Seam pucker detection through presser foot displacement monitoring

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DEMBOSKI GORAN
JANKOSKA MAJA
MIGUEL ANGELO CARVALHO

ABSTRACT – REZUMAT

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The paper investigates the relation between seam pucker, woven fabric formability, and the presser foot displacement during stitch formation. Superimposed seams of class 1 were sewn in warp and weft direction using woven fabrics for tailored garments. The presser foot height was continuously monitored during stitch formation for different sewing machine speeds. The foot displacement during the sewing cycle was correlated with seam pucker. The obtained results showed various patterns of pressure foot displacement regarding the sewing machine speeds. It was found that at a lower machine speed there is no bouncing of the presser foot and the ratio of the height of the presser foot before and after rising and declining movement versus double thickness of the fabric (h/T_1), correlates significantly with the seam pucker percentage. The fabrics having a higher h/T_1 ratio showed a higher percentage of seam pucker. The obtained results suggest that online monitoring of this parameter can be a useful indication of on-seam pucker appearance, providing reliable means to obtain a quality seam.

Keywords: *seam pucker, presser foot displacement, online monitoring, formability, sewing dynamics*

Detectarea încrețirii cusăturilor prin monitorizarea deplasării piciorului de presare

Lucrarea investighează relația dintre încrețirea cusăturii, formabilitatea țesăturii și deplasarea piciorului de presare în timpul formării cusăturii. Cusăturile suprapuse de clasa 1 au fost realizate în direcția urzelii și a bătăturii folosind țesături pentru articole de îmbrăcăminte. Înălțimea piciorului de presare a fost monitorizată continuu în timpul formării cusăturii, pentru diferite viteze ale mașinii de cusut. Deplasarea piciorului în timpul ciclului de coasere a fost corelată cu încrețirea cusăturii. Rezultatele obținute au arătat diferite modele de deplasare a piciorului de presare, în funcție de viteza mașinii de cusut. S-a constatat că, la o viteză mai mică a mașinii nu sare piciorul de presare, iar raportul dintre înălțimea piciorului de presare înainte și după mișcarea de ridicare și scădere față de grosimea dublă a țesăturii (h/T_1), se corelează semnificativ cu un procent de încrețire a cusăturii. Țesăturile cu un raport h/T_1 mai mare au prezentat un procent mai mare de încrețire a cusăturilor. Rezultatele obținute sugerează că monitorizarea online a acestui parametru poate fi un indiciu util al aspectului încrețit al cusăturii, oferind mijloace fiabile pentru a obține o cusătură de calitate.

Cuvinte-cheie: *încrețirea cusăturii, deplasarea piciorului de presare, monitorizare online, formabilitate, dinamica coaserii*

