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Influence of Selected Machine and Material Parameters on the Stitch Length and Its Irregularity

Abstract
One of the main demands for sewing garment quality is good-looking seams, the appearance of which is greatly influenced by the stability of stitch length. The method and equipment for measuring stitch length in the seam are presented. The article reveals the influence of fabric tensile stiffness, friction force, and sewing speed upon the stability of stitch length. Experimental results evidently prove that the mean stitch length decreases and the stitch length variance increases as the fabric tensile stiffness grows. However, the mean stitch length increases and the stitch length variance tends to decrease as the fabric external friction grows. The rotational speed of the main shaft also has a great influence on the process. The increase in the rotational speed of the main shaft increases both the mean stitch length and the stitch length variance. Thus, in order to obtain good-looking seams it is very important to evaluate the forces acting in the sewing process, sewing speed, etc.

Key words: *stitch length, fabric tensile stiffness, variance, rotational speed, friction force.*

Introduction

The good appearance of seams is determined by the straightness of seam lines, thread tension, stitch density, and particularly by the stability of stitch length at certain intervals of the seam. Unstable stitch length is very evident during garment wear, especially when it is stitched in threads of contrasting colours.

An earlier analysis [1] showed that only a visually imperceptible deflection of stitch length is permitted in ready-made garments. It was determined that a deflection of 0.1 mm is noticeable at the distance of 25 cm for a stitch length greater than 1 mm. The quality control must be carried out not only visually, but also by comfortable and reliable measuring instrumentation.

The literature and patent analyses dealing with stitch length stability allowed us to state that this problem has not yet been fully solved, and only certain problems have been discussed [1-3]. In addition, the stability of stitch length is related to the mechanical properties of the fabrics and the sewing equipment. Thus, a high quality of garments can be obtained only by a complex solution of this important problem.

In the sewing process the garment is affected by various forces (Figure 1). In stitch formation, the material sewn is deformed, while the level of deformation is defined by the fabric tensile stiffness in the sewing direction. The garment sewn may undergo the action of all components of deformation starting with the reversible and up to the residual due to the garment mass, its uneven holding, acting acceleration of sewing machine parts, etc. At the same time, the relaxation process takes place in the material sewn. The same processes occur in sewing threads because the thread tension also varies during sewing.

Obviously, the ratio of reversible and residual deformation changes according to the magnitude of the acting forces. This means that, in general, the material sewn is affected by internal and external forces.

The parameters of sewing object, thread and pressing mechanism are shown in mechanical models in Figure 1. In this case, they describe the elasticity characteristics and viscosity of these elements.

Frictional forces play an important role in the stitch formation process. According to the friction force magnitude, the garment sewn may slip along the toothed plate during its shift, and later move under the influence of inertial force. In the analysis of friction mechanism, the internal and external friction of the garment sewn and of the thread may be marked out. The value of internal friction determines the relaxation process that takes place in the garment.

Thus, in order to move garment at a distance of one stitch length, the resultant force in this direction must be:

$$Q > F_1+F_2+R_1+R_2 \pm F_3 \qquad (1)$$

The range of acting forces determines the garment's shifting conditions, i.e. the stitch length. These forces are determined by fabric properties, i.e. by the tensile stiffness coefficient c_1 (Figure 1), whereas the internal and external friction are determined by the coefficient k_1 (Figure 1). These are mainly influenced by fibre and weave.

The influence of technological factors upon the stitch length has already been investigated [4], but the effect of fabric properties has not yet been evaluated. So this research is aimed at investigating the influence of some fabric parameters on the stitch length.

Experimental Methods

A lock stitch (Figure 2) consists of two threads, the upper and lower ones. A tangle of threads falls either to the right or the left. The correctly formed upper and lower tangles have to be inside the material sewn.

To facilitate the analysis, we carried out experiments with seam patterns as experts do while analysing seam quality. There were about 40 stitches in every seam. Several stitches were ignored at the beginning and the end of a seam, and about 30 stitches were used for the analysis.

Optical systems are widely applied for estimating the stability of an object form [4]. Computerised estimation of sewing objects may also be carried out on these images. The contact-free estimation of the sewing object is an advantage in industrial conditions.

