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The Research on the Accuracy of the Geometrical Parameters of the Closed-Circuit Embroidery Element

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The creation and application of embroidery systems in manufacturing the products of special purposes are rapidly expanding and requires a great accuracy of the elements. Both during the process of manufacturing and during the period of exploitation the shape of the embroidery element gets deformed and changes due to the impact of different mechanical forces. In the research, the form of five square elements of similar size but with different closed contour widths of 6 mm, 10 mm, 14 mm, 18 mm and 22 mm were analysed according to the characteristics of the materials affecting their performance. In the research there has been determined the inaccuracy of the whole width Fc and inner width FIc, different with respect to the threads of the structure of the fabric in all five closed-circuit square-shaped widths of the embroidery elements. The results of the research showed that irrespective of the width of the contour, the width of the embroidered element and the accuracy of the shape, in all cases, the direction of the fabric thread depends on the technological parameters of the process, and on the structure of the fabric, the operational, geometric properties depending on their characteristics.

Keywords: embroidered element, form, fabric.

1. INTRODUCTION

Due to structure and viscously tight deformation properties, textile materials are significant for their unique ability to acquire complex forms. This property enables them to be applied in various spheres. In smart garment industry the creation of embroidery systems is a relevant theme, comprising the properties of functionality, for which the accuracy of embroidery elements is one of the main quality requirements. Therefore, new methods and instruments of defect recognition of embroidery elements, enabling automatically to classify them, are being created [1], different scientific investigations are being performed, which enable to evaluate, to investigate and to predict the properties of these materials and their combinations, their changes and deformations during the processes of manufacturing and exploitation [2 – 6]. For the recognition of the defects of the embroidery elements, scientists have created the classification of the textile machines, which have an influence on the defects of the embroidery elements. The compiled classification was based on the visual monitoring of the embroidery and its comparison to the standard [6].

The quality of seamed joints and the quality of the embroidery is dependent not only on the physical and mechanical properties of the layers of the textile materials, joined together, but on the raw thread material, linear density, twist, surface treatment, the stability of the stitch length and the relaxation during the process of exploitation [7 – 9]. While sewing and embroidering, the joining of the textile materials into one system is performed applying the shuttle stitch [4, 10].

While filling the embroidery area applying the selected filling types, e.g. zigzag, tatami, the purpose is to achieve the uniformity of the forms of the elements [11, 12], therefore, while making stitches during the process, the interconnection of the threads should be visible only on the flip-side of the element [5, 6, 11, 12]. The appearance of undesirable defects, shrinking of the fabric, puckering is influenced by relaxation phenomena, taking place in the threads after the process of sewing, in which, during the shrinking of the threads, the cohesion between the threads of the fabrics is reduced and the fabric gets wrinkled [11 – 14]. Therefore, in order to manufacture embroidery elements without any defects, it is necessary to determine the characteristics of the applied textile materials, threads and their physical and mechanical properties.

In Bulgaria the scientists performed the research on the defects of the embroidery elements in one of the enterprises, where they analyzed the reasons of their appearance and their repeatability [13]. During the research there have been found different defects of the embroidery elements, such as: the element not fully filled with embroidery threads, the beating of the stitches in the corners, the visibility of the ground thread on the upside, the defects of the textile, the skip of the stitches, jumping, the rupture of the threads, the distortion of the form of the elements, the defects of the needle piercing, noncompliance of the obtained element with the digitally designed one etc. and they have been classified into groups. It has been noted that incorrectly chosen design of the embroidery process and the stages of the technological modes of the manufacturing had an impact on the 45 % of the obtained defects. The analysis

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demonstrated that in order to prevent the vulnerability of the needle piercing, a proper choice of the type of needle, selected according to the characteristics of the embroidery thread and by regulating the tightening of the thread, it is possible to avoid the interconnection of the upper and ground threads on the upside [13]. However, in this case, there was no research on the properties of the base material on the quality of the embroidery element. The appearing defects are inseparable from the technical status of the sewing machines and the chosen parameters, the forces of friction, the stability of the stitch [1 – 6, 13]. The research shows that when embroidery systems are impacted by external forces, the inequality of the surface of the material, its characteristics influence the quality of the elements [15]. All textile materials can be characterized as possessing the irregularity of the salience of the surface, which most often influences the response to the external force [11, 16 – 19].