INTRODUCTION

The apparel industry has been in constant demand for increasing the degree of sewing machines automation, directed towards improved control and higher quality of sewing operations. However, as a result of variation in structural fabric properties that influence sewability and garment appearance, there are still obstacles in achieving this goal. The appearance of seams on a finished garment is one of the most important properties of high-quality garments. As the interest in garment, quality has been increasing, seam quality problems have received more attention [1]. Seam pucker is defined [2] as “a ridge, wrinkle or corrugation of the material or several small wrinkles running across and into one another, which appear in sewing together two pieces of cloth”. It has been regarded as one of the most serious faults in garment manufacturing, thus reducing the aesthetic value of garments [3]. It appears along the seam lines of garments when the material properties and sewing parameters are not properly chosen [4, 5]. For several decades, much research on-seam pucker was conducted to solve the problem in garment manufacturing. Researchers, including Dorkin and Chamberlain, have identified four primary causes of puckered seams [6]. Nowadays, technology offers online monitoring of the sewing operations parameters, which offers possibilities to reduce the percentage of faulty garments. Park and Ha developed a process for optimizing sewing conditions to minimize seam pucker using the Taguchi method [7]. The parameters selected for optimization were: sewing speed, stitch length, sewing thread tension, and presser foot pressure. Dobilaite and Petrauskas determined fabric deformation during the sewing process and assumed that the fabric shear and flexural rigidity are the main factors influencing the occurrence of pucker [8]. In addition, they found that surface density, extensibility, and formability of the fabric are also associated with this defect. Dobilaite and Juciene [9] investigated the effect of the rotational frequency of a sewing machine's main shaft and pressing force on-seam pucker. It was found, that in all cases the pucker height increases with the rotational frequency of the main shaft while decreasing with increasing pressing force. Mariolis and Dermatas have proposed a method of estimating the seam pucker with automatic control of the seam quality, focusing only on the evaluation of seam pucker [10]. Mak and Li have presented an objective method using image analysis and pattern recognition technologies for the evaluation of seam pucker [11]. Nassif has studied the influence of sewing machine parameters (sewing needle size, sewing thread tension, stitch density and sewing direction) on cotton woven fabrics seam pucker [12]. He has found that most sewing machine parameters have a significant influence on woven fabric seam pucker and also showed that there is a good correlation between the subjective and objective measuring methods of seam pucker, especially in the case of the effects of needle size and sewing thread tension. Kim et al. [13] have developed an automated sewing machine controller to find the optimum sewing conditions that minimize seam pucker. They developed a laser-based scanning system for the objective evaluation of seam pucker. The grade of seam pucker was evaluated by fractal dimension calculation based on the three-dimensional shape of the specimen. Chmielowiec and Lloyd [14] equipped a Pfaff lockstitch machine with sensors measuring presser-foot force and displacement, thread tension and needle penetration force. They investigated the effect of "presser-foot bouncing" and analysed correlations between presser foot compression force and seam pucker. It was found that seam pucker is influenced by a number of various factors, such as sewing thread and fabric properties, needle penetration and stitch formation, sewing thread tension, fabric feeding system and seam construction. Particular great attention was paid to fabric properties and sewing machine factors as well as to the compatibility of both in the process of sewing [15–19]. Mousazadegan and Latifi [20] have studied the formation of tension seam pucker in more detail in order to compute the thread compression load in terms of sewing thread tension. The results of this research helped to analyse the compression load on the fabric based on sewing thread tension. Muhammad *et al.* [21] have compared the numerical estimation of pucker derived from the model of a lockstitch seam (301), with fabric mechanics experiments and visual assessments of the phenomenon, showing that there is a good linear correlation between the two. The model was used to evaluate with precision, which of a selection of stiffeners, is required to reduce the pucker to an acceptable level, without over stiffening the seam.

Besides the increase in the degree of automation and monitoring of the sewing machine, there is still a need for getting information before production and especially during the sewing process, regarding fabric inclination to puckering in order to take action to minimize its incidence.

The aim of this paper is to investigate the occurrence of seam pucker of wool and wool blend woven fabrics for tailored garments using online monitoring of the sewing machine pressure foot displacement.

EXPERIMENTAL PART

Materials and methods

The object of the investigation is a series of wool and wool blend worsted woven fabrics for tailored garments, commonly used by this sector of the textile and apparel industry. The fibre composition of the fabrics varies from 100% wool and wool blend with elastane (*Lycra*) and polyester (PES). Fabrics are made in basic weaves of even repeat such as twill 2/1, twill 2/2 and plain weave. The mass per unit area of the fabrics ranges from 164–252 g/m^2 and fabric thickness ranges from 0.15 to 0.23 mm. In this fabric range, the highest mass per unit area and thickness fabric is 1.5 times greater than the fabric with the smallest mass per unit area and thickness. This variation in mass per unit area and thickness was expected to result in seam pucker variation on the finished seams. Some of the fabric features are shown in table 1.

In order to investigate fabrics formability, the samples were tested on a KES-FB system for fabric objective

Table 1

FABRIC PROPERTIES

Fabric	Composition	Warp density (cm^{-1})	Weft density (cm^{-1})	Mass per unit area (g/m^2)	Thickness (mm)	Weave
A	98% Wool 2% Lycra	32.0	24.8	204	0.18	2x1 twill
B	98% Wool 2% Lycra	32.0	26.2	212	0.21	2x1twill
C	100% Wool	31.2	27.6	164	0.15	2x1twill
D	100% Wool	31.2	28.0	186	0.17	2x1twill
E	100% Wool	30.8	25.6	194	0.20	2x2 twill
F	100% Wool	30.8	28.2	204	0.21	2x2 twill
G	44% Wool 54% PES 2% Lycra	29.0	20.0	204	0.20	plain
H	44% wool 54% PES 2% Lycra	35.4	24.4	252	0.23	2x2 twill

evaluation under small loads. The samples were sewn on a Pfaff 1183 industrial lockstitch sewing machine, stitch type 301, sewing needle size 100 Nm and sewing thread count of Tt = 25 tex. Two plies of fabrics were sewn with the class 1 superimposed seams type 1.01.01 and stitch density of 4 stitches per cm in warp and weft direction. The machine speed was varied between 1000, 3000 and 4000 rpm (revolutions per minute).

