The change of the electrical characteristics of the electrically conductive thread due to the action of force

Assoc. Prof. **Željko Knezić**, Ph. D.[1]
Ivanka Hrgarek, mag. ing. techn. text.[2]
Prof. **Siniša Fajt**, Ph. D.[3]
Prof. **Dubravko Rogale**, Ph. D.[1]
Prof. **Željko Penava**, Ph. D.[1]
Prof. **Snježana Firšt Rogale**, Ph. D.[1]
[1]University of Zagreb Faculty of Textile Technology,
Zagreb, Croatia
[2]Finesa Consora d.o.o.,
Donje Ladanje, Croatia
[3]University of Zagreb Faculty of Electrical Engineering and Computing,
Zagreb, Croatia
e-mail: zeljko.knezic@ttf.unizg.hr
Received December 20, 2021

UDC 677.017.57:537.311
Original scientific article*

The paper presents research on the influence of force on the values of the electrical resistance of electrically conductive threads and on their elongation. The measurements were carried out on the measuring system developed at the Faculty of Textile Technology. Changes in the electrical resistance of electrically conductive threads exposed to the tensile load forces were investigated. The research was conducted on monofilament and threadlike yarn of the same raw material composition, different construction, different number of monofilaments and different fineness. Experimentally obtained values indicate that the electrical resistance of an electroconductive thread changes depending on the number of monofilaments, the construction of the thread, the fineness and the magnitude of the force used to tension the thread.
***Key words**: tension change, electrically conductive yarn, electrical conductivity, elongation*

1. Introduction

Fibres, yarns, and textile fabrics are being developed for incorporation into smart and intelligent clothing that change their properties in a controlled manner by controlling the application of electrical voltage or current [1]. Multiple textile fibres may form micropores that change shape and diameter with voltage changes. The unconnected voltage does not affect the micropores and they are closed. The positive polarity of the connected voltage opens the pores to the outside, allowing air and liquid droplets to flow in, creating a capillary effect, which is supported by the conical shape of the pores. Negative polarity similarly opens the pores inward. Changes in voltage values can affect the size of the pore diameter in such a way that higher voltage values enable the pores to spread

*Paper presented at the 14th Scientific-Professional Symposium “Textile science and economy”, January 26, 2022, Zagreb, Croatia

out more, i.e. their larger diameter. In the manner described, voltage regulation may provide active thermal protection for smart and intelligent clothing.

Foils capable of changing their colour based on changes in the value of the connected voltage, and embedded in flat textile surfaces without connected voltage, have a basic colour, and by connecting to the voltage and its changes, the colours change. These effects can be used as indicators, for signalling, marking of work clothes, etc.

Similarly, the property of colour change is used by connecting voltage and its changes. The weft and warp thread system is connected to the control devices, and the combinations of voltages at the intersections of the threads, i.e. at the connection points, their colour change. In this way, a coordinate system of connection points is created, similar to the dot screens of computer monitors (e.g. LCD). Such a system can be used as a flexible computer display to show data directly on textiles or clothing.

The volume of the fibres or foils can also be changed depending on the voltage value. The fibre without applied voltage has its standard diameter and its diameter increases up to 30% when voltage is applied (value 1-3 V). This property can be used to improve the thermal protection of garments: in the cold environment, the fibre diameter would increase, thus increasing the overall thickness of the textile flat products. Increasing the thickness would also improve the thermal insulation properties of the garments. The property of volume change can also be used, for example, to seal the seams of gloves and sleeves and trouser legs and shoes on work clothing. Such protective clothing is put on in a voltage-free relaxed state, and the sealing of the seams is achieved by adding voltage. The described changes in volume due to interchangeable connection of voltage enable ventilation of clothing in case of heat or water vapour extraction under physiologically unfavourable working conditions or activities [2-4].

Electrical conductors can be embedded into textile fibres or electrically conductive metal foils can be embedded into textile flat products. The conductive fibres and foils may be used in the form of receiving and transmitting antennas in clothing. Conductors in textile fibres can also be used to implement very light, thin and invisible electrical and electronic collections for powering all installed devices and for transmitting data between these devices and for transferring data between them [5].

Electrically conductive fibres and foils can also be used as electrical heaters embedded directly into the fabric or knitted fabric threads. Due to the flow of electricity, conductive fibres and foils can generate heat due to their resistance, which can be regulated by adjusting the voltage values, helping to maintain body temperature in colder environmental conditions [1].