The evaluation of the defects is helpful in managing the manufacturing of the embroidery elements since it highlights the main problems related to the primary stages of designing and manufacturing [13, 15]. Later the designed forms of the element are converted into digital format and transferred to the computer [18, 19].

Technicians-designers, applying present modal constructions, have created 3-D format and the vector image of the design, comprising the parameters of the technical form of the element and its measurements. While generating the information from 3D format to the embroidering equipment, the technical image of the embroidery element becomes 2-D format and after that the embroidering is performed [21, 22]. The method allows creating new forms of the embroidery elements by changing their measurements. Among the quality requirements for the functional embroidery elements the accuracy of the forms is one of the most important ones and to achieve this goal it is necessary to choose both the textile materials with correct properties and appropriate technological parameters.

It is evident from the analyzed scientific researches that for the purpose of improving the quality of the embroidery elements, methods of defect recognition, their classification are being created, embroidery technical equipment, the composing of packages of program forms are being perfected etc. However, it has been noted that material science factors, influencing the transformation of the form of the embroidery element, have not been thoroughly investigated yet.

The aim of the work is to investigate square shaped embroidered elements, taking into account the accuracy of the geometrical parameters, to evaluate the influence of the properties of the materials on the accuracy of the shape of the embroidered element.

2. EXPERIMENTAL DETAILS

The objects of the research are prepared by using a one-head embroidery machine BEXT-S901CAII by applying speed $V = 800\ min^{-1}$. The images of the closed-circuit square-shaped embroidery element are generated by applying Wilcom Embroidery Studio E2 program package. During the experiment five different types of the closed-circuit, 60 × 60 square-form embroidery elements, with the area of 6 mm, 10 mm, 14 mm, 18 mm and 22 mm have been analysed. The embroidery area was filled by using type T filling.

To perform the research textile materials of different weave, fiber composition of which was the same and due to their properties suitable for manufacturing work apparel, have been used. The test samples were embroidered with 100 % PES threads (the linear density of the upper thread 30.2 tex, the linear density of the ground thread 24.7 tex). The main characteristics of the composition of the textile materials are presented in Table 1. The relative random error of the measurement results, determined by the standards of investigated fabrics characteristics, did not exceed 5 %. Surface density and yarn density of investigated fabrics were determined according to LST ISO 3801 standard, yarn density according to LST EN 1049-2 standard.

The scheme of the measuring of the embroidery process is presented in Fig. 1. It is evident from Table 1 that both the primary and the final point of the process is point A. The needle, forming a succession of stitches is moving from point A towards points B, C, D and, having moved around the trajectory of the square, stops at the initial point A. The embroidery element is achieved by embroidering the sides of the outline according the directions of the threads of the material: AB – in the direction of weft, BC – in the direction of warp, CD – in the direction of weft, DA – in the direction of warp.

Due to the peculiarities of closed-circuit square-form embroidery element, two widths are being analysed in the research: the width of the whole test sample Fc and the inner width of the test sample FIc. The measurements of the geometrical parameters are performed by using program COREL DRAW 12. The width of the whole test sample Fc is measured at the length of the sides, at the points of the intersection of the inner sides and at the middle of the sides (Fig. 1 f). The width of the sides of the inner part of the test sample FIc is measured in the middle (Fig. 1). Accuracy of the square-shaped form are analysed in the experiment. The changes of the whole width of the embroidery element Fc and the inner width FIc and their impact on the final result of the value of the widths is considered to be the arithmetical average of 6 test samples.

3. RESULTS AND DISCUSSION

After completion of the analysis of the accuracy of the form of the embroidery elements it has been established the width of the embroidery element Fc and the inside width of the embroidery element FIc. The results of Fc width are shown in Fig. 2. While investigating the embroidery elements, accomplished on canvas weave fabric A1, it has been obtained that the width of the element Fc in the warp direction of the fabric is from 58 mm to 59.3 mm, i.e. from ~1.2 % to ~ 3.3 % smaller than the digitally designed one (Fig. 2 a). The width of the element in the weft direction Fc in the majority of the measured spots has been found from ~ 0.2 % to ~ 3.3 % bigger than the designed one (Fig. 2 b). It is obvious from the presented examples that while evaluating the average width of the embroidery element, accomplished on fabric A1, the greatest noncompliance with the form is received in the warp direction of threads of the fabric.

