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ANALYSIS ON THE CONFORMITY BETWEEN THE CLOSED-CIRCUIT EMBROIDERY ELEMENTS OF DIFFERENT WIDTHS AND THE DIGITALLY DESIGNED ELEMENTS

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Abstract:

The embroidery process is one of the means of joining textile mate-rials into a system, which is widely applied in the creation of prod-ucts of special destinations. The development of the functionality of embroidery systems is indissoluble from high-quality requirements for the accuracy of the form of the element. In the embroidery pro-cess, the system of textile materials experiences various dynamic loads, multiple stretching, and crushing; therefore, the geometrical parameters of the embroidery element change. The objective of this paper was to analyze the widths of the different square-form closed-circuit embroidery elements and also to perform their analysis with the purpose to evaluate the embroidery accuracy of the embroidered elements. Test samples were prepared in the form of square-form closed-circuit embroidery elements of five different contour widths: 6 mm, 10 mm, 14 mm, 18 mm, and 22 mm. During the in-vestigation, it has been determined that in most cases the contour widths of the five closed-circuit square-form embroidery elements were obtained, smaller than the size of the digitally designed ele-ment.

Keywords:

embroidered element, fabric, closed circuit, width

1. Introduction

The formation of defects in the embroidery systems is a problem, which is encountered within technological processes when a textile material is impacted mechanically and then it is pressed, crushed, stretched, bent, and pierced multiple times by the head of the needle. As a result, depending on the parameters of the technological process, the characteristics of the loads, the technology of stitch making and the properties of the materials, their composition, and mechanical and physical properties change. Therefore, while investigating the defects of the embroidery systems and the reasons for their formation, the evaluation of the deformation of textile materials plays a very important role [1–4].

The quality of the embroidery systems relies on the initial stages of manufacturing, where the forms of the elements are being designed, a desirable size and color are chosen, and textile materials as well. In further stages, the created form of the element is converted into a digital format and passed on to the computer [3, 5]. By applying modern technologies, the embroidery elements can be designed with regard to the individual needs of the clients and very high-quality requirements as well. The form quality of the embroidery elements is immensely impacted by the technological peculiarities of the applied filling type [6]. It is worth mentioning that a smooth and even surface of the embroidery area is one of the main quality requirements, which is directly impacted by the uneven thickness of the upper and bottom threads, chosen to be used in the process of stitch making and also the relaxation process of the system itself and physical properties of the materials [1, 4, 7, 8].

In manufacturing, defects are identified by the help of the automated defect recognition programs [7, 9, 10]. The methods of the defect recognition of the embroidery elements enable us to automate inspection procedures. After investigating the embroidery defects detected in one of the Bulgarian enterprises, they have been classified into groups [9]. It has been determined that the vulnerability of the textile base to needle piercings can be eliminated by selecting a proper technology mode, also the type of the needle should be selected to suit the characteristics of the material and embroidery thread [9]. It has been noted that the majority of the analyzed researches on the classification of the defects of embroidery elements and also by carrying out a visual inspection the geometrical parameters of the form of the embroidery elements are not being investigated and analyzed.

The smartest and newest technologies are available, and only high-quality experienced specialists are capable to convey precisely the elements of original design from the digital system on the textile products [11–13]. Thus, the compliance of the digitally created image with the completed embroidery element is of the essential importance while creating embroidery systems.

While analyzing rectangular mobile conversation antennas, embroidered applying different density, it has been obtained that the functionality of the antenna is influenced by the accuracy of the embroidery element, the type of filling, the orientation of the lines of stitches with regard to the thread system, and density [14]. The analysis shows that scientific research analyzing embroidery systems and the factors influencing the quality of their precision are becoming more and more relevant [1, 2, 7, 11–13]. To evaluate the deformation behavior of the embroidery systems more precisely, it is necessary to create new methods, corresponding certain conditions of testing, very much adequate to their functionality.

The aim of this paper was to analyze different widths of square-form closed-circuit embroidery elements and perform their analysis with the purpose to evaluate the accuracy of the embroidered elements.

2. Experimental

2.1. Materials

The object of the research is three fabrics of the same fiber composition (Table 1). Polyester embroidery threads are used in the embroidery process. The linear thread density of the upper thread is 30.2 tex and that of the bottom thread is 24.7 tex.

2.2. Methods

The form of the embroidery elements is created in Wilcom Embroidery Studio E2 program package. The investigated test samples were accomplished with BEXT-S901CAII one-head embroidery machine, using filling type T, when one line is made of just a few stitches.