The sewing machine was equipped with a linear variable differential transformer (LVDT). This electromechanical device produces an electrical output proportional to the displacement of a separate movable core [22]. The core was linked to this presser bar and the cylindrical case attached to the machine frame, which together with a piezoelectric force transducer placed on the same bar, can provide information on feeding system dynamics during the sewing cycle. Thus, LVDT (with electronics to provide a dc output proportional to the displacement) was used for real-time monitoring of the movement of a presser foot bar [23]. That device is connected to a data acquisition board installed in a PC, with software that allows sensor calibration, online graphical display and signal processing functions (figure 1).

The results of the presser foot displacement represent the average of 20 stitches acquired in each experiment.

Fig. 1. The control device in the lockstitch sewing machine and connected PC

The degree of seam pucker for the sewn samples was calculated via percentage equation, where the percentage of pucker in the seam is calculated from the difference between the thicknesses of the seam and the double thickness of the tested fabrics for the Class 1 seam type, equation 1:

$$SP = \frac{T_2 - T_1}{T_1} \cdot 100 \qquad (1)$$

where SP is seam pucker in %, T_1 – double thickness of fabric (two layers of fabric) in mm and T_2 – seam thickness in mm.

The thickness of the fabrics was determined according to ISO 5084:1996 standard using a fabric thickness meter [24]. The seam thickness is measured by a fabric thickness meter and the measurement is done along the length of the seam line.

The term formability has been established to describe the ability of two-dimensional fabrics to get converted into three-dimensional garments and for predicting fabric propensity to seam pucker occurrence, especially in sewing operations with overfeeding. For this investigation, the formability of the samples was calculated using Kawabata and Niwa equations 2 [25, 26]:

$$F = \frac{EM}{F_m \cdot LT} \cdot B \cdot \frac{G}{2HG5} \qquad (2)$$

where F is formability in mm^2, EM – extensibility strain at 500 gf/cm of tensile load, B – fabric bending rigidity in gf·cm^2/cm, G – fabric shear stiffness in gf/cm·deg, F_m – maximum force of fabric extension of 500 gf/cm, LT – linearity of load/extension curve and 2$HG5$ – hysteresis of shear force at 5° shear angle in gf/cm.

RESULTS AND DISCUSSION

The results of seam thickness, fabric thickness and seam pucker percentage for seams in warp and weft directions are depicted in table 2. The warp, weft and average formability according to Kawabata and Niwa are shown in table 3.

The results of the seam pucker percentage (table 2) show that all samples in the warp direction obtain higher pucker than weft samples. On average, the pucker of the warp direction seams is 32.9% and in the warp direction seam is 26.6%, i.e., warp seams

Table 2

SEAM PUCKER PERCENTAGE IN WARP AND WEFT DIRECTION

Fabric	T_{21} * (mm)	T_{22} * (mm)	T_1 (mm)	SP_1 (%)	SP_2 (%)
A	0.95	0.92	0.36	31.9	27.8
B	1.00	0.95	0.41	22.0	15.9
C	0.90	0.85	0.29	55.2	46.6
D	0.95	0.90	0.34	39.7	32.4
E	1.05	1.00	0.39	34.6	28.2
F	1.07	1.02	0.41	30.5	24.4
G	0.95	0.90	0.39	21.5	15.4
H	1.15	1.10	0.45	27.8	22.2

Note: SP_1 and SP_2 – seam pucker in warp and weft direction in %; T_{21} and T_{22} – seam thickness for seams in warp and weft direction in mm; T_1 – double thickness of fabric (two layers of fabric) in mm.

Table 3

FORMABILITY OF THE FABRICS BY WARP – F_1, WEFT – F_2 AND AVERAGE – F

Fabric	F_1 (mm^2)	F_2 (mm^2)	F (mm^2)
A	0.0589	0.4250	0.1881
B	0.0576	0.3850	0.1783
C	0.0210	0.1214	0.0596
D	0.0310	0.0841	0.0537
E	0.0473	0.1735	0.0992
F	0.0503	0.1691	0.1005
G	0.0208	0.3993	0.1343
H	0.0281	0.6323	0.2044

