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Textronic mat with heating function

Mata tekstroniczna z funkcją grzewczą

Abstract*. Relatively recently, in the 1980s, a new generation of textiles emerged when work began on smart materials, resulting in the development of textronics. Textronics is widely used in medicine and health care. This paper presents research and construction work related to the development of a prototype mat with a heating function. Heating is realized by means of electroconductive threads and the use of a knitted spacer as a substrate allows the heating function to operate only under pressure.*

Streszczenie. *Stosunkowo niedawno, w latach 80-tych, pojawiła się nowa generacja tekstyliów, kiedy rozpoczęto prace nad inteligentnymi materiałami, co doprowadziło do rozwoju tekstroniki. Tekstronika jest szeroko stosowana w medycynie i opiece zdrowotnej. W artykule przedstawiono prace badawcze i konstrukcyjne związane z opracowaniem prototypu maty z funkcją ogrzewania. Ogrzewanie jest realizowane za pomocą nici elektroprzewodzących, a zastosowanie dzianej przekładki jako podłoża pozwala na działanie funkcji ogrzewania tylko pod ciśnieniem.*

Słowa kluczowe: tekstronika, grzanie, nici elektroprzewodzące, tekstylia
Keywords: textronics, heating, electroconductive threads, textiles

Introduction

Textiles have played a pivotal role in human history, initially serving mainly for protection and thermal comfort. The original uses of clothing and other textiles focused on protection from the weather, rough surfaces, plants and insect bites, acting as a barrier between the skin and the environment. As civilization developed, textiles began to serve additional decorative and informational functions, reflecting cultural, professional, religious or social status (Figure 1).

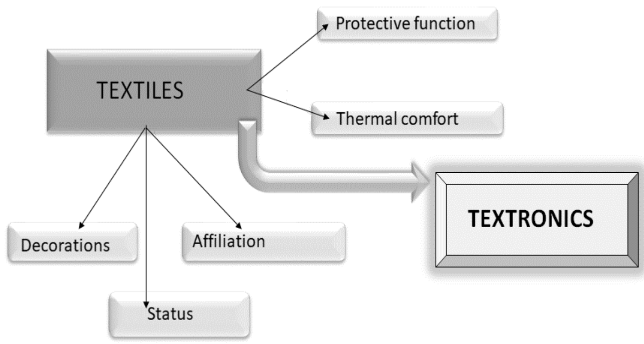


Fig. 1. Functions of textiles

With advances in technology, textiles have gained new functional capabilities. The main goal of textronics is to create materials that have additional, advanced functions beyond the basic properties of protection and comfort. By integrating miniaturized electronics into the textile material, textronics allows the creation of advanced products that can monitor body temperature, heart rate, respiratory rate and detect the presence of harmful gases [1-5]. Since the days of Steve Mann, who is considered a forerunner of textronics, the field has been growing rapidly, with applications in healthcare, everyday objects, sportswear and decorative products. The antibacterial properties of textronic materials [8,9] or the shielding of electromagnetic fields with them [10] are also being exploited.

As part of the completed work, research and development work was carried out on the development of a prototype of a textronic mat with a heating function. Heating is implemented using electroconductive threads, and the use of a knitted spacer as a substrate allows the heating function to operate only under the pressure.

Ultimately, this solution is to be used in mattresses, seats (e.g. in cold places such as ski lifts) and even animal beds. The idea is to manage electricity economically so that it is only consumed when the facility is in use.

Prototype design

Commercially available carbon fibers, powered via a USB connector, were pre-selected as the heating element. The carbon fibers were placed on a substrate (knitted spacer) measuring approximately 50 cm x 50 cm, and then covered with a second layer of substrate, obtaining a mat demonstrator with a heating function. After feeding the carbon fibers, temperature measurements were taken at the selected points of the demonstrator, both near the fibers and in areas offset from the fibers. Rapid heating of the mat surface was found, indicating correct operation of the demonstrator. The disadvantage of the solution was the relatively high stiffness of the mat, especially in areas where power cables were located. In addition, as a result of tests, it was found that commercially available carbon fibers are not suitable as a material for embroidering heating elements, mainly due to their mechanical properties (tearing of fibers during embroidering).

