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Influence of Technological Factors on Geometrical Parameters of Electrical Conductive Embroidered Element

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1. Introduction

Modern new generation electrically conductive textile embroidery systems are capable of controlling health condition, warning of possible alarm and performing a lot of similar functions [1 – 4]. Extremely durable, flexible and even washable multi-layer electronic schemes can be integrated on the textile base while creating electrically conductive embroidery elements of different forms and combining them with appropriate electronic components [3 – 5].

Electrically conductive threads are classified into several groups. The threads which belong to the first group are created from conductive metals (nickel, titan, copper etc.), another group consists of the threads the electrical conductivity of which is achieved by special treatment process, e.g. by covering them with metals or metal salts (copper sulfate etc.). The mechanical behavior of electrically conductive threads is similar to the behavior of the threads used in the embroidery process, their surface is rough and manufacturing is rather expensive. [6 – 7]. In the manufacturing process, in order to achieve stronger electrical conductivity, the upper and ground threads are electrically conductive in the embroidery [2 – 4].

In the research, while analyzing the performance of the electrically conductive embroidered mobile talk antenna, it has been obtained that the embroidered antenna, where the stitch density is 0.4 mm, works with 37.6 % bigger efficiency than the embroidered antenna performed applying 0.8 mm stitch density, the efficiency of which is 29.6 %. The obtained results showed that the accuracy of the form of the embroidered elements, stitch density, their direction with respect to the fabric and the technological parameters have an influence on the performance of the antenna [5]. Therefore, the factors which have an impact on the accuracy and quality of the electrically conductive embroidered elements is a very relevant topic.

While analyzing the symtoms of nocturnal enuresis, in order to achieve a greater comfort, the scientists proposed to use a moisture sensor embroidered on textile base. While analyzing two electrically conductive systems-one of them spirale type, another one-comb type, embroidered at different distances between the lines, it has been determined that the speed of recognition of the sound of the sensor is impacted by the technological parameters of the process, the applied textile materials, the technical characteristics of the electrically conductive threads, i.e. the density of the embroidery stitch, moisture sorption [3 – 4]. Consequently, the character of exploitation plays an important role in applying electrically conductive embroidery systems.

While analyzing different circle-form and square-form elements of the same perimeter, embroidered with PES metallized silver threads, it has been determined that the greatest, ~ 37 % electrical conductivity, possess rectangular-form embroidery elements. It has also been noticed in the research that the size of uneven forms of different shape have an influence on the change of the electrostatic power [2].

While analyzing the compliance of the closed-circuit square-form embroidery elements to the digitally designed ones the scientists have determined that the contour area of the fabrics of different weave in warp direction in most cases does not comply with the designed size and the area is bigger in the direction of warp than in weft [8]. It is also emphasized that the parameters of the technological mode of the process, also the activated forces of compression, tensile, friction, sliding etc. occurring in the process of the mechanical impact, have got a considerable influence on the accuracy of the forms and the quality of the stitches on the area of filling [9 – 11].

The analysis also showed that the accuracy of the forms of the electrically conductive embroidery systems is a significant factor. Therefore, in order to improve electrically conductive embroidery systems, it is necessary to perform an exhaustive research on the exploitation factors which influence the accuracy of the form of the electrically conductive embroidery elements. The objective of the work is to research and to analyze the influence of the exploitation factors on the geometrical parameters of the close-circuit electrically conductive embroidery element.

2. Experimental part

The object of the research has been chosen a canvas weave fabric made of 65 % PES and 35 % cotton, surface density of which was 257 g/m^2. The linear density of warp and weft threads of the fabric – 37 tex, the thread density in warp direction – 40 cm^{-1}, in weft direction – 22 cm^{-1}. In the research there have been used electrically conductive polyamide threads, possessing silver strands - Elitex 110/34 dtex 2ply. Both upper and ground threads used in the embroidery process were the same and electrically conductive.

Square-form 60×60 mm closed-circuit 6 mm and

14 mm width embroidery elements have been performed with an automatized embroidery machine Brother PR-600II with the speed *V*=600 rotations/min. The form of the embroidery element in the research is carried out by using filling type *T* and applying different stitch densities – 3 stitches/mm and 4.5 stitches/mm. According the prepared embroidery program, when the direction of the movement is clockwise, the lines of the stitches evenly fill up the area of the contour in warp and weft directions.

The contour width CS of the embroidered square-form test samples has been measured with COREL DRAW 12 program package. The measurements of the contour width CS are performed at all sides of the square alongside the length and height of the designed element, at the points of the intersection of the inner sides, in the middle of the sides and in the middle of the quarter. In the presented measurement scheme point *L* is the initial and the final point of the embroidery process. In the embroidery process the direction of the movement corresponds the clockwise direction. In one case the direction of the embroidery is in the direction of weft threads, sides LM, NO, in another case- parallel to the direction of warp threads, sides MN, OL (Fig. 1).