The optical system for image acquisition consists of the video camera 1 (CCD-

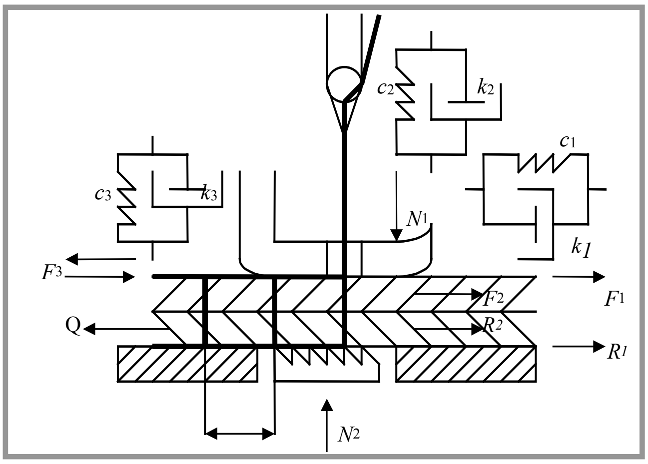

Figure 1. *The scheme of stitch formation and of acting forces: F_1, F_2 - external and internal friction forces of garment, F_3 - the inertial force of garment, R_1, R_2 - the load acting on the garment and the tensile force, N_1, N_2 - pressing forces, $c_1, c_2, c_3, k_1, k_2, k_3$ - the stiffness and viscosity coefficients of sewing object, thread and pressing mechanism respectively.*

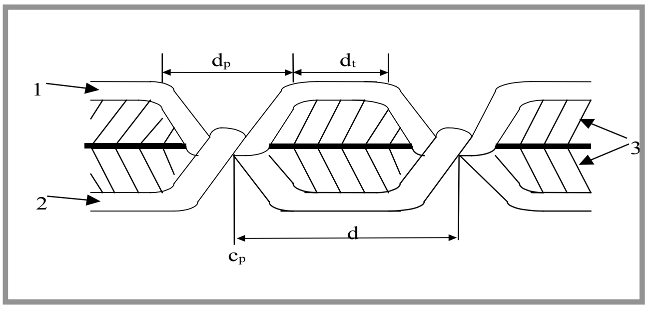

Figure 2. *Section view of lock stitch: 1 - upper thread, 2 - lower thread, 3 - materials sewn, d_t - length of a stitch, d_p - length of space between stitches, c_p - centre of spaces, d - approximate length of a stitch.*

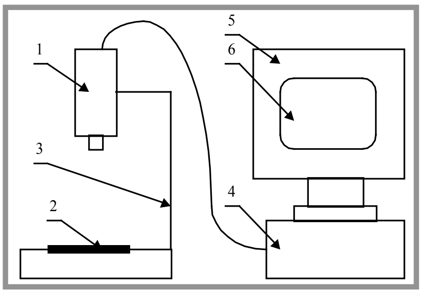

Figure 3. *Functional scheme of optical system: 1 - video camera, 2 - sewing object, 3 - special stand, 4 - personal computer (PC), 5 - monitor, 6 - display.*

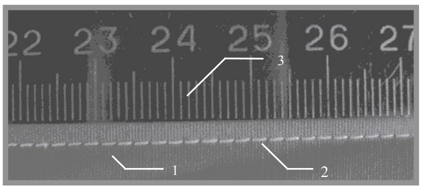

Figure 4. *Image of seam acquired using CCD camera: 1 - fabric, 2 - seam, 3 - ruler.*

30BP), which registers the image of the sewing 2 (Figure 3). The video camera is attached to a special stand 3 and it is connected to a personal computer 4 with a frame grabber card. On the display 5, the image 6 of the sewing 2 is presented. The image acquired using the optical system is presented in Figure 4.

The seam in Figure 4 is usually distorted, and in addition some parts of the seam are brighter while others are darker because of non-homogeneous lighting. The drawbacks of a camera are overcome by an ordinary scanner which has homogeneous lighting and higher resolution than a camera (stitches could be estimated up to a precision of 0.1 millimetre). Images acquired using an ordinary scanner (HP Scan Jet5p) had little distortion (Figure 5). However, an ordinary scanner cannot be applied in the industrial conditions, and can only be used for the seam pattern analysis.

The main steps of the algorithm for automatic detection of a seam are as follows:

- Interactive definition of a rectangular region of interest (ROI);
- Image smoothing along the seam;
- Detection of sequences of pixel with the maximum value in the seam cross section;
- Selection of the longest sequence without discontinuities;
- Detection of the remaining seam segments using tracking technique.

The definition of ROI is used to focus on the desirable seam. The user defines ROI by selecting a rectangular region of an image with a mouse. The spaces between stitches have lower pixel values (Figure 6, profile C). The seam can be detected incorrectly in these segments. Smoothing (low pass filtering) along the seam was used to reduce false detected points. After smoothing, the image was analysed as a set of seam cross sections. The maximum pixel value in each cross section was detected.