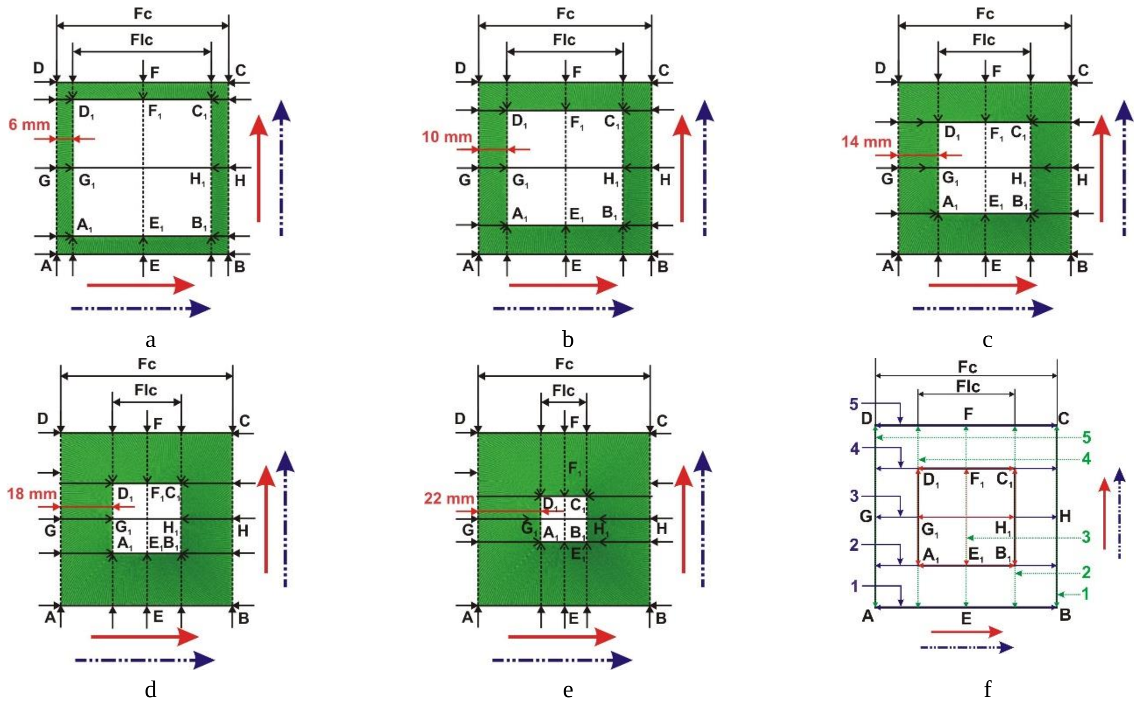

Fig. 1. The measurement scheme of the width of the closed-circuit square-shaped embroidery element Fc, inside width FIc: here a – the width of the contour is 6 mm; b – the width of the contour is 10 mm; c – the width of the contour is 14 mm; d – the width of the contour is 18 mm; e – the width of the contour is 22 mm; f – the scheme of the overall width of the measured segments Fc – embroidery direction; – fabric weft threads; – fabric warp threads

It has also been obtained that in the middle spots of the measurement the width of the element Fc was received from ~ 0.5 % to ~ 3.4 % bigger than the designed one (Fig. 2 a, b, the spots of measuring 3). Similar results have been obtained while analysing the widths of the embroidery elements performed on fabric A2. During the research it has been concluded that the width of the element Fc differs the most in the ends of the measured segments. When the width of the contour is from 6 mm to 14 mm, the width of the embroidery element Fc in the direction of warp threads is from ~ 1.3 % to ~ 2.5 % smaller than the designed one (Fig. 2, c). The width of the embroidery elements Fc performed in the direction of weft threads has been determined as close to the designed ones (Fig. 2 d).

While assessing the compliance of the embroidery element with the digitally designed one, it has been obtained that the designed square-shaped element, performed on the fabric in most cases acquires the rectangular form. On the upper side of the twill weave fabric A2 the ceiling of warp threads twills is predominant, the density of which is ~ 36 % bigger and the linear density of the threads is ~ 8 % smaller than that of the weft threads (Table 1). Different characteristics of the thread systems demonstrate the anisotropy of the fabric. The threads of the warp system of fabric A2 due to the peculiarities of their weave and bigger density are stretched more, more crushed than weft threads, therefore after the embroidery process in this direction the threads of the fabric inside the embroidery element are deformed more (Fig. 2 c, d).