After the embroidery process, with the purpose of evaluating the influence of the exploitation factors on the contour width CS of the embroidery element, the objects have been researched in accordance with standards EN ISO 6330, they have been treated applying seven circles of washing. The contour width of the embroidery element had been measured before washing, then again after one, three, five and seven circles of washing. The results of the measurement have been obtained from the arithmetical medium of the five test samples. The dissemination of the results of the measurements of all contour widths of all samples under investigation is small, the value of the variation coefficient did not exceed 6 %, the relative error of the measurements did not exceed 7 %.

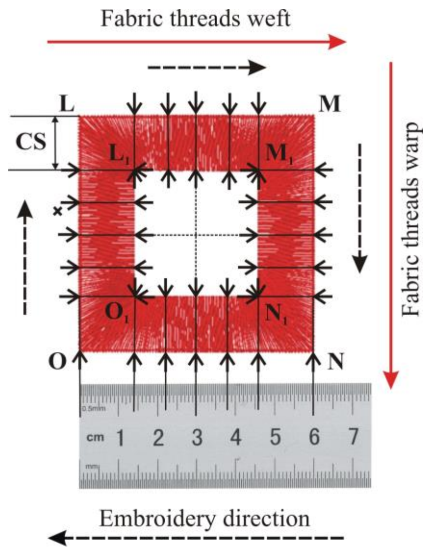


Fig. 1 The measurement scheme of the contour width of the electrically conductive element

3. Results and disscusions

While researching the contour width of the electrically conductive embroidery element, it has been determined that it does not match the designed and the embroidered width of the test sample CS. Analyzing the contour width of the 6 mm embroidery test sample, it has been noted that while evaluating the average, the size which was the most adequate to the designed one, was obtained in the group of test samples where the stitch density was 4.5 stitches/min, CS was obtained bigger by ~ 0.9 % (Fig. 2). While analyzing the embroidery elements of wider, 14 mm, contour width, it has been obtained that when the stitch density is 4.5 stitches/mm, the contour width CS is obtained as the most adequate to the designed size (Fig. 2). It is obvious from the results presented in Figs. 2 and 3 that contour width CS of the embroidered elements in warp direction is obtained bigger than the designed one from ~ 1.7 % to ~ 6.6 % (Fig. 2, a). In general case it has been obtained that contour width is more close to the designed size when the test samples have been embroidered applying 4.5 stitches/mm density. It is important to emphasize that in the process of embroidery, when the needle is piercing the fabric, the thread strands inside the structure distribute themselves differently, with reference to the direction of the embroidery and as a result the contour width does not match the designed size (Fig. 2 – 5) [8, 10 – 11]. Electrically conductive embroidery threads are extremely thin strands of metal, the diameter of which is from 1 to 80 microns and their structure can be characterized as possessing rough and uneven surface, therefore they tend to break down in the embroidery process [12].

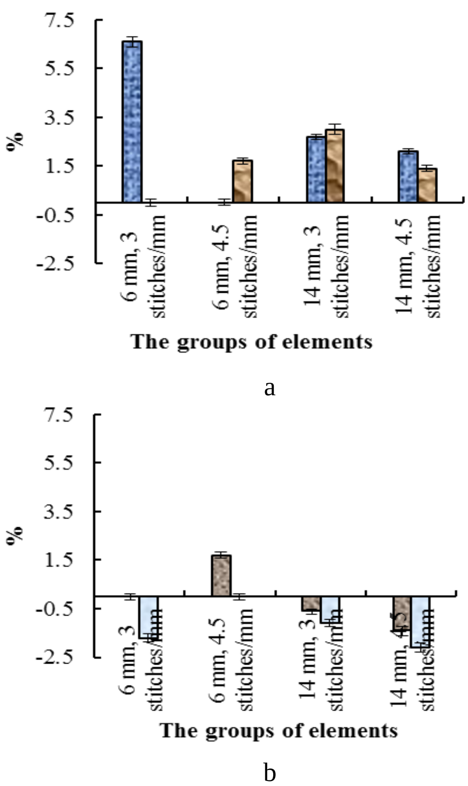
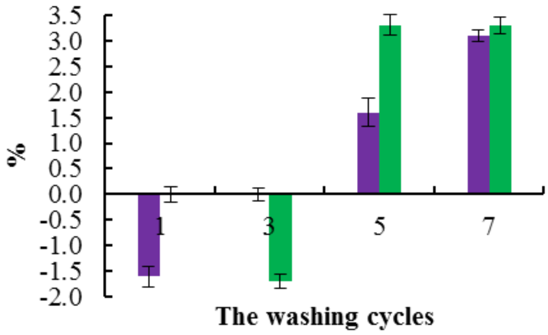