During the research, there have been embroidered square-form 60-mm × 60-mm closed-circuit embroidery elements of five different widths: 6 mm, 10 mm, 14 mm, 18 mm, and 22 mm. The start and stop point in the embroidery process is A as shown in Figure 1.

The closed-circuit square-form element is embroidered in the counterclockwise direction. The embroidered element is accomplished by embroidering two sides in the weft direction of the fabric, sides AB and CD, and two sides having been embroidered in warp direction of the fabric sides BC and DA. In the corners of the square, the stitches have been accomplished in the oblique direction of the fabric. The contour width EW is measured at four sides of the square, at the length of the designed element and its height, at the intersection points of inside sides and also at the quarter and middle points of inside sides. The geometrical parameters of the elements are determined with COREL DRAW 12 program package. The measurement scheme is shown in Figure 1.

The results of the research have been statistically processed, and the variation of the error did not exceed 6%. The errors of the accomplished measurements ranged from ±1% to ±5%.

3. Results and discussion

While comparing the width of the contour of the embroidery element EW between the sides of the square to the designed one, it has been obtained that in the segments of the same

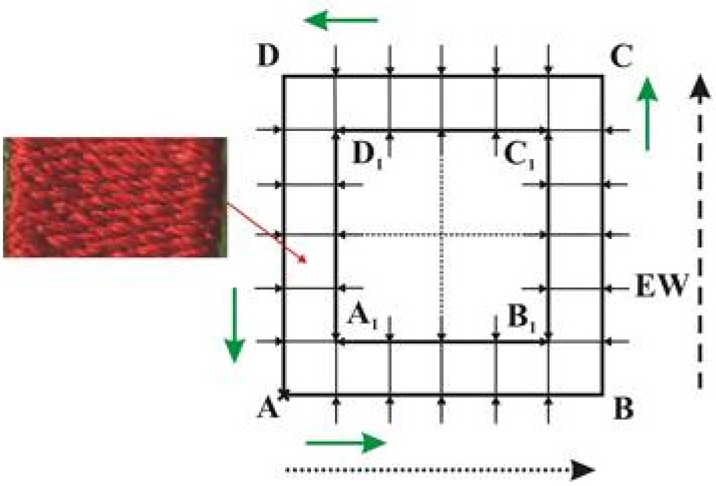

Figure 1. The measurement scheme of contour width of the embroidery element; EW, the contour width of the embroidery element; A, the start and end points of the embroidery process; embroidery process direction, ⟶; fabric threads warp, ·······▶; fabric threads weft, – – – –▶

Table 1. Characteristics of the fabrics

Fabric symbol	Composition	Weave	Thread density (cm^{-1})		Surface density (g/m^2)	Linear density, tex		Fabric linear filling indicators		Fabric surface filling indicator, es
			Pwarp	Pweft		Twarp	Tweft	ewarp	eweft	
A1	65% PES; 35% cotton	Plain weave	40	22	257	37	37	0.971	0.534	0.986
A2		Twill 4/1	45	29	287	37	40	1.092	0.732	1.000
A3		Twill 3/1	39	19	251	30	50	0.852	0.536	0.931

direction the contour width EW is not the same (Figure 2a). In the case under investigation, it is evident from Figure 2a that the width on fabric A1 in the segments of different directions and especially at the corners is different. In previous researches, it has been determined [7] that in the warp direction segment BC, at the corners, the width of the element EW is ~1.7% which is smaller than the designed one and in other places of measuring the width *EW* is bigger, i.e., ~2.8%. Meanwhile, in segment DA, the contour width of the element *EW* at the corners is obtained, bigger from ~1.3% to ~1.7% than the designed width and in other places of the segment the average width *EW* is smaller (~1.7%) than the designed width (Figure 2a).