Slightly different results are obtained while performing embroidery elements on fabric A3. In the latter case, the length of the embroidery element in both directions of the threads of the fabric is similar (Fig. 2 e, f). Even though the width is determined by 1.5 % smaller than the designed one, the form remains more adequate to the designed one. Such results are obtained due to the indexes of the linear fillings of the fabric, which are closer in different directions in fabric A3 than in cases of other fabrics under investigation (Table 1). It is evident from the received result that independently on the width of the contour, the width of the embroidery element Fc in all cases is narrower towards the corners of the sides than in the middle. This is characteristic to both directions of the threads of the fabric (Fig. 2). Depending on the concentration of textile materials in the zones of tensile, stretching, crushing, due to the increased pressure of the inner layers of the outer yarns, the fibres shift and the geometry (cross-section, collapse, twist) of the yarn forming the structure of the fabric changes, affecting the operational formation properties [4 – 6, 10 – 12]. In the investigated case, the most embroidered items were of a smaller size (Fig. 2). One of the most important factors influencing the geometric properties of the fabric are the diameter of the yarn, density, length, fabric weave, how tight the fibres are located, interconnected with each other, and what cohesion they have. Therefore, it can be stated, that when applying embroidered items of one size on fabrics, whose weaves are different and their fibres are unevenly mixed, the accuracy of the embroidered system is influenced by the direction of the fabric thread depending on the size of the contour width and the geometric properties of the yarn, which changes during mechanical influence according to their characteristics (Fig. 2, Table 1).