2. Experimental part

An innovative measurement system, shown in Fig.1, was constructed for measuring electrical resistance and thread elongation, both at a load determined by force, as part of the HRZZ project IP-2018-01-6363.

The measuring system consists of a mechanical device for obtaining the tension of an electrically conductive thread with a digital dynamometer, a digital instrument for measuring the elongation of an electrically conductive thread due to the action of a certain force, a digital laboratory metre ESCORT ELC-3133A for measuring the value of the electric resistance of the electrically conductive threads gripped in electrically insulated

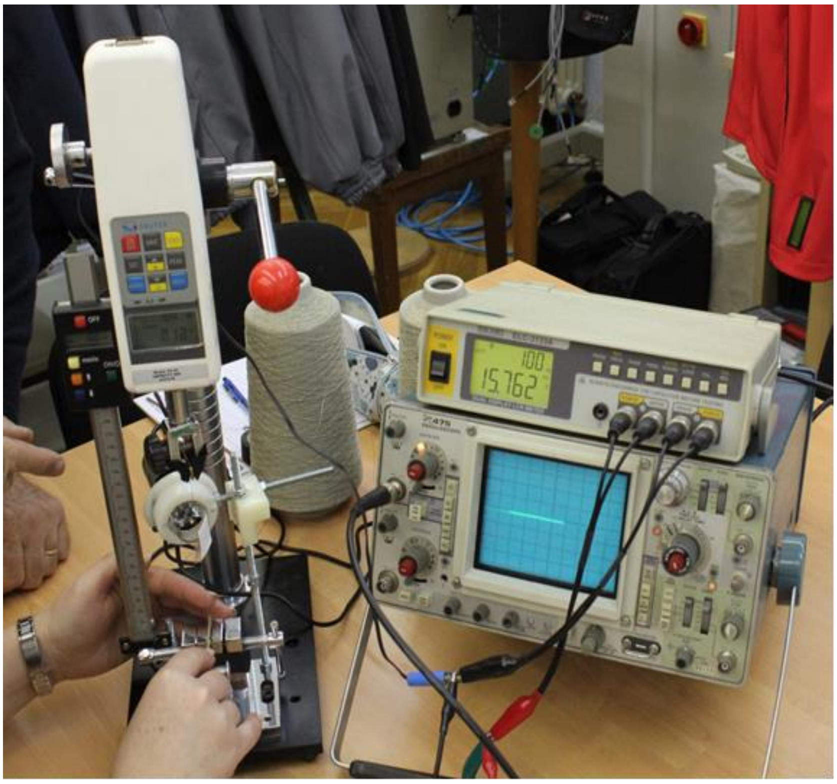

Fig.1 Measurement system for measuring electrical resistance and thread elongation, both at a load determined by force

dynamometer clamps, and a computer for storing and processing the measured data and computer support in working with the camera.

2.1. Material and methods

The electrically conductive thread used in the experimental work is Statex SHIELDEX® Yarn by Shieldex Trading Inc. The electrically conductive threads are poliamide thread coated with silver, which has antibacterial properties and it is thermally and electrically conductive. Three different electrically conductive thread are used in the experimental part of the paper (codes 117/17Z, 117/17x2 and 235/36x2). All three electrically conductive threads are made of high strength polyamides (PA 6.6) and are coated with silver of 99% purity. The thread 117/17Z is single and has 17 filaments, its fineness after coating with silver is 142 dtex. The thread 117/17x2 is double and has twice 17 filaments, a total of 34 filaments, its fineness after silver coating is 295 dtex. The thread 235/36x2 is double and has 2x36 filaments, its fineness after silver coating is 604 dtex.

To determine the properties of the bonding components in smart and intelligent clothing, measurements of the changes in resistance to the flow of electric current and the magnitude of the increase in length of three electrically conductive threads due to voltages of certain forces were carried out. The used electrically conductive threads and their properties are listed in Tab.1. The measurements are carried out in such a way that the tensile force of the electrically conductive thread is increased, while the value of the electrical resistance and the magnitude of the sample elongation are read at the certain moment of the application of this force. The sample of the electrically conductive thread is clamped under a preload of 0.1N in clamps spaced 150 mm apart. The tension of the electrically conductive thread is increased with the aid of a mechanical device which causes a displacement of the distance between the clamps. The digital indicator reads the elongation magnitude of the tested sample. The electrical resistance and elongation values are read in 1 N increments from a force of 1 N until the thread breaks. After each reading, the test sample is unloaded (the sample is loosened by returning the clamps to its original position at 150 mm intervals). The changes in electrical resistance are measured with an ommeter connected to the ends of the test sample of the electrically conductive thread. The action of the force and the return to the initial position are carried out at equal time intervals.