Most of these pixels (which values reach the maximum along the cross section of a seam) correspond to the centre of the seam (Figure 7, curve 1). However, there are some maximum values which correspond to noise or the bright spots of the fabric. Such bright spots cause falsely detected points of the seam (Figure 7, see peaks of curve 2). Therefore, a tracking technique was used to eliminate the falsely detected pixels.

The main idea of the tracking technique is as follows.
The pixels belonging to the longest sequence without discontinuities were selected. Discontinuity was defined as the difference $t(x+1)-t(x)\geq 2$, where x is the detected pixel position on the horizontal axis and t is the detected pixel vertical position.

Other points were tracked starting from the ends of the longest sequence. A non-linear procedure was developed to track the vertical position of a seam at every successive point x. Some short discontinuities on the seam still remained after the image smoothing along the seam. To avoid these discontinuities, the interval of tracking was selected every 15 pixels (i.e., the pixels of the image were examined at the interval along the vertical axis: $[t(x)-l, t(x)+l]$, $l=7$).

The algorithm described was adapted for detecting a bright seam on the dark material. If the material is brighter than the seam, the image was inverted. Next, the pixel values of the detected seam were analysed to estimate the parameters of stitches. Sometimes it is difficult to de-

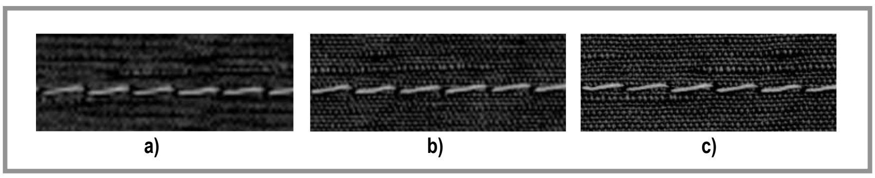

Figure 5. *Images of seams scanned using grey-scale format and different resolutions: a) 300 dpi, b) 600 dpi, c) 1200 dpi.*

tect spaces between the stitches because of the discontinuity of seam brightness and of additive noise (Figure 8; the local minimum values corresponding to the centres of spaces between stitches are marked by vertical lines). The low pass filter was applied to reduce this impact [5]. The filter mask was selected with a radius of 3 pixels. The automatic stitch detection algorithm was then applied. It included the following parameters:

- Estimation of the invisible length of a stitch;
- Detection of the stitches using the estimated length.

The signal under investigation had a periodical component. The frequency corresponding to a stitch length showed a peak in the signal spectrum. A discrete cosine transform (DCT) [6] was applied to evaluate the signal spectrum. The approximate length of a stitch was calculated as follows:

$$d = 2M/f_{max} \qquad (2)$$

where:
d - the approximate length of a stitch,
M - the length of the signal $t(x)$,
f_{max} - the width of the spectrum of the signal $t(x)$.

The estimated length d (Figure 2) was used to evaluate the approximate centres c_p of spaces between stitches. Then the centres were more precisely detected as minima in short intervals (Figure 8). The threshold was applied to estimate the length of stitches d_t and the spaces between them d_p. A threshold was calculated for every space:

$$t_t = 0.1(t_m - t(c_p)) \qquad (3)$$

where:
t_t - a threshold value,
t_m - the mean value of a signal $t(x)$,
$t(c_p)$ - the vertical position of a seam at the detected centre of the space c_p.

Thus, after the image of the seam acquisition, the length of the stitches or spaces between stitches is automatically measured. The various parameters of stitches and spaces between them were estimated. They included the mean value, the variation, and the difference between the maximum and minimum length of a stitch or a space.

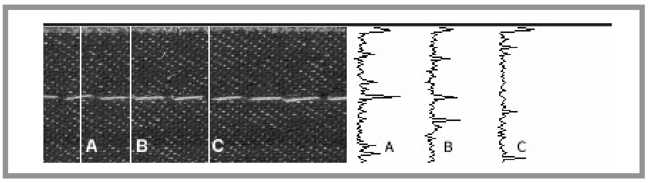

__Figure 6.__ Seam with marked cross sections A, B, C. On the right profiles of cross sections A, B, C are presented.

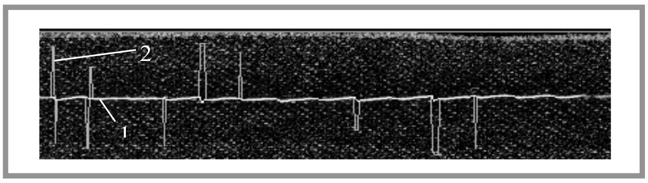

__Figure 7.__ The image of a seam after automatic seam detection. Curve 2 (peaks) marks the sequences with maximum pixel values. and curve 1 marks the corrected pixels, which values are maximal along the cross-section of a seam.