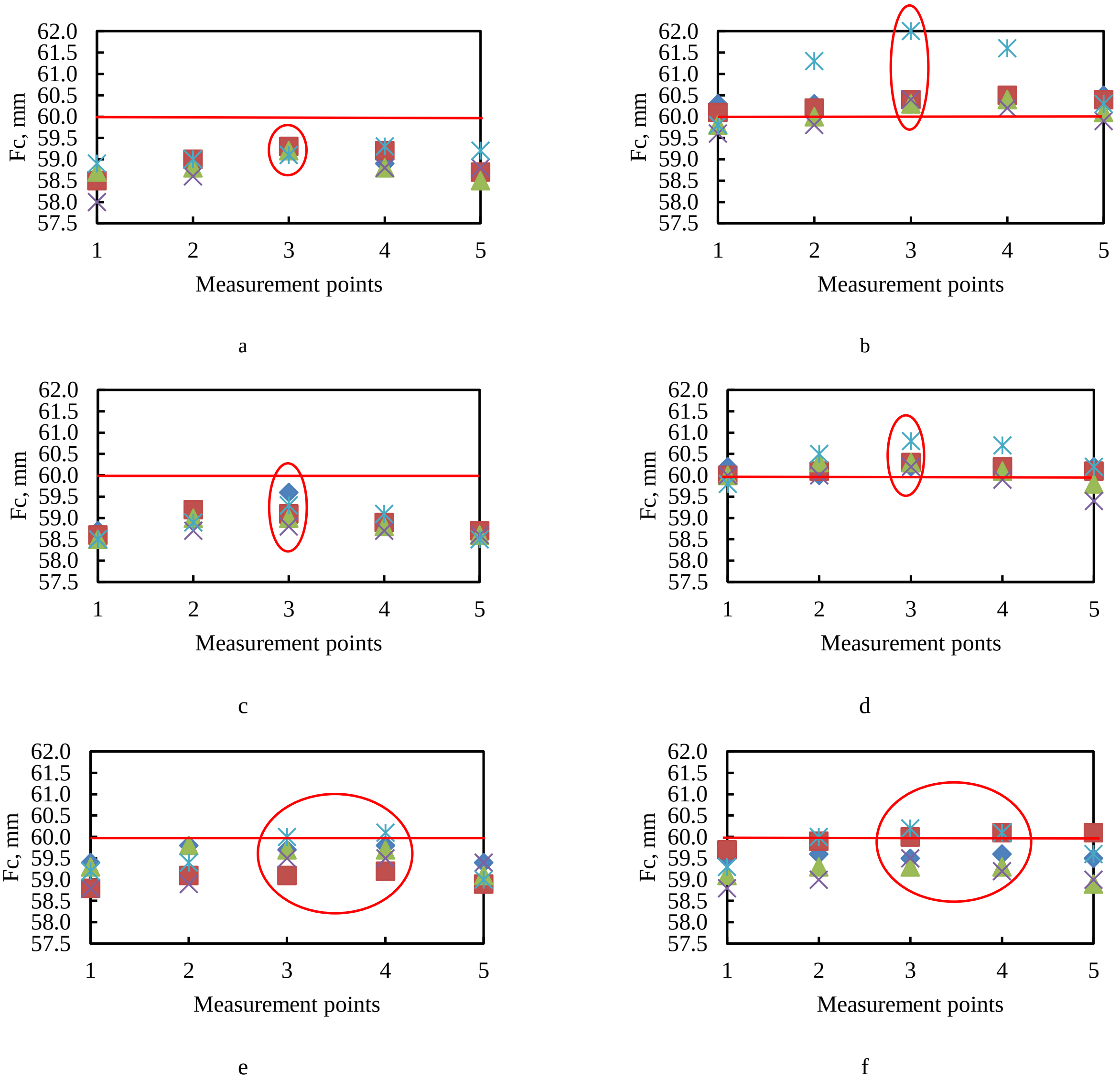

Fig. 2. The width of the embroidery elements Fc, when the width of the designed outline is: a – accomplished on fabric A1 in warp direction; b – accomplished on fabric A1 in weft direction; c – accomplished on fabric A2 in warp direction; d – accomplished on fabric A2 in weft direction; e – accomplished on fabric A3 in warp direction; f – accomplished on fabric A3 in weft direction, when ◆ – 6 mm; ■ – 10 mm; ▲ – 14 mm; × – 18 mm; ✳ – 22 mm

Table 1. The characteristics of the fabrics

Fabric symbol	Weave	Composition	Surface density, g/m^2	Linear density, tex		Fabric linear filling indicators		Threads density, cm^{-1}	
				T_{m1}	T_{a1}	e_{warp}	e_{weft}	P_{warp}	P_{weft}
A1	plain weave	65 % PES; 35 % cotton	257	37	37	0.971	0.534	40	22
A2	4/1 -twill		287	37	40	1.092	0.732	45	29
A3	3/1- twill		251	30	50	0.852	0.536	39	19

Different form of the embroidery element is also obtained in the researches performed by other authors in their investigations, where they highlight the physical and mechanical properties of the fabric, which have an impact on the aesthetic and exploitation quality of the embroidery elements [11 – 14]. The research focus on the precision of the single closed contour width of the embroidered elements [11]. After a synergistic research has been accomplished the scientists analysed the changes in the geometrical parameters of the rectangular elements, performed by using three different lengths of the stitch and came to the conclusion that by using the materials, providing additional stiffness to the form and technical conditions remaining the same, the geometrical parameters of the investigated knitted materials, opposite to the of the structure, are received different because of the differences in the physical properties of the materials [2].

The review of the scientific literature confirmed that the majority of the authors are researching and analysing completely filled embroidery elements and their form [1, 2, 4 – 6, 10 – 13].

However, it is equally important to evaluate how several threads of different colour, purpose, function etc. are joined into one embroidered element. Because of this purpose in this research there was an evaluation not only of the exterior compliance of the embroidered element with the designed one, but also the inside width of the element FIc (Table 2). The accuracy of the latter parameter is of great importance when the inside of the closed -circuit during the next stage of the embroidering must be filled with threads. In case inner measurement does not comply with the designed one, the defects of the embroidery element appear, such as a gap between the elements, the offset of different threads of the elements etc. [2, 5, 11]. Therefore, the compliance of these parameters is so important and relevant.

It should be emphasized that this research analyses the width of the embroidered element of the entire square, including contour embroidered with five different widths, and the inside of the element. The novelty of the research is that it reveals a close relationship between all the components of elements, making the square are, and which deformations are characterized by close, strong interconnectedness. Table 2 shows the FIc (mm) values of the internal width of the squares of the projected embroidered elements with different contour widths, and the results of Flc research of embroidered element widths.

According to the presented results, it has been obtained that the inside form of the embroidery element is not precise. The inside width FIc accomplished on fabric A1 in the direction of warp threads is narrower at the sides than in the middle (Table 2). The inside width FIc, performed on fabric A1 in the direction of warp, is received from ~ 0.6 % to ~ 1.3 % smaller than the designed one (Table 2). While analysing the results of the inside width FIc performed on fabric A1in the direction of weft, it is evident that the latter is obtained closer to the designed size. It has been determined that the inside width of the element FIc of the widest (22 mm) contour width in both directions in all measured spots is obtained as the least adequate to the designed size, from ~ 1.7 % to ~ 6.5 % bigger than the designed one (Table 2).