Fig. 2 The difference of the contour width CS of the electrically conductive embroidery elements in comparison to the designed size, when the contour width of the designed element is x axis, here: ▪ – the section MN; ▪ – the section OL; ▪ – the section LM; ▪ – the section ON; a – accomplished in warp direction; b – accomplished in weft direction

In order to analyze the influence of exploitation on the contour width CS of the electrically conductive embroidery element further in the research there is the investigation of the contour widths of the washed test samples by comparing them with the embroidered test samples. The obtained results showed that after the cycles of treatments with washing the contour width CS of the element differed in both warp and weft directions. It is important that width CS both of the embroidered and washed test samples is not the same even between the sides of the same direction. While analyzing the group of elements, when the contour width is 6 mm and the stitch density is 3 stitches/mm, it has been obtained that contour width CS of the embroidered test sample both after 1 and 3 cycles of washing decreased in size up to ~ 1.7 % both in warp and weft directions in comparison to the embroidered ones and after 5 washing cycles they increased up to ~ 3.3 % (Fig. 3).



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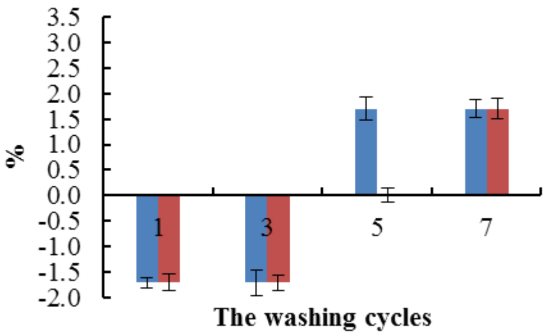

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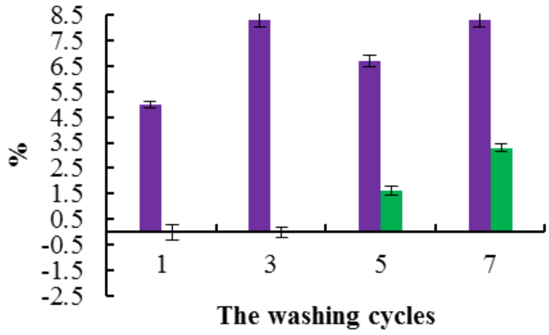
Fig. 3. The difference of the contour width CS of the electrically conductive embroidery element after the exploitation in comparison with the embroidered element when the contour width is 6 mm, when stitch density is 3 stitches/mm, when the contour width of the embroidered element is x axis, here: ■ – the section MN; ■ – the section OL; ■ – the section LM; ■ – the section ON; a – in warp direction; b – in weft direction

The results of the research have shown that the groups of embroidered elements, the contour width CS of which is 6 mm and stitch density is 4.5 stitches/mm differ in comparison to the contour width of the washed elements in warp direction and increased up to ~ 8.3 %, in weft direction, the obtained difference is minimal (Fig. 4). It is expected that warp threads of cotton became bigger after washing, increasing the width of the embroidery element at the same time. While analyzing the results of washing and their influence on the quality of threads in the studies of other scientists, it has been determined that different modes of washing have a different impact on the mechanical properties of the fabric and their structure [14 – 15].



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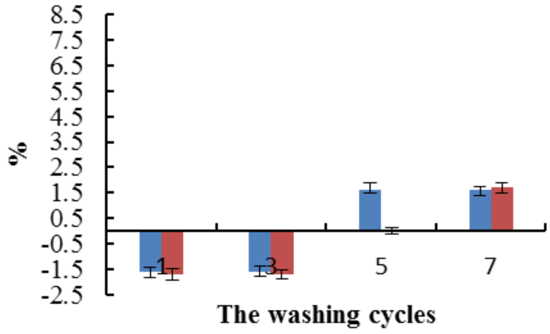

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Fig. 4. The difference of the contour width *CS* of the electrically conductive embroidery element in comparison to the embroidered element when the contour width is 6 mm, when stitch density is 4.5 stitches/mm, when the width of the embroidery element is x axis, here: ■ – the section MN; ■ – the section OL; ■ – the section LM; ■ – the section ON; a – in warp direction; b – in weft direction

Comparing the results of changes in contour widths CS of groups of test samples of the same contour width 6 mm and different density and the embroidered contour width, it becomes evident that the greatest, from ~ 1.1 % to ~ 8.3 % difference, is determined in warp direction after 7 cycles of washing (Fig. 2, 3). A significant increase in the contour width CS – up to ~ 8.3 % is evident in the group of test samples where stitch density is bigger – 4.5 stitches/mm, in weft direction in segment MN (Fig. 3, a). In the case under investigation, the fabric thread density in warp direction is (40 cm^{-1}), by ~ 55 % bigger than that of the weft direction (22 cm^{-1}) threads and that influences their deformation characteristics when they bloat [3, 14 – 15].