show on average 6.3% higher pucker than weft seams.
Weft formability ranges from 0.0841 to 0.6323 mm^2 and is higher than warp formability which ranges from 0.0208 to 0.0589 mm^2. The difference is a result of the unbalanced fabric set which affects the mechanical properties in both directions. Average weft formability is 7.6 times higher than the warp one. This suggests that seams in weft directions are expected to show less puckering than the warp ones. The lowest average and weft formability is obtained for fabrics C and D which have the lowest fabric mass per unit area, while the highest formability is obtained for sample H (the largest fabric mass per unit area out of all samples). The highest coefficients of linear correlation obtained are –0.70, between the seam pucker in the warp direction and average formability and –0.65, between the seam pucker in weft and average formability.
Figure 2 represents graphs of presser foot displacement during the sewing cycle for fabric C (figure 2, *a*) and fabric D (figure 2, *b*) at sewing speeds of 3000 and 4000 rpm. The sewing cycle diagram starts from 0 degrees and represents the beginning of the descending movement of the feed dog below the throat plate; from 20–70 degrees the feed dogs are at the lowest position and began rising to throat plate level; where at 80 degrees they are exactly at throat plate level. So, in all these sequences from 0–100 degrees, the presser foot is at the throat plate level. Above 100 degrees, the feed dog has a rising movement along with presser foot, reaching its maximum height and declining afterwards till 260 degrees, when returning at the throat plate level. Finally, after 280 degrees, the feed dog drops to its lowest position at 360 degrees. Therefore, from 260 till 360 degrees, the presser foot is again at the throat plate level.
The highest position of the pressure foot at 4000 rpm is higher than at the speed of 3000 rpm for both investigated fabrics (figure 2, *a* and *b*), suggesting that increasing the machine speed increases the maximum height of the pressure foot displacement due to higher presser foot inertia at higher speeds. Although the results indicate some relation between the machine speed and maximum pressure foot height, there is no correlation between the maximum pressure foot height and the occurrence of seam pucker. Therefore, the maximum presser foot height does not provide relevant information regarding the occurrence of seam puckering during the online monitoring of the pressure foot displacement.
The height of the presser foot before and after the rising and declining movement varies for both machine speeds and obtains several values depending on the main shaft position. Generally, this happens from 0–100 degrees and from 260–360 degrees, (the pressure foot is at the throat plate level) and is the result of presser foot bouncing. This is the case for both fabrics (figure 3) and similar graphs were obtained for all other fabrics. This presser foot bounce phenomenon appears to result from high inertial forces being transferred into the presser foot by the feed dog at higher speeds [27].
Again, there is no good correlation between seam pucker and presser foot height, before and after the rising and declining movement for speeds of 3000 and 4000 rpm. Moreover, there are several levels of pressure foot heights in this phase (from 0.39 to 0.55 mm), as indicated in the graphs.
In further investigation, the machine speed was lowered to 1000 rpm and the results are shown in figure 3, *a* for sample C and figure 3, *b* for sample D, respectively. Graphs show that at 1000 rpm, the height of the presser foot does not vary before and after rising and declining movement and there are no indices of pressure foot bouncing. In this case, the height of displacement of the presser foot is the same before and after the peak (from 0–110 and to 260–360 degrees).
Various relationships between the height of the presser foot, fabric thickness, and seam pucker percentage, were investigated at the sewing speed of 1000 rpm. The best significant linear correlation was found between the seam pucker percentage and the