Due to the identified disadvantages of the solution with carbon fibers, the embroidered carbon fibers were replaced with conductive yarns in further development of the layer with heating function. Yarns with electroconductive properties are created by introducing metals into the composition of synthetic or natural fibers. This can be done by sputtering a metallic coating, saturating non-conductive fibers with molten metal and combining conductive fibers with natural or synthetic fibers. The SILVER COATED POLYAMIDE CONTINUOUS FILAMENT (SILVER-TECH+) thread was used in the ongoing research. This thread provides low electrical resistance and retains the flexibility and mechanical strength typical of traditional textile fibers. In addition, the silver, used here to coat the fibers, has natural antibacterial properties, which is an additional advantage in the proposed solution.

Laboratory tests included the selection of appropriate heating element shapes, embroidery path densities and power path layout (Fig.2a). Finally, the geometry of the heating electrode was modified to form a "square" spiral (Fig.2b).

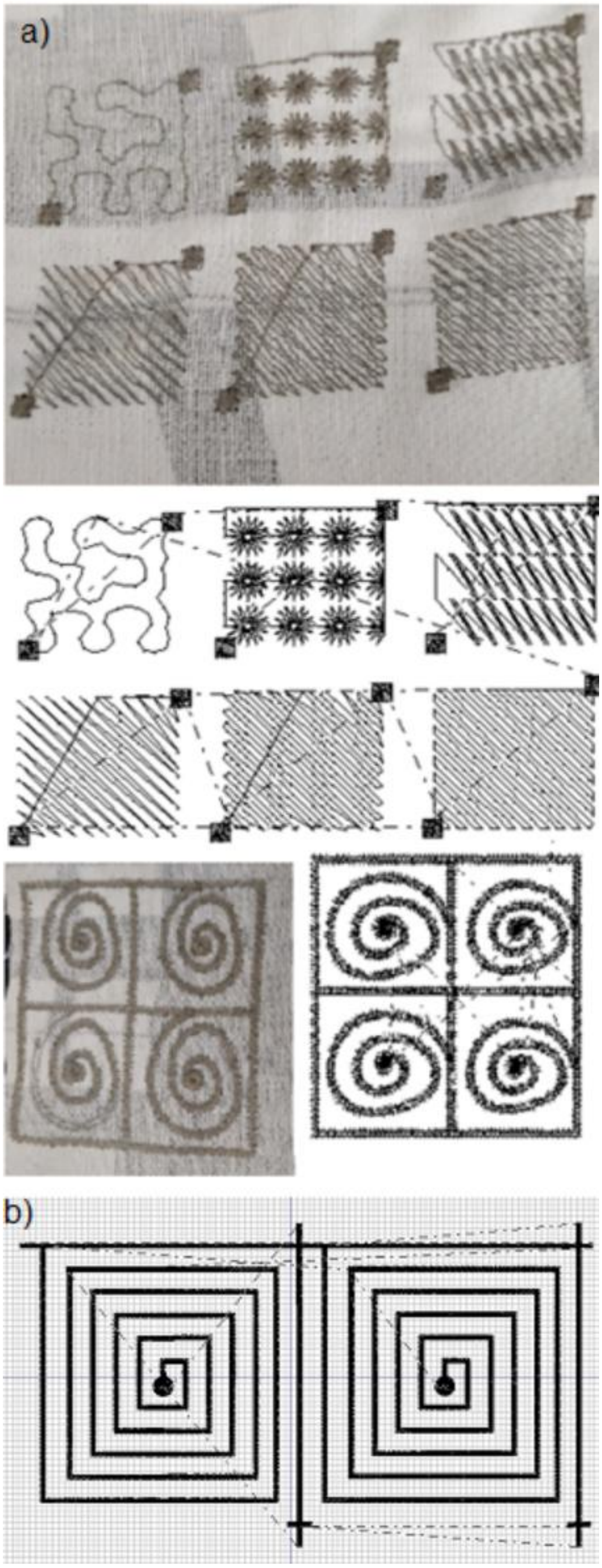


Fig. 2. Stitch and pattern tests for spot arrangement of heating elements

The originally fabricated element did not have a pressure-acting function, and the purpose of its fabrication was to confirm the feasibility of using conductive thread embroidery to realize a heating function.