The size of the deformed polymeric body forms and the size of the intensity of warp changes are dependent on the amount of the acting force, time, etc. Polymeric bodies maintain their typical form due to their mutual forces, acting among the elements of their structure. When a body is impacted by outside forces, it gets deformed, i.e., the interaction among the elements of their structure gets disrupted and there emerge additional, resisting deformations, inside forces [5, 15, 16]. In previous researches, it has been determined [7] that in the final DA closed-circuit square-form segment the path of stitches, performed by the needle, from the start point A is longer than BC and because of that in the embroidery system different forces of compression, stretching, and resistance are created and that influences the changes of the fiber movements in relation to each other in the composition of the fabric. The average contour width in segment AB in weft direction accomplished on fabric A1 is ~4.3% and in segment CD is ~5% which is smaller than the designed width (Figure 2a). When the contour width of the element is 10 mm, accomplished on plain weave fabric A1, the noncompliance between the contour width of the embroidery element and the designed one is in warp direction – ~2% – and in weft direction – ~4.2% – which is smaller (Figure 2a). It has also been determined that closed-circuit 14-mm and 18-mm width embroidery elements accomplished on plain weave fabric A1, and the noncompliance between the embroidery element and the designed one is ~2% in warp direction and ~4.2% in weft direction which is smaller (Figure 2a). It has also been determined that closed-circuit embroidery elements, 14 mm and 18 mm in width, accomplished on plain weave fabric A1, and the contour width of the element in warp direction is obtained from ~1.6% to ~2.6% and in weft direction ~5.4% which is smaller than the designed contour width (Figure 2a). While analyzing the widest 22-mm contour width of the embroidered test samples, the defect of the sliding of fabric threads in the seam has been noticed. While comparing 22-mm contour width of the embroidery elements to the designed one, it has been obtained that it is by ~1.4% in warp direction and by ~5.1% in weft direction, smaller than the designed size of the contour (Figure 2a). The sliding of the thread connections in the seam is strongly impacted by the characteristics of the fabric and the technological parameters of the embroidery process. While filling the embroidery elements of bigger contour width, a greater amount of needle stitches is made, the needle moving at a great speed on the fabric becomes hot and due to this heat impact, embroidery systems are being mechanically damaged. It has been noted that during the time of piercing the needle