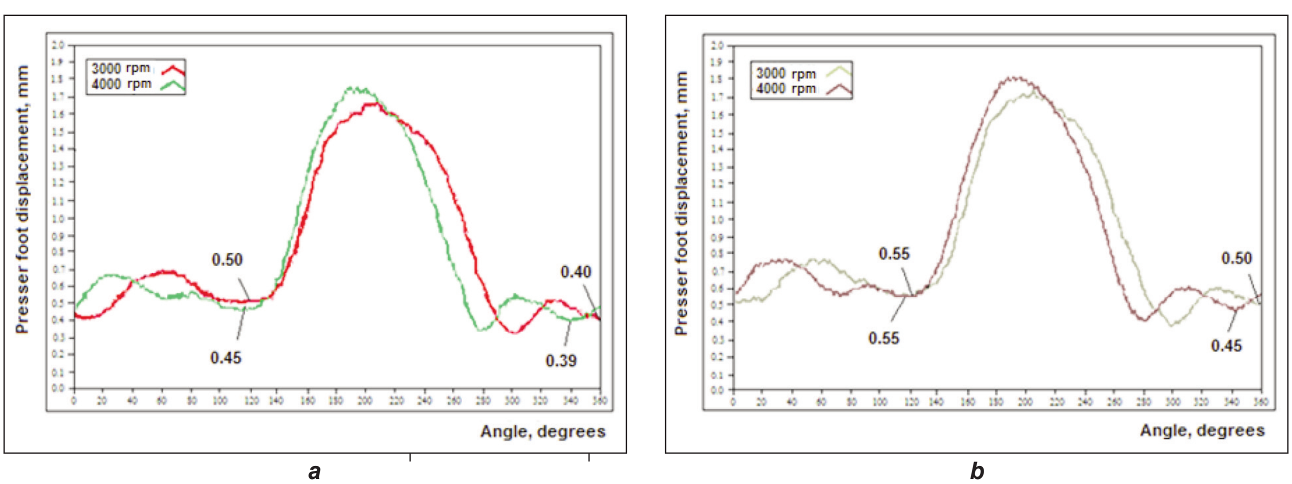
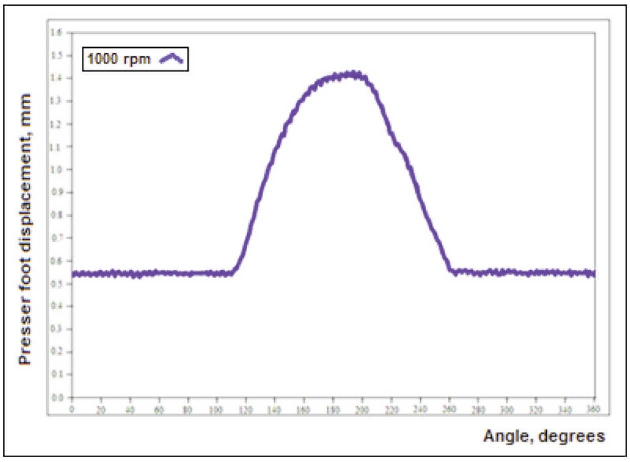
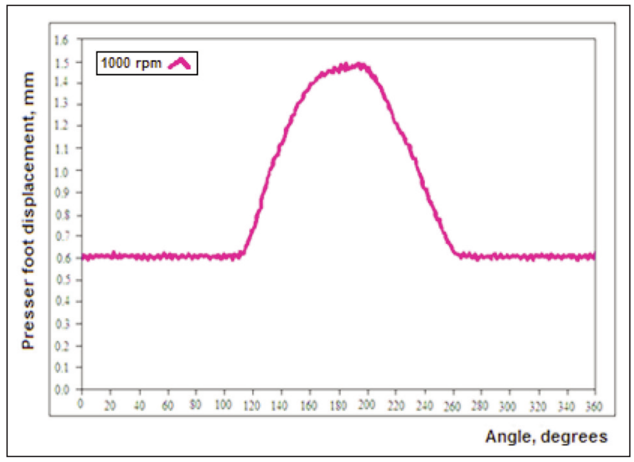


Fig. 2. Presser foot displacement at sewing speeds 3000 and 4000 rpm, sewing in warp direction:
a – fabric C; *b* – fabric D



a



b

Fig. 3. Presser foot displacement at sewing speed 1000 rpm, sewing in warp direction: *a* – fabric C; *b* – fabric D

ratio of presser foot height versus the thickness of two layers of fabric (h/T_1). The value of pressure foot height before and after rising and declining movement (at the throat plate level), is actually the thickness of the seam at the moment of sewing. So, the higher ratio value of the h/T_1 when monitoring the pressure foot height during the sewing process can indicate that at that very moment, the seam of higher thickness is created, which in turn points out that seam pucker is created.

Table 4 shows the values of the ratio h/T_1 at sewing speed 1000 rpm for all tested fabrics. The values of the ratio h/T_1 confirm that this relationship may be a relevant indicator for the occurrence of seam pucker. The highest h/T_1 ratio of 0.95 is obtained for sample C, which has the highest seam pucker in both directions of 55.2% and 46.6% (table 3). Samples with a lesser h/T_1 ratio have a lower percentage of seam pucker. This is the case for fabric G which has h/T_1 values of 0.78 and 0.85, in the warp and weft direction, respectively, and seam pucker of 21.5% and 15.4%, in warp and weft directions.

The relationship of seam pucker (*SP*) and ratio h/T_1, in warp and weft directions, are presented in figures 4 and 5. The highest significant correlation was obtained between *SP* and h/T_1 ratio: 0.89 for warp seams and 0.82 for weft seams.

