constructed multi points probes, between which a textile electrode (60mm x 60mm) was placed. The ends of the individual coaxial probes of the measuring electrodes were connected to Agilent 34401A Digital Multimeter with inaccuracy of reading 0,010% and inaccuracy of range 0,001%. The measuring scheme is presented in Fig. 2B.



1 – dual points probes
2 – textile electrode
3 – Agillent 6,5 Digits Mullimeter

1 – upper multipoints measurement probe
2 – lower multipoints measurement probe
3 – textile electrode
4 – Agillent 6,5 Digits Mullimeter

Figure 2. The simplification scheme of measurement devices, (A) dual points measurement probes; (B) multipoints measurement probe

To the visualization of received results was used Surfer program (Fig. 3 and Fig. 4). 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, (that 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.

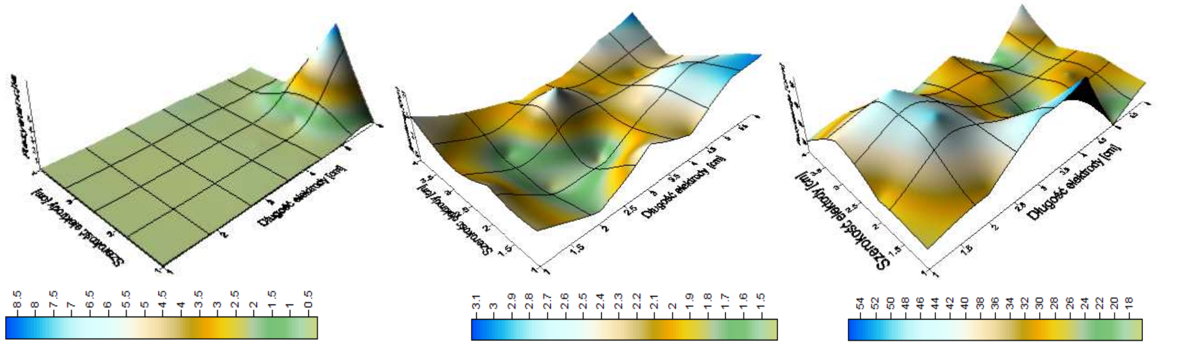


Figure 3. The example of surface resistance distribution on the textile electrode: 1 – electroconductive silicone with silver particles, 2 – woven, made from Nitril Static yarns, 3 – graphite nonwoven

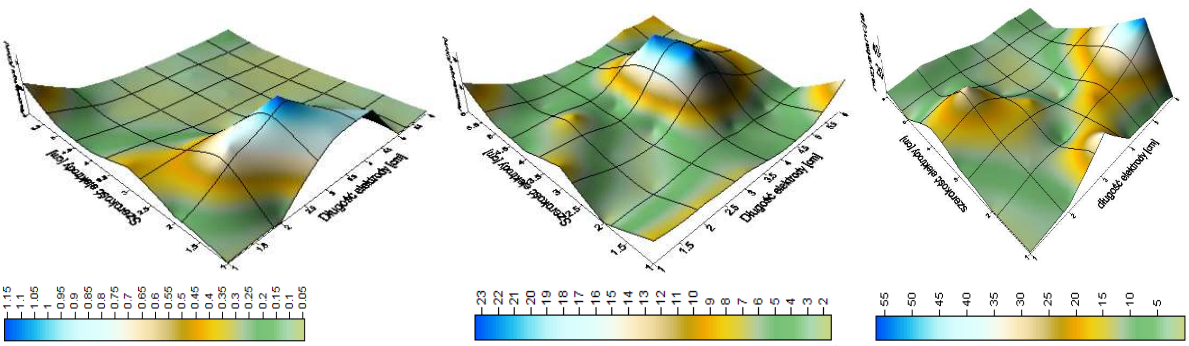


Figure 4. The example of volume resistance distribution on the textile electrode: 1 – electroconductive silicone with silver particles, 2 – woven, made from Nitril Static yarns, 3 – graphite nonwoven

Fig. 3 and Fig. 4 presents example of surface resistance and volume resistance distribution on the investigated materials.