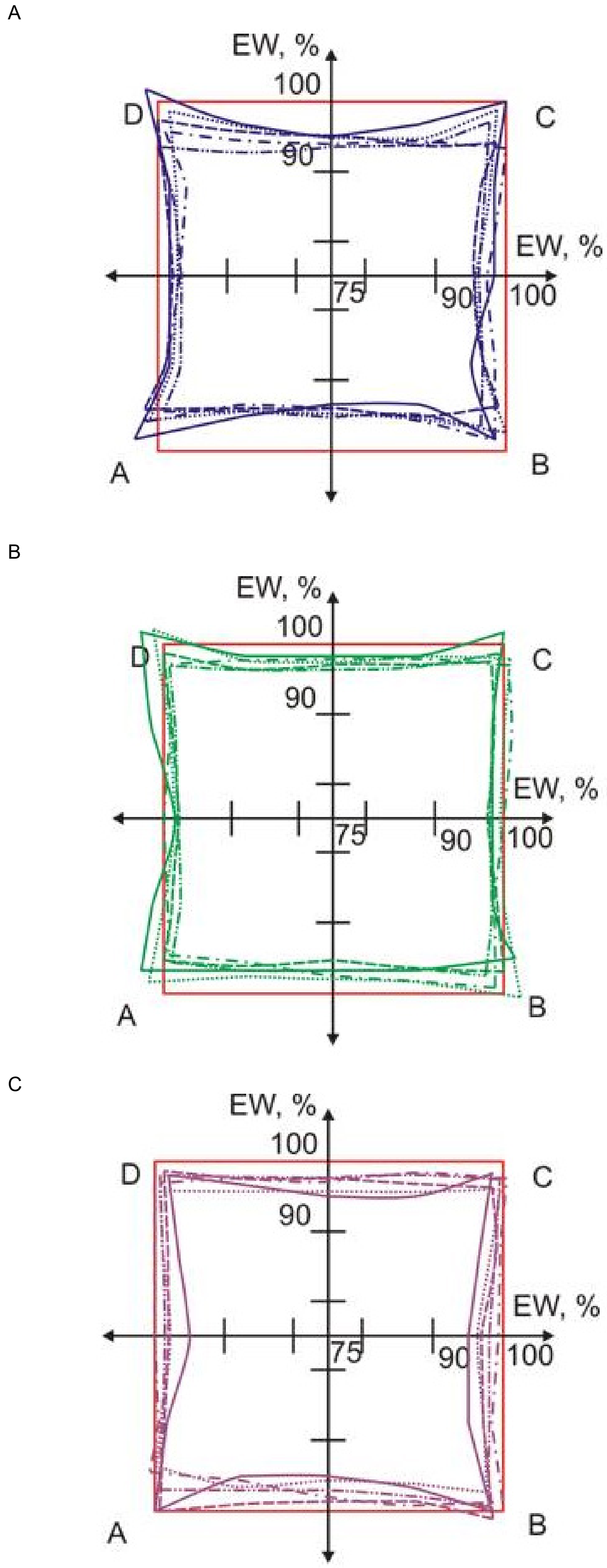

Figure 2. The contour width of the embroidery element EW, accomplished on: a, fabric A1; b, on fabric A2; c, on fabric A3, when the designed contour width of the element ——— , 6 mm; ··········· , 10 mm; – – – – – , 14 mm; –··–··– , 18 mm; – · – · – , 22 mm; ——— , the contour width EW of the designed element

compresses, crushes textile material, then it penetrates deeper, disrupts its structure, moves its fibers. The stronger activities of thread sliding are related to the increased filling area and also to the number of times when the needle comes out of the fabric [5–7, 17]. That gives ground to the identified defect of thread sliding in the seam, which have been obtained accomplishing the widest 22 mm contour embroidery elements, where lines of stitches are longer than those in the other tested widths of the embroidery elements.

While analyzing the widths of the different closed-circuit embroidery elements, accomplished on plain weave fabric A1 and while comparing them to the digitally designed one, it has been obtained that in most cases contour width EW is obtained, smaller than the designed one (Figure 2a). In this case, the most accurate contour width of the embroidery element (~2.1% smaller than the designed width) was obtained while embroidering the smallest 6-mm width (Figure 2a). The peculiarity of the plain weave fabrics is that threads of the same type get in contact with each other in all intersection corners of the elements of the system, and because of this reason it is impossible to eliminate any gaps between the threads. Therefore, this weave is the busiest and its coefficient is the biggest, equal to 1 [16–20]. While accomplishing the embroidery element of a bigger contour width, the systems are affected mechanically longer than while embroidering a smaller one, as a consequence, the change in the structure of the fabric increases. In the case under investigation, the nonconformity between the embroidery element with a bigger contour and the designed one is more evident.

The analysis of the results of the investigation showed that the widths of the embroidery elements, accomplished on twill weave fabric A2, in comparison to the designed ones, in most cases, are obtained closer to the designed size in warp direction than in weft direction (Figure 2b; Table 2). The results of the research showed that the contour width EW of the wider embroidery elements accomplished on twill weave fabric A2 in warp direction were obtained closer to the designed ones than in weft direction. It has been determined that a thread sliding was noticed in the biggest 22-mm contour width elements, in relation to other tangential systems. It has also been observed that in this case, a fold of fabric appears in the corners of the embroidery element, which is not covered with embroidery threads. Textile materials, when they are compressed and affected by small linear forces, buckle. During the buckling due to transverse forces of compression, they loose their plain shape and make a circular wave, the form of which changes when the compression deformation increases [7, 21, 22]. In the process, when the stitches are made in the direction which does not coincide with the trajectory of their movement, the threads of the fabric, because of the forces of compression and tensile, offset in relation to each other due to the phenomena of shear. When such phenomenon is taking place, the corners among warp and weft threads change, and later the tensile of the fabric threads themselves occurs [7, 23, 24]. The formed defect fold and the lack of stitches in the corner of the element could be characterized as the effect of the buckling phenomena, which is strongly influenced by the concentration of stretching tensile, emerging next to the defect during the process. When comparing all contour widths EW of the closed-circuit square-form embroidery elements accomplished on fabric A2 to the designed ones and to each other, it becomes evident that the most precise contour width EW of the embroidery element, the most adequate to the designed one, was obtained on test samples, the contour width of which was 6 mm and 10 mm in warp direction segments (Figure 2b; Table 2).

After the completion of the research, it has been determined that contour widths of the embroidery elements in warp direction, accomplished on twill weave fabric A3, are obtained, more adequate to the designed ones than those in weft direction (Figure 2c). While exploring the widths of embroidery elements accomplished in warp direction on fabric A3, it has been determined that the average value of width EW is ~1.7%, smaller than the designed one. The embroidery elements of the biggest contour width 22 mm in the direction of warp have been determined as more adequate to the designed size than the elements of other sizes (Figure 2). It is worth mentioning that while embroidering a bigger contour width of the element, its geometrical parameters are determined closer to the designed ones.