While analyzing the group of embroidery elements the contour width CS of which is 14 mm and stitch density is 3 stitches/mm, it has been obtained that in weft direction after 1 and 3 cycles of washing the contour width has decreased up to ~ 1.4 %, after 5 and 7 cycles of washing it increased up to ~ 1.4 % (Fig. 5, b). It has also been noticed that the difference of the contour width CS in comparison to the embroidered contour width in warp direction changed most significantly after 7 cycles of washing, it was obtained bigger up to ~ 2.1 % (Fig. 5, a).

In the same group, when stitch density is 4.5 stitches/mm, the difference of the contour width CS of the washed elements in comparison to the embroidered ones has increased by ~ 2.1 % in warp direction of the fabric and in weft direction the width has increased by ~ 2.2 % (Fig. 6). The obtained results demonstrated that in the group of test samples the major changes in the width took place after 5 and 7 cycles of washing.

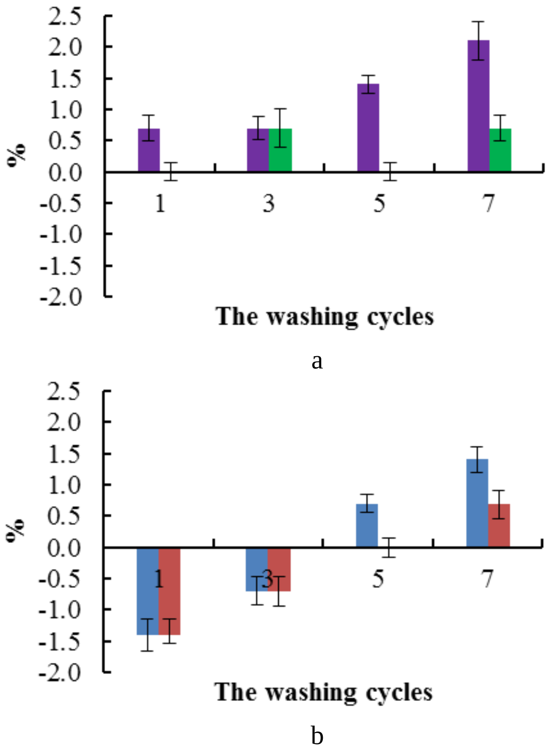

Fig. 5 The difference of the contour width *CS* of the electrically conductive embroidery element after the exploitation and the embroidered element when contour width is 14 mm and stitch density is 3 stitches/mm, when the width of the embroidery element is x axis, here: ■ – the section MN; ■ – the section OL; ■ – the section LM; ■ – the section ON***;*** a – in warp direction; b – in weft direction

While comparing the results of all four groups of the washed embroidery elements under investigation it has been obtained that in most cases contour width CS in warp direction of the fabric was obtained bigger than the embroidered size and in weft direction-smaller (Fig. 5). It has also been determined that after washing the smallest change in the contour width CS was observed in the group of test samples where the width of the element is 6 mm and the density is 3 stitches/mm.

Washing is a very frequent and important process used in cleaning and decoration of different products of textile. During the washing due to the absorption of moisture the fiber bloat and the structure of the fabrics change, as well as their physical and mechanical properties. The phenomena of moisture absorption, evaporation and structural changes are closely connected to each other [14 – 17]. In the case under investigation the canvas weave fabric consisting of 65 % PES and 35 % cotton is used. The cotton fiber consists of 95 – 96 % cellulose, the degree of polymerization of which is 10 000, and the degree of crystallization of which is not smaller than 65 – 70 %. The fiber can be characterized as possessing enough strength, moisture absorption etc. [18 – 19]. During deformation process the fiber or the textile construction made of it, a part of the used energy is accumulated for the elasticity and another part is dispersed similar to the processes taking place in viscous liquids. Therefore, it is possible that fibers after different washing cycles do not bloat evenly. In case of the bigger amount of washing cycles the diameter of the strand bloats more, the structure widens [14 – 17]. In the case under investigation the contour width increased by ~ 2.2 % after 7 washing cycles.