4. Assessment of inaccuracy of resistance measurements

The resistance measurements were carried out in accordance with the concept of direct measurement. The analysis of inaccuracy of determination of the resistance *R* was carried out on the basis of the uncertainty theory [4]. The complex uncertainty is defined by the formula below:

$$U(R) = k u_C(R) \tag{1}$$

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 given by formulae:

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

4.1. Inaccuracy of surface resistance and volume resistance measurements conducted at ambient conditions

Analysis of inaccuracy of surface resistance of investigated electroconductive materials was conducted. Calculations of the standard uncertainties by the method of B type were made with an assumption of uniform distribution of possible values within the interval. In Tab. 2 a budget of uncertainty of determination of the surface resistance R_s for choosed probes (measurement points) is shown.

Table 2. Uncertainty budget of surface resistance measurement

Kind of material	**Estimate of input quantity value**	**Standard uncertainty of Type A**	**Standard uncertainty of Type B**	**Combined uncertainty square**	**Complex uncertainty**	**Relative complex uncertainty**
	Ω	**Ω**	**Ω**	**$Ω^2$**	**Ω**	**%**
1	0,40	$1{,}5 \cdot 10^{-2}$	$5{,}8 \cdot 10^{-5}$	$2{,}4 \cdot 10^{-4}$	0,03	7,5
2	2,09	$9{,}8 \cdot 10^{-2}$	$5{,}8 \cdot 10^{-5}$	$9{,}6 \cdot 10^{-3}$	0,20	9,6
3	55,99	6,88	$5{,}8 \cdot 10^{-5}$	47,39	13,77	24,6

Finally, the relative uncertainty (for k=2) of the measurements of surface resistance of investigated materials is:

- from 4,6 to 23,4 % for material 1;
- from 6,2 to 23,4 % for material 2;
- from 11,8 to 75,9 % for material 3.

Next an analysis of inaccuracy of volume resistance of materials was conducted. Calculations of the standard uncertainties by the method of B type were made with an assumption of uniform distribution of possible values within the interval. In Tab. 3 a budget of uncertainty of determination of the volume resistance R_v for choosed probe (measurement point) is shown.

Table 3. Uncertainty budget of volume resistance measurement

Kind of material	**Estimate of input quantity value**	**Standard uncertainty of Type A**	**Standard uncertainty of Type B**	**Combined uncertainty square**	**Complex uncertainty**	**Relative complex uncertainty**
	Ω	**Ω**	**Ω**	**$Ω^2$**	**Ω**	**%**
1	0,21	$2{,}5 \cdot 10^{-2}$	$5{,}8 \cdot 10^{-5}$	$6{,}5 \cdot 10^{-4}$	0,05	23,8
2	4,39	0,73	$5{,}8 \cdot 10^{-5}$	0,53	1,45	33,0
3	15,98	1,70	$5{,}8 \cdot 10^{-5}$	2,90	3,41	21,3

Finally, the relative uncertainty (for k=2) of the measurements of volume resistance of investigated materials is:

- from 0,2 to 42,7 % for material 1;
- from 10,7 to 54,1 % for material 2;
- from 2,7 to 36,1 % for material 3.

4.2. Inaccuracy of volume resistance measurements conducted in environmental chamber

Analysis of inaccuracy of volume resistance of investigated materials for specified temperatures (31,7^{o}C, 32,3^{o}C and 35,7^{o}C) was conducted. Calculations of the standard uncertainties by the method of B type were made with an assumption of uniform distribution of possible values within the interval. In Tab. 4, Tab. 5 and Tab. 6 budgets of uncertainty of determination of the volume resistance R_v for choosed probe (measurement point) are shown.