Electrodes of the selected geometry were used to prototype a small-scale heating mat (about 50 cm x 30 cm), consisting of 8 heating elements. The system was supplied with 6 V, obtaining for a single heating element a current flow of about 270 mA, a power consumption of about 1.61 W (Figure 3) and a temperature exceeding 40ºC.

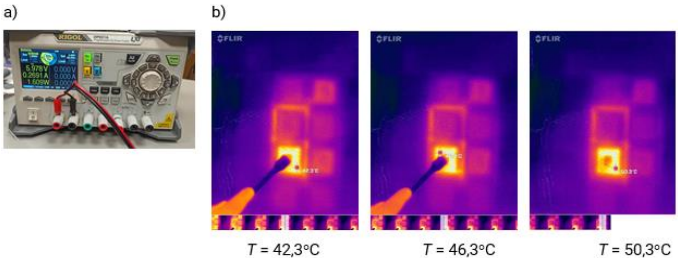


Fig. 3. The heating layer of the mat under the pressure: a) power supply, b) thermograms

However, from the point of view of the new functionality of pressure-only heating, the mat's multi-layer design is key (Fig.4). Heating is accomplished by two separately powered heating layers separated by a layer of spacer material, which allows the pressure-only heating function to work.

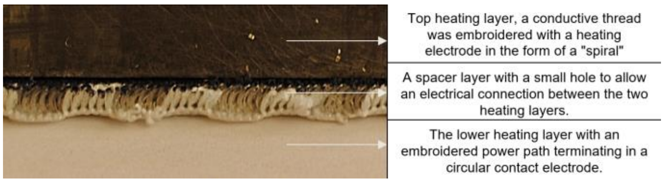


Fig. 4. Multilayer construction of the heating mat

A conductive thread with a heating electrode in the form of a "spiral" with a power path and a circular contact electrode in the center of the component was embroidered on one (top) heating layer, while a power path terminating in a circular contact electrode was embroidered on the bottom heating layer. A small hole was made in the spacer layer to allow an electrical connection between the two heating layers. In the absence of pressure, the spacer layer provides electrical separation between the heating elements. When the pressure is applied to the mat, the heating electrodes are connected, causing an electric current to flow and activating the heating function.

A prototype of the heating layer of a 200 cm x 90 cm mat was made, on which 30 heating elements were placed, in an arrangement of 3 rows (A-B-C) by 10 columns (1÷10). (Fig.5).

Fig. 5. Prototype of the heating mat in actual dimensions of 200 x 90 cm. Top layer - heating elements, bottom layer - connections and power lines.

Measurements

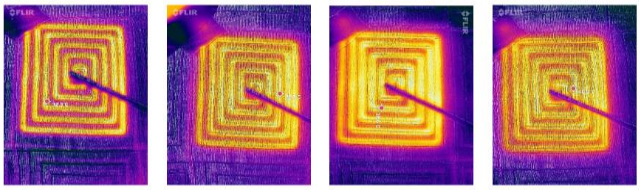
After the heating mat was fabricated, the resistance of the individual heating elements was measured, the results of which are summarized in Table 1.