Table 4

DISPLACEMENT OF PRESSER FOOT AND RATIO h/T AT SEWING SPEED 1000 rpm

Fabric	h_1 (mm)	h_2 (mm)	h_1/T_1	h_2/T_1
A	0.64	0.64	0.89	0.89
B	0.66	0.65	0.80	0.79
C	0.55	0.55	0.95	0.95
D	0.60	0.60	0.88	0.88
E	0.67	0.71	0.86	0.91
F	0.70	0.71	0.85	0.87
G	0.61	0.66	0.78	0.85
H	0.79	0.81	0.88	0.90

Note: The indices 1 and 2 marked samples by warp and weft, respectively: *h* – the height of presser foot before and after the rising and declining movements in mm; T_1 – double thickness of fabric (two layers of fabric) in mm.

The graph in figure 4 shows that the seams in warp direction having the ratio h/T_1 of 0.85 and higher during the sewing process, obtained 30% and higher puckered seams. Therefore, monitoring pressure foot height at the throat plate level, at lower speeds, usually at the beginning of sewing and calculating the h/T_1 ratio, can provide relevant information, warning the user regarding the possibility of occurrence of puckered seams while sewing.

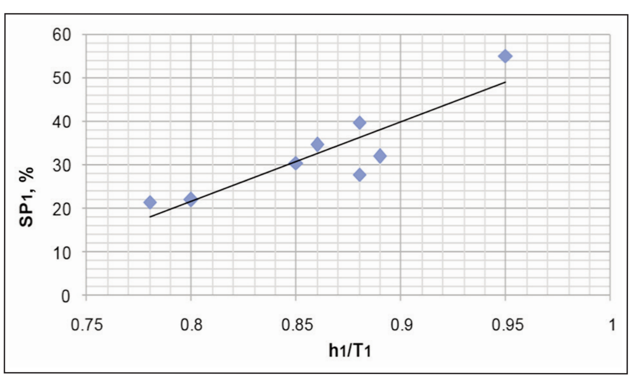


Fig. 4. Relationship of seam pucker and h_1/T_1 ratio, for seams in warp direction

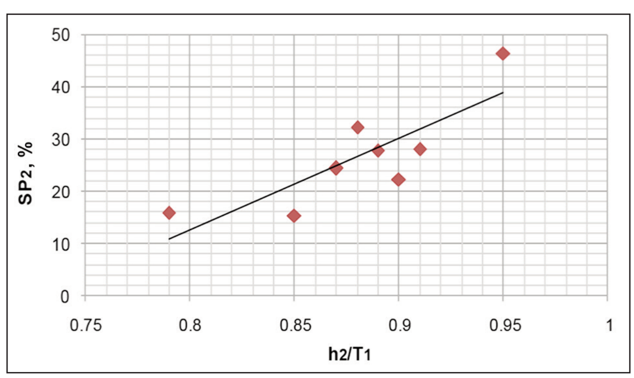


Fig. 5. Relationship of seam pucker and h_2/T_1 ratio, for the seams in weft direction

CONCLUSION

The relationship between seam pucker and presser foot displacement during the stitch formation cycle has been investigated for seams of class 1 made of woven fabrics for tailored garments.

The results show that warp seams show on average 6.3% higher pucker occurrence than weft seams. Fabric formability in seams developed in the weft direction is 7.6 times higher than in the warp direction. The highest linear correlation was found between the average formability and seam pucker in the warp direction.

Monitoring of the presser foot displacement during the stitch cycle formation showed that the maximum value of presser foot height varies as a result of the machine speed.

The value of presser foot height, before and after the raising and declining movements, at higher speeds obtained various values, due to presser foot bouncing, and does not correlate with seam pucker.

A significant correlation was found between seam pucker percentage and the ratio h/T_1 before and after the rising and declining movements of the pressure foot, at a machine speed of 1000 rpm. The higher value of the ratio h/T_1 can indicate the formation of seams with a high percentage of seam pucker occurrence. Therefore, monitoring h/T_1 values at lower sewing speeds can be used to detect the occurrence of seam pucker during the sewing process and it is expected that the concept can be applied to other types of textile materials.

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Authors:

DEMBOSKI GORAN[1], JANKOSKA MAJA[1], MIGUEL ANGELO CARVALHO[2]

[1]University “Ss. Cyril and Methodius”, Faculty of Technology and Metallurgy, Department of Textile Engineering,
Rudjer Boskovic 16, 1000 Skopje, North Macedonia
e-mail: goran@tmf.ukim.edu.mk

[2]University of Minho, School of Engineering, Department of Textile Engineering, Campus de Azurém
4800 - 058 Guimarães, Portugal
e-mail: migcar@det.uminho.pt

Corresponding author:

JANKOSKA MAJA
e-mail: maja@tmf.ukim.edu.mk