While analysing the form of the embroidery elements accomplished on fabric A2 it has been established that in most cases the inside width FIc, obtained in warp direction, is smaller than the designed size: when the width of the contour is 6 mm, 10 mm, the noncompliance is ~ 1.3 %, when the width of the contour is 14 mm, 18 mm, the noncompliance is ~ 0.9 %. In case of the greatest width of the contour (22 mm), the inner width of the element FIc in warp direction is ~ 3.1 % bigger than the designed size (Table 2). The inside width FIc when the width of the contour is 14 mm, 18 mm, 22 mm in weft direction, accomplished on fabric A2 is obtained bigger than the designed one by ~ 4.4 % (Table 2).

When the widths of the contours are narrower, the inner width of the embroidery element accomplished on fabric A3 is very close to the designed size. In this case, it is impossible to distinguish great differences in threads of warp and weft directions. The greatest noncompliance with the designed parameter is also obtained in the presence of the widest width of the contour 22 mm, in this case the noncompliance parameter was more than ~ 6 %.

A very significant influence on the accuracy of the embroidery elements has got the direction of the process in relation to the structure of the fabric and the technical characteristics of the applied type of filling [11 – 15, 17]. In this case, depending on filling type T, when the closed-circuit square-shaped contour is wider in embroidery elements, longer successions of stitches are formed than in the investigated narrower contours. In type T filling the interconnection of the stitches is on the bottom side of the embroidery system, therefore, the loads of stretching of the threads are distributed unevenly [11, 12, 14]. While joining longer successions of stitches by using type T filling, the upper sewing thread more times passes the eye of the needle than in shorter successions of stitches; therefore, the embroidery elements of wider closed contour are more affected mechanically. During the process while making the stitches, stretching is performed vertically towards the direction of the system, the embroidery system is not only stretched, but crushed as well [12, 17].

Table 2. Results of the internal width FIc (mm) of the embroidered elements

Fabric symbol	Designed width of the closed-circuit embroidery element	Designed inside width of the embroidery element FIc, mm	The inner width Flc (mm) of the embroidered elements					
			Warp direction			Weft direction		
			Measurement			Measurement		
			B_1C_1	E_1F_1	A_1D_1	A_1B_1	G_1H_1	D_1C_1
A1	6	48	47.2 ± 0.11	47.8 ± 0.13	47.2 ± 0.07	48.0 ± 0.16	**48.4±0.13**	48.2 ± 0.21
	10	40	39.4 ± 0.20	39.9 ± 0.21	39.7 ± 0.21	39.8 ± 0.21	**40.6±0.12**	40.1 ± 0.15
	14	32	32.0 ± 0.20	32.0 ± 0.09	31.5 ± 0.14	31.2 ± 0.20	**32.6±0.09**	32.0 ± 0.20
	18	24	23.2 ± 0.09	23.8 ± 0.15	24.3 ± 0.15	23.9 ± 0.20	**24.9±0.15**	24.2 ± 0.20
	22	16	16.3 ± 0.08	16.4 ± 0.09	16.6 ± 0.13	16.6 ± 0.09	**16.8±0.08**	17.0 ± 0.10
A2	6	48	47.4 ± 0.13	47.7 ± 0.19	47.0 ± 0.14	47.7 ± 0.14	**47.8±0.13**	**47.8±0.13**
	10	40	39.4 ± 0.14	39.8 ± 0.20	39.2 ± 0.10	39.9 ± 0.10	**40.2±0.16**	39.9 ± 0.16
	14	32	31.6 ± 0.19	31.9 ± 0.17	31.5 ± 0.20	32.0 ± 0.18	**32.5±0.13**	32.1 ± 0.20
	18	24	23.8 ± 0.18	24.0 ± 0.08	23.6 ± 0.09	24.4 ± 0.13	**24.6±0.04**	24.3 ± 0.10
	22	16	16.0 ± 0.18	16.4 ± 0.14	**17.2±0.11**	16.6 ± 0.16	17.0 ± 0.12	16.5 ± 0.10
A3	6	48	47.6 ± 0.14	**47.9±0.08**	47.5 ± 0.15	47.8 ± 0.10	**47.9±0.19**	47.8 ± 0.07
	10	40	39.4 ± 0.19	39.8 ± 0.13	39.9 ± 0.16	40.1 ± 0.15	**40.4±0.15**	40.2 ± 0.13
	14	32	31.9 ± 0.16	**32.3±0.14**	31.8 ± 0.16	31.8 ± 0.15	32.2 ± 0.14	31.7 ± 0.14
	18	24	24.0 ± 0.09	**24.5±0.13**	24.2 ± 0.13	23.8 ± 0.18	24.4 ± 0.13	23.5 ± 0.11
	22	16	16.2 ± 0.13	16.9 ± 0.10	**17.8±0.16**	16.3 ± 0.12	16.5 ± 0.14	16.2 ± 0.10