Table 1 Results of resistance measurements of heating elements (A-C- row number, 1-10 column number)

Element designation	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**
Resistance [Ω]	57,5	51,7	50,4	53,4	55,6	58,2	54,1	57,2	62,1	60,0
Element designation	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Resistance [Ω]	61,8	57,3	55,4	53,4	53,5	51,9	54,6	52,4	55,7	59,7
Element designation	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Resistance [Ω]	61,7	54,7	49,7	56,1	53,7	54,8	50,8	55,6	55,8	60,5

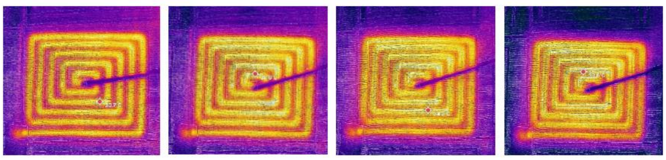
The results of the resistance measurements confirm the repeatability of the electrical parameters of the individual heating elements made of conductive threads using the embroidery method: the average resistance value is 55.64 Ω, the maximum error does not exceed 12%, and the average percentage error is 3.34%.

The performance of the individual elements of the heating layer of the mat was carried out at 2 power levels of 12 V and 15 V. Example measurement results are shown in Figures 6-7. After 120 seconds at 15 V supply, a temperature exceeding 40ºC was reached, while at 12 V supply, a temperature slightly lower by 40ºC was reached, and exceeding 40ºC occurred after about 140 seconds.



t = 30 s, *T* = 32,3°C   *t* = 60 s, *T* = 37,0°C   *t* = 90 s, *T* = 38,6°C   *t* = 120 s, *T* = 40,2°C

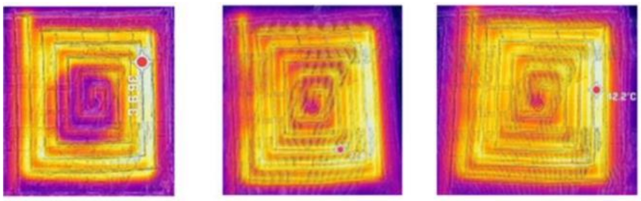
Fig. 6. Temperature measurements of the heating element at 15 V supply (I = 253 mA, P = 3.75 W)



t = 30 s, *T* = 30,7°C   *t* = 60 s, *T* = 32,6°C   *t* = 90 s, *T* = 34,3°C   *t* = 120 s, *T* = 39,6°C

Fig. 7. Temperature measurements of heating element at 12 V supply (I = 204 mA, P = 2.46 W)

In the next stage of testing, the heating elements were covered with a layer of spacer material, and the pressure was modeled with a 2 kg weight. Examples of the results are illustrated in Figure 8.



t = 60 s, *T* = 36,9°C (U= 12 V, I= 255 mA, P=3,1 W)   *t* = 60 s, *T* = 37,4°C (U= 15 V, I= 260 mA, P=3,9 W)   *t* = 60 s, *T* = 42,2°C (U= 17 V, I= 253 mA, P= 4,3 W)

Fig. 8. Temperature measurements of heating element C2 at different supply levels at 2 kg pressure.

Finally, the prototype of the heating layer of the mat was also tested under near-real conditions, i.e. under the load of a seated person weighing 80 kg. The test results are shown in Figure 9. Thermographic measurements confirm that the person activates the heating elements of the mat, which heats up to a temperature of more than 35ºC in about 60 seconds.

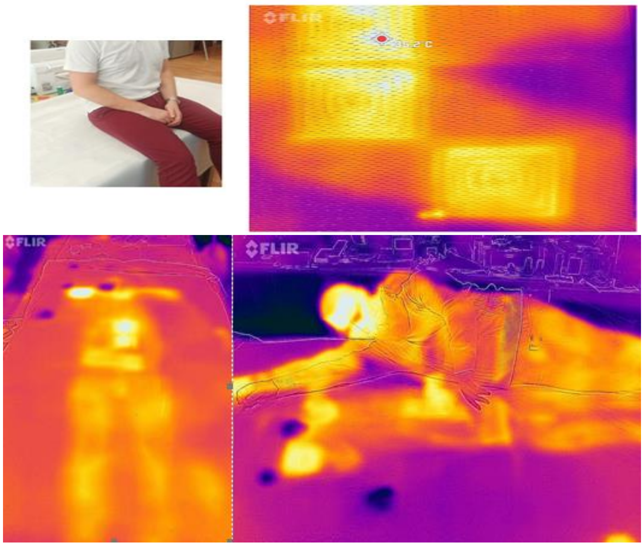


Fig. 9. Testing of prototype heating layer under human load: a) test course, b) thermogram c) reality tests.