3. Results and discussion

The electrical resistance and elongation values were measured during the action of a certain force on electrically conductive thread.

Tab.1 Electrically conductive thread used and their characteristics

Sample code	117/17Z	117/17x2	235/36x2
Sample Layout			
Material	Polyamide 6.6 filament		
Deposits	silver 99%		
Strength	>55 cN/tex	44 ±5 cN/tex	>55 cN/tex
Resistance	< 500 Ω/m	< 300 Ω/m	< 80 Ω/m

The influence of the action of a certain force on the electrical resistance values of the electrically conductive thread is shown in Fig.2, and the elongation under the action of a certain force on the electrically conductive thread is shown in Fig.3. From the results shown in Fig.3 it can be seen that the action of a force on electrically conductive thread changes the value of electrical resistance. For the same difference in the magnitude of the force (from 1 to 5 N), a greater change in electrical resistance (about 100 Ω) is observed in a structurally simpler sample (code 117/17Z) and the smallest change in electrical resistance (about 2 to 3 Ω) for the same change in the acting force (from 1 to 5 N) is observed in the last sample of electrically conductive thread - code 235/36x2.

It is obvious that the filaments are more elastic, they have lower electrical resistance and lower changes in electrical resistance because there are constantly parallel connections due to the contact of the surface conductive layers (pairing) of the individual monofilaments (they are more joined together by twisting). This can be explained by the fact that a single filament acts like a series of serially coupled resistors, while in a filament the sequence is doubled and interspersed with parallel connections [6-8].

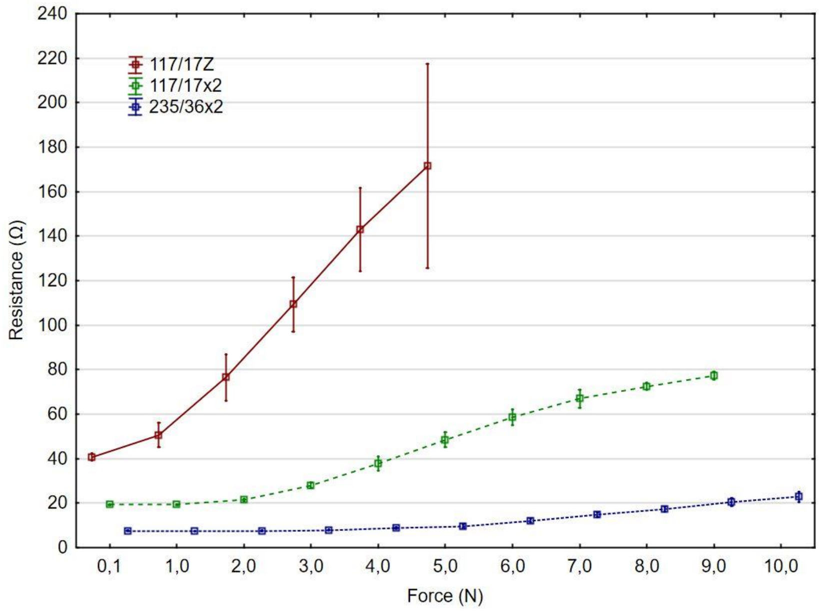

Fig.2 Effect of the action of a certain force on the values of electrical resistance of electrically conductive thread.