It is obvious from the results of the experiment that in most cases the width of the element Fc in all researched fabrics and the inside width FIc are obtained different in relation to the thread system and a greater change is determined in warp direction. While comparing the changes of the form of the embroidery elements to each other and with the designed size, it has been obtained that a repetitive defect of the form is characteristic for all fabrics i.e the curvature of the sides of the square in the middle of the form (Fig. 2). It has been determined that in majority of cases the obtained form is closer to the designed one in weft direction. Based on the obtained results, it is possible to state that while geometrical parameters of the embroidery elements are different; their form is obtained different as well. In previous scientific researches, while analysing the width of the contour it has been determined that the type of filling and the direction of the stitch formation have an impact on the width of the square-shaped embroidery element depending on the characteristics of the fabric [11].

In the process of embroidering while making the stitches the threads limit the form of the roundabout of the fabric and they move away from the rectangular. This change takes place because of the inclination corners of the bottom and upper threads towards the basting stitch due to the appearing additional friction between the mechanisms taking part in the process and the structure of the materials, which resists the sliding of the threads towards the direction of the succession of the stitches [11, 22 – 24]. This means that during the formation of the next succession of the stitches, while the needle goes down, the stretching from the already formed thread offshoot of the succession of the stitches is influenced by the stretching of the previously formed thread stitches and the compression in relation to the thread system. In the investigated case, while embroidering the widths of the elements of different closed-circuit square, the number of accomplished stitches differs, therefore, the changes of their forms are obtained uneven. The obtained results of the investigation demonstrated that in most cases the form of the closed-circuit square-shaped embroidery elements changes due to the physical, mechanical properties and that the accuracy of the widths of the analysed Fc and inside FIc depends on the width of the closed-circuit contour. In the previous studies, when analysing the deformations of the width of the single closed contour, the researchers quantified the non-compliance of the embroidered elements of closed contour with the designed size. [11]. In this study, the analysis of five square shaped embroidered elements with different widths was done; taking into account that the changes in the total and inner width of the element reveals the importance of process technological parameters for the formation the quality of the embroidered elements. Therefore, the changes in forms of embroidery elements should be analysed and defined; both relating them to the accuracy of geometrical parameters, physical properties of the fabric and to the technological parameters as well.

4. CONCLUSIONS

The research shows that the analysis of embroidered elements based on the geometrical parameter analysis, according to the characteristics of the fabric structure, can be applied to the development of advanced embroidery systems technology, avoiding unwanted defects, time consuming costs and investment. It was determined that the size of the contour width influences the shape of the embroidered elements matching the chosen size. It was found that the narrower (6 mm and 10 mm) contour width of the embroidered elements has a more precise shape. The wider the contour width, the greater effect of external pulls and compression forces are. The changes in the shape of such elements are clearly visible and no longer correspond to the designed forms. Making conclusions of the research it can be stated that the properties of the fabric, technological processes affect the accuracy of the embroidered element.

It has been obtained that the compliance of geometrical parameters of embroidery elements with the designed size is inseparable from the stability of the form. It has been determined that the investigated geometrical parameters of closed-circuit square-shaped embroidery element, i.e. the whole width Fc and the inner width FIc changes differently in relation to the thread system of the fabric. During the mechanical impact the structure of the fabric is affected by the stretching of opposite forces and the forces of crushing, the needle and the systems of fabric ceilings and threads. While covering the surface of the fabric with the embroidery threads, when there is the presence of interconnection between the contact systems, the friction and the stretching change depending on their characteristics, therefore, the form of the embroidery gets deformed unequally.

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