Conclusions

The design of the mat with a multilayer heating system, where heating is activated under pressure, proved effective. Under pressure from the weight of the body (e.g., a seated person), the heating elements were activated, thus saving energy by heating only where needed. Laboratory tests carried out at the preliminary research stage showed that the solutions used make it possible to achieve a heating effect of 40C. And maintain the set temperature for up to 8 hours.

The average temperature of the mat during the tests was about 40ºC, which is optimal for therapeutic purposes, such as relieving muscle and joint pain, improving blood circulation and providing general thermal comfort.

Resistance measurements of individual heating elements showed good repeatability of electrical parameters, confirming the reliability of conductive thread embroidery technology.

The prototype heating mat has great potential for therapeutic applications, especially in physiotherapy, rehabilitation and as a support for the treatment of rheumatic and muscular ailments. The ability to precisely control the temperature and the function to activate heating under pressure make the mat suitable for use in home, office and medical settings.

It is recommended that research continue on optimizing the heating system, especially with regard to the long-term durability of the materials and further increasing energy efficiency.

The prototype of the heating-enabled textile mat demonstrates how modern technologies can transform traditional textiles into advanced, multifunctional products. The heating efficiency, reliability of electrical parameters and functionality under the pressure point to broad potential for therapeutic and commercial applications. Further research and development can contribute to even more advanced and eco-friendly solutions in this field.

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REFERENCES

[1] Skrzetuska E., Trendy rozwojowe w tekstronice – Rozwiązania tekstroniczne dla ochrony zdrowia, *Przegląd Elektrotechniczny*, 90 (2014), 34-40

[2] Frydrysiak M., Pomiary temperatury skóry jako etap projektowania specjalistycznej odzieży tekstronicznej*, Acta Bio-Optica et Informatica Medica*. *Inżynieria Biomedyczna*, 21.2 (20150, 91-101

[3] Sibiński M., Ciupa E., Tekstroniczne czujniki temperatury, *Elektronika: konstrukcje, technologie, zastosowania*, 51.10 (2010), 122-123

[4] Jakubas, A., et al., Koncepcja tekstronicznego systemu do pomiarów funkcji życiowych małych dzieci, *Przegląd Elektrotechniczny*, 12 (2015), 121-124

[5] Paradiso R., Wearable health care system for vital signs monitoring, C *In Proc. 4th Int. IEEE EMBS Special Topic Conf. Inf. Technol. Applic. Biomed*, 2003, 283-286

[6] Zięba J., Frydrysiak M., Badania doświadczalne i symulacyjne światłowodowego czujnika rytmu oddechu. *Pomiary Automatyka Kontrola*, 53(2007), 83-87

[7] Ostrowski J., et al., System tekstroniczny do pomiaru częstości oddechu, *Elektronika: konstrukcje, technologie, zastosowania*, 58.10 (2017)

[8] Matyjas-Zgondek E., et al., Antibacterial properties of silver-finished textiles, *Fibres & Textiles in Eastern Europe*, 5(2008), 101--107

[9] Lada-Tondyra E., Jakubas A., The Concept of a Textronic System Limiting Bacterial Growth. *In: 2018 Progress in Applied Electrical Engineering (PAEE). IEEE*, 2018, 1-4.

[10] Ziaja J., et al., Elastyczne materiały stosowane w technice ekranowania pola elektromagnetycznego. *Przegląd Elektrotechniczny*, 94 (2018), 94, 73-76