By comparing the contour widths of the embroidery elements in both warp and weft directions among themselves and to the designed one, it has been determined that, in most cases, the closest to the designed size are the embroidery elements accomplished on twill weave fabric A2 (width EW was obtained from ~0.1% to ~3.4%, smaller than the designed one; Figure 2; Table 2). In the researches performed by other scientists, it has

Table 2. The research results of the noncompliance of the contour width of the embroidery element with the digitally designed one

Fabric symbol	The noncompliance of the embroidery element contour width to the digitally designed one (%)					
	Embroidery direction	The contour width of the embroidery elements (mm)				
		6	10	14	18	22
A1	Warp	-1.0	-1.9	-1.6	-2.6	-1.4
	Weft	-3.2	-4.2	-5.4	-5.4	-5.1
A2	Warp	0.5	0.1	-1.2	-1.7	-0.3
	Weft	-2.0	-1.4	-3.4	-3.2	-2.8
A3	Warp	-2.8	-1.6	-1.7	-1.3	-0.2
	Weft	-3.0	-4.2	-1.6	-2.3	-2.6

been determined that, inside the structure of the twill weave fabrics, due to the formed free fields, bond fields of ceilings weaken and the cohesion increases due to the physical properties [18, 25–27]. Because of the mechanical impacts, textile material inside the embroidery element is compressed and buckled [2, 4, 15, 28, 29].

The size and the characteristics of the deformation of the embroidery elements are strongly influenced by the composition and the physical properties of the fabric [3, 5, 7, 30]. While analyzing the contour width changes, taking place in the closed-circuit square-form embroidery element, a buckling correlation dependency between the filling indexes of the fabric and the changes in the contour width EW has been determined, and it shows that the indexes of fabric thread filling have got an impact on the geometrical parameters of the closed-circuit embroidery element. In the research, it has been obtained a medium strength and a strong buckling correlation dependency (Figure 3).

The strongest correlation bond between the indexes of fabric filling and the changes in the contour width of the embroidery element EW was determined in the 6-mm, 10-mm, and 22-mm contour width EW elements (Figure 3). It was noticed that in general case, the most adequate to the designed size are the contours of the embroidery elements on fabric A2. The filling indexes in warp direction on fabric A2 are ~28%, bigger than those of the other fabrics and in weft direction ~37% (Table 1). It has been determined by the research that the indexes of the linear filling of the fabric demonstrate the relation between the thread area of the fabric in the smallest element and the area of the whole element, and it has a great influence on deformations of threads of the fabric. The filling indexes are not dependent on the sort of the weave of the fabric and the size of the repeat, since they are limited by the same neighboring warp and weft threads' sides, they supplement the characteristics of the fabric density. Fabrics possessing greater value indexes of linear filling can be characterized as having smaller deformations [2, 17]. This explains the obtained results of the experiment. It has been obtained that in most cases the contour width of the closed-circuit square-form embroidery element EW is closer to the designed one in warp direction. In the case under investigation, the linear e_m filling indexes of the fabric in warp direction are bigger from ~33% to ~45% than the linear filling indexes e_a in the direction of weft threads. The filling index e_s of fabric A2 was determined from ~1.4% to ~6.9%, bigger than those of the other test samples (Table 1). Because of that, during the process, strong bond fields form among the threads of fabric A2 due to which the number of free fields decreases, the degree of bond tying increases and the widths' EW of the closed-circuit square-form embroidery elements is obtained which is most adequate to the designed one [7, 16]. The analysis of the contour width of the embroidery element showed that in different spots of the contour of the square the noncompliance to the designed size differs (Figure 2). It should be emphasized that in the corners the direction of the stitches is slanting in relation to the system of fabric threads. The fabric is more tensile in oblique direction than in warp and weft directions and introduced additional embroidery threads that widen the fabric even more [7]. In addition, at the corners of the embroidery contour, the length of the lines of stitches is bigger than the sides of the square. For instance, in the investigated case, while accomplishing one line of stitches on the side of the contour of the closed-circuit square-form element, which is 10 mm in width, the needle pierces the fabric ~25 times, and while making lines of stitches at the corners ~35 times, that means that the needle pierces the fabric at the corners of the contour by ~40% more times than at the sides of the contour. Because of the bigger amount of needle piercings into the fabric and the insertion of the embroidery threads into the element, the threads of the system are expanded strongly and less attached to each other; therefore, the contour width of the closed-circuit square-form embroidery element in most cases is obtained, bigger in the corners than in the other spots of the contour [7]. Because of the greater amount of needle piercings into the fabric and the insertion of embroidery threads into the element, the threads of the system are expanded more and stick to each other less; therefore, the