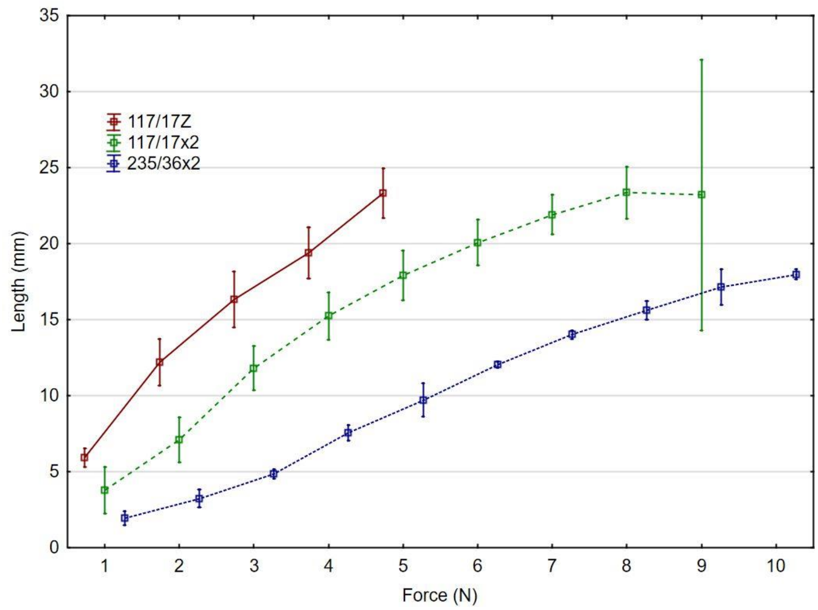

Fig.3 Effect of the action of a certain force on the values of elongation of the electrically conductive thread

5. Conclusion

One of the biggest problems with smart clothing, including smart textiles, is electrical resistance of thread, which changes due to mechanical influences when the clothing is worn and washed. For this reason, it is a constant challenge to find solutions to problems that minimise this influence. The influence of force on electrical resistance values of electrically conductive thread and their elongation are presented in the paper. It was found that the electrically conductive thread can be used as wiring and buses in smart and intelligent clothing. It was also found that electrically conductive thread show specific behaviour compared to conventional wire conductors, namely insulated wires and multicore cables. This is reflected in the fact that the electrical resistance changes with the elongation of the thread which is often the case in garments. The mentioned change in electrical resistance is not negligible, but it takes on a relatively large value from the initial few tens to several hundred Ω, depending on the construction of the electrically conductive thread.

Appropriate attention should be paid to the mentioned researched features in the construction and technical design of smart and intelligent clothing.

Acknowledgement

This work has been supported in part by the Croatian Science Foundation through the project IP-2018-01-6363 "Development and thermal properties of intelligent clothing (ThermIC)", as well as by the University of Zagreb through research grant TP11/21 "Parameters of ultrasonic joining of polymeric materials".

References

[1] Firšt Rogale S. *et al*: Inteligentna odjeća, Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, ISBN 978-953-7105-52-5, Zagreb (2014)
[2] Knezić Ž. *et al*: The Impact of Elongation on Change in Electrical Resistance of Electrically Conductive Yarns Woven into Fabric, Materials 14 (2021) 3390, 1-18
[3] Rogale D., S. Firšt Rogale: Visokotehnološki izvori električne energije ugrađeni u obuću i odjeću, Koža i obuća 66 (2017) 4, 8-14
[4] Firšt Rogale S., D. Rogale, G. Nikolić: Intelligent clothing: first and second generation clothing with adaptive thermal insulation properties, Textile research journal 88 (2018) 19, 2214-2233
[5] Penava Ž., M. Milenković, Ž. Knezić: Povezivanje i spajanje elektronike u e-tekstilu, Zbornik radova 5. međunarodnog znanstveno-stručnog savjetovanja Tekstilna znanost i gospodarstvo, Ujević D.; Penava Ž. (ur.), Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Zagreb (2012), 301-308
[6] Penava Ž., Ž. Knezić, M. Kujundžić: Promjene električne vodljivosti u području elastičnosti elektrovodljive pređe, Tekstil 62 (2013) 5-6, 207-214
[7] Chawla S., M. Naraghi, A. Davoudi: Effect of twist and porosity on the electrical conductivity of carbon nanofiber yarns, Nanotechnology 24 (2013) 25, 1-9
[8] Penava Ž., Ž. Knezić, D. Bonefačić: Utjecaj uvojitosti na električnu vodljivost elektrovodljive pređe, Zbornik radova 11. znanstveno-stručnog savjetovanja Tekstilna znanost i gospodarstvo, Ercegović Ražić, S.; Glogar, M. I.; Novak, I. (ur.), ISSN 1847-2877, Zagreb, Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Zagreb (2018), 62-67