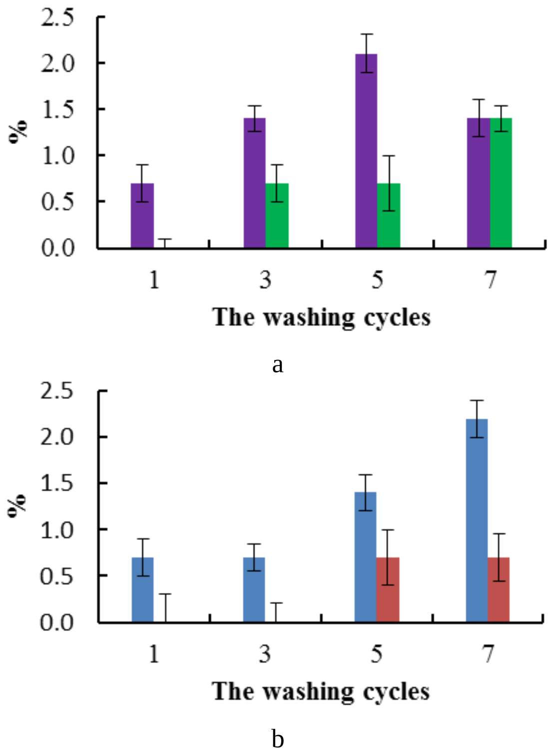

Fig. 6 The difference in the contour width *CS* of the electrically conductive closed-circuit embroidery element after the exploitation when contour width is 14 mm, when stitch density is 4.5 stitches/mm, here: ■ – the section MN; ■ – the section OL; ■ – the section LM; ■ – the section ON***;*** a – in warp direction; b – in weft direction

It is worth mentioning that during the embroidery process the breakages of silver strands inside the electrically conductive threads took place. During the embroidery the threads experience the whole complex of different impacts, such as compression, twisting, stretching, pressure, bending etc. which impact the changes in their structure and physical and mechanical properties as well [8, 20 – 21]. During the exploitation different dynamic stretching take place and the embroidery system becomes deformed, it slides, the micro-structural ceilings inside them straighten, the orderliness of the fabric threads vertical to the direction of stretching threads increases and the process of the ductility of the threads begins [8, 10 – 11, 20 – 21]. It is obvious from the analysis that while researching the impact of the exploitation factors on the accuracy of the form of the electrically conductive embroidery systems it is important to choose the optimal size of the form of the element, the parameters of the technological process and to evaluate the mechanical and physical characteristics of the fabrics and threads used in the process.

3. Conclusions

After the analysis of the impact of the exploitation factors on the contour width of the electrically conductive embroidery element it has been determined that a bigger amount of washing cycles and the appliance of the bigger stitch density have got the greatest influence on the contour width of the embroidery element. When the embroidery element is accomplished applying the stitches of greater stitch density – 4.5 stitches/mm, in most cases the contour width after the exploitation process is obtained bigger in warp direction than the designed size and in weft direction it is smaller. In the exploitation process the embroidery systems are impacted in different directions of the fabric by the whole complex of mechanical forces, they bloat while being washed and because of those reasons their surface, form and properties change irretrievably.

The analysis of the obtained results has demonstrated that the width of electrically conductive embroidery elements is different when exploitation conditions differ and it changes depending on the parameters of the technological mode, the choice of the size of the element and the direction of the fabric.

Creating new electrically conductive embroidery products, it could be recommended to accomplish a complex evaluation of the characteristics of the fabric, according which the optimal parameters of the technological process could be applied.

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INFLUENCE OF TECHNOLOGICAL FACTORS ON GEOMETRICAL PARAMETERS OF ELECTRICAL CONDUCTIVE EMBROIDERED ELEMENT

In various technical areas textile materials possessing exceptional exploitation properties such as electrical conductivity are being applied more and more frequently. The electrical conductivity of the embroidery system depends not only on the accuracy of the accomplishment of the element, the mechanical impacts experienced in the manufacturing process but also on the exploitation factors experienced during the process of wearing. The objective of this work is to research and to analyze the influence of the exploitation factors on the geometrical parameters of the electrically conductive closed-circuit embroidery element. In the research the embroidery area is accomplished by filling it with different stitch density 3 stitches/mm and 4.5 stitches/mm and by using closed-circuit embroidery elements of different width 6 mm and 14 mm. The obtained results demonstrated that in general case, when the number of washing cycles increases the contour width increases as well. In most cases contour width CS in warp direction of the threads has been determined as bigger than the embroidered size and in weft direction the obtained area is smaller.

Keywords: embroidered element, fabric, coductive thread, resistivity.