Table 4. Uncertainty budget of volume resistance measurement (for 31,7°C)

Kind of material	Estimate of input quantity value	Standard uncertainty of Type A	Standard uncertainty of Type B	Combined uncertainty square	Complex uncertainty	Relative complex uncertainty
	Ω	Ω	Ω	Ω^2	Ω	%
1	0,024	0,001	$5{,}8 \cdot 10^{-4}$	$1{,}3 \cdot 10^{-6}$	0,002	8,3
2	0,026	0,007	$5{,}8 \cdot 10^{-4}$	$4{,}9 \cdot 10^{-5}$	0,014	53,8
3	0,035	0,010	$5{,}8 \cdot 10^{-4}$	$1{,}0 \cdot 10^{-4}$	0,020	57,1

Finally, the relative uncertainty (for k=2) of the measurements of surface resistance of investigated materials in temperature equals 31,7°C is:

- from 9,6 to 29,1 % for material 1;
- from 7,7 to 54,0 % for material 2;
- from 7,7 to 91,0 % for material 3.

Table 5. Uncertainty budget of volume resistance measurement (for 32,3°C)

Kind of material	Estimate of input quantity value	Standard uncertainty of Type A	Standard uncertainty of Type B	Combined uncertainty square	Complex uncertainty	Relative complex uncertainty
	Ω	Ω	Ω	Ω^2	Ω	%
1	0,028	0,001	$5{,}8 \cdot 10^{-4}$	$1{,}3 \cdot 10^{-6}$	0,002	7,1
2	0,026	0,002	$5{,}8 \cdot 10^{-4}$	$4{,}3 \cdot 10^{-6}$	0,004	15,4
3	0,024	0,001	$5{,}8 \cdot 10^{-4}$	$1{,}3 \cdot 10^{-6}$	0,002	8,3

Finally, the relative uncertainty (for k=2) of the measurements of surface resistance of investigated materials in temperature equals 32,3°C is:

- from 7,7 to 43,9 % for material 1;
- from 9,6 to 52,4 % for material 2;
- from 5,7 to 32,3 % for material 3.

Table 6. Uncertainty budget of volume resistance measurement (for 35,7°C)

Kind of material	Estimate of input quantity value	Standard uncertainty of Type A	Standard uncertainty of Type B	Combined uncertainty square	Complex uncertainty	Relative complex uncertainty
	Ω	Ω	Ω	Ω^2	Ω	%
1	0,030	0,002	$5{,}8 \cdot 10^{-4}$	$4{,}3 \cdot 10^{-6}$	0,004	13,3
2	0,026	0,006	$5{,}8 \cdot 10^{-4}$	$3{,}6 \cdot 10^{-5}$	0,012	46,2
3	0,021	0,001	$5{,}8 \cdot 10^{-4}$	$1{,}3 \cdot 10^{-6}$	0,002	9,5

Finally, the relative uncertainty (for k=2) of the measurements of surface resistance of investigated materials in temperature equals 35,7°C is:

- from 4,1 to 44,6 % for material 1;
- from 10,0 to 71,5 % for material 2;
- from 5,3 to 11,0 % for material 3.

5. Conclusions

As a result from conducted research of resistance measurements, investigated materials can be apply as a electrodes to muscle electrostimulation. The value of the resistance of the electrodes was negligible, as the producers of medical devices for electrotherapy recommend, that maximum resistance between every two points on the surface of the electrode should not exceed 300Ω.

Measurements of the local resistances (surface resistance and volume resistance) of selected electroconductive materials in ambient conditions are characterized by varying the relative uncertainty. In the case of surface resistances a relative uncertainty changes from 0,2 to 54,1%. In the case of volume resistances a relative uncertainty changes from 4,6 to 75,9%.

The relative uncertainty of local volume resistances change with changing of investigation conditions in the range of 0,2 to 91,0%.

Conducted analysis shows the effect of environmental conditions on the results of the investigated electroconductive materials. The variable relative uncertainty is connected with heterogeneous structure of the electro conductive materials.

6. Acknowledgement

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