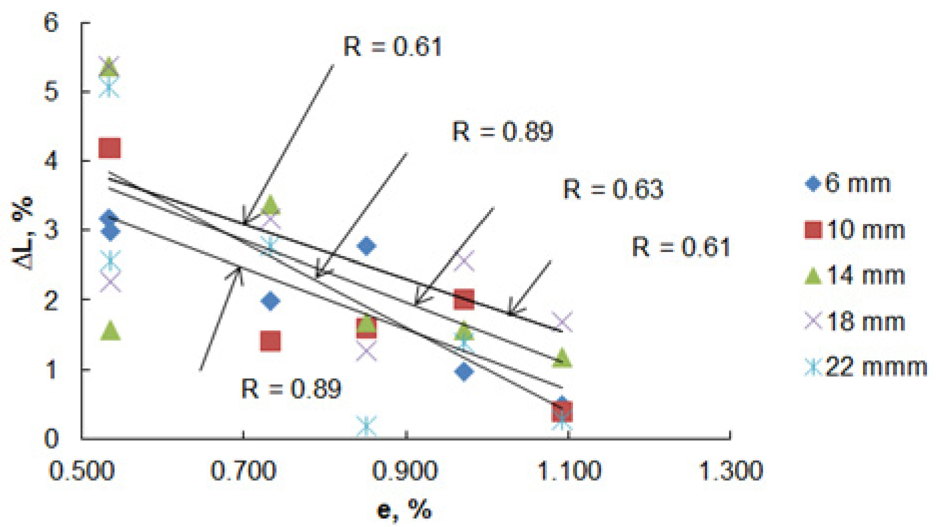

Figure 3. The dependency of contour width changes of the embroidery element ΔL (%) on the indexes of fabric filling e (%), when the contour width of the embroidery element EW is as follows: ◆, 6 mm; ■, 10 mm; when ▲, 14 mm; when ×, 18 mm; when ✳, 22 mm

width of the closed-circuit square-form embroidery elements in the corners in most cases is obtained, bigger than in other spots of the contour [7]. It is also necessary to underline that the behavior of the mechanically influenced embroidery system is strongly influenced by the emerging individual and complex phenomenon of relaxation processes [4, 5, 31].

Thus, the performed research shows that the experiment on the accuracy of the contour widths of five square-form embroidery elements describes the compliance of the embroidery elements of different geometrical parameters with the designed size and also assessing generally, individually, and together the directions of the systems of fabric warp and weft threads. Therefore, while creating textile products with integrated embroidery systems, where precision is a necessity and while analyzing the defects of the embroidery elements, the completed research is of extreme importance and value.

4. Conclusions

The identified reverse correlation dependency between the indexes of fabric filling and the change of the contour width of the embroidery element show that technological parameters and the properties of the fabric structure determine the reaction of the systems of the embroidery elements to the outside impact and accuracy.

In the investigated case, it has been obtained that five contour widths of the embroidery elements accomplished on the fabrics of different densities are not the same in comparison to the designed width and are dependent on the technological peculiarities of the type of filling, the indexes of the fabric structure, and the direction of stitches of the embroidery element in relation to the fabric. In most cases, the contour widths of the embroidery elements are obtained, smaller than the designed size, and in warp direction their width is obtained as being closer to the designed one than that in the weft direction.

It has been determined that the contour width of the closed-circuit square-form embroidery element at the sides and in the corners is not the same for each contour width. The lines of stitches increase at the corners; the corner of the stitch also changes in relation to the system of the fabric threads. When the embroidery system is deformed in different directions of the systems of fabric threads, the size of the corner, accomplished on textile base structure strands, as well as orientation and anisotropy, changes. Therefore, while accomplishing the embroidery elements of extreme precision, it is necessary to evaluate and match the properties of the textile materials of the embroidery system and technological factors.

With regard to the results of the research, we recommend the embroidery elements that demand very strong accuracy to be accomplished on thick fabrics which possess a greater index of filling (recommended filling index is close to 0.9–1). In thicker fabrics possessing bigger filling indexes, the compression between the punctures of the needle in the space boundered by embroidery threads and the spinning of the threads of the fabric with regard to each other is eliminated and the decrease in the contour width of the embroidery element with regard to the digitally projected one is guaranteed.

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