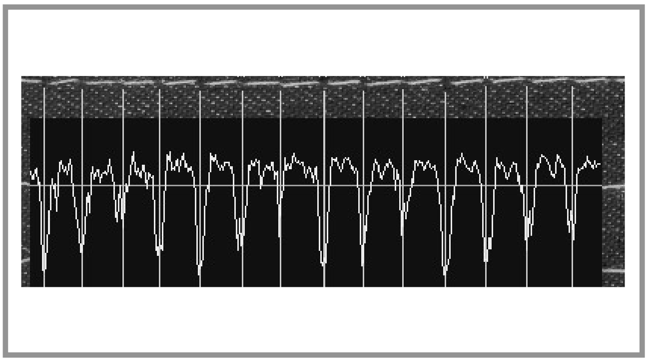

__Figure 8.__ The seam pixel values with the detected centres of spaces between stitches.

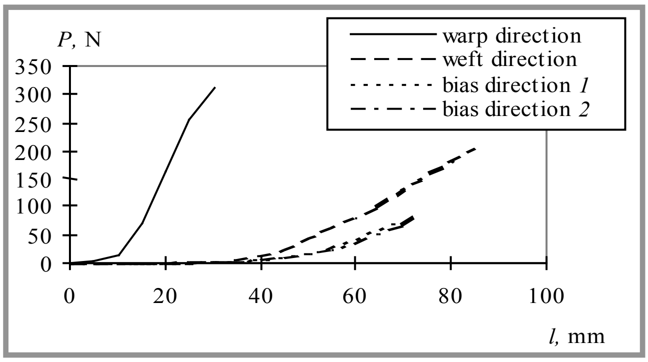

__Figure 9.__ Force-elongation curves of tested fabric at different directions: P - tensile force, Δl - extension.

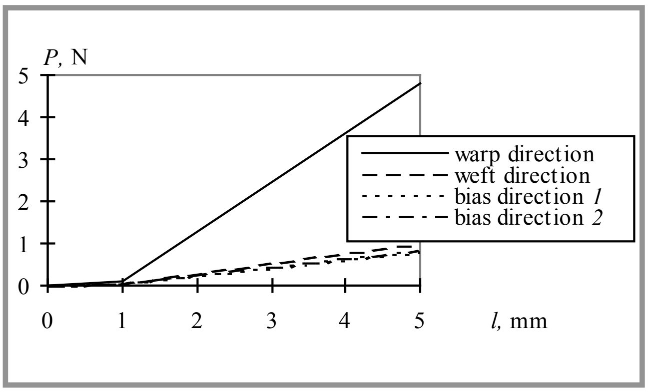

__Figure 10.__ The initial zone of force-elongation curves of the fabric: P - tensile force, Δl - extension.

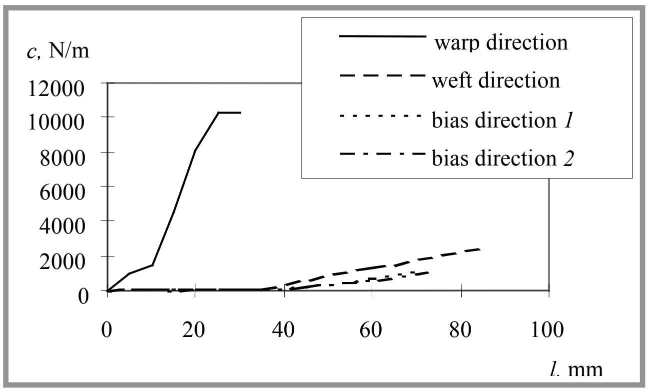

__Figure 11.__ The development of the fabric tensile stiffness: c - coefficient of tensile stiffness, Δl - extension.

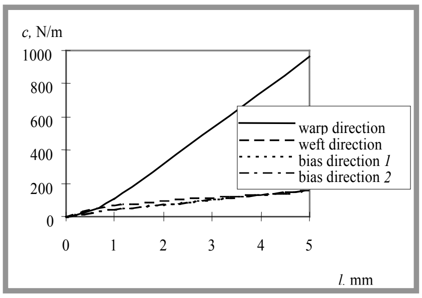

***Figure 12.** The initial zones of the development of fabric tensile stiffness: c - coefficient of tensile stiffness, Δl - extension.*

Investigation

The object of this research was the fabric for women's suits. Fabric specimens were prepared in four different directions, i.e. warp, weft and two bias directions: 1 - at 45° in respect to the warp direction; 2 - at 135° in respect to the warp direction. The fabric tensile stiffness coefficient c and the friction force F_{fr} were determined for all the directions mentioned.

The investigation was carried out at 9 different rotational speeds of the sewing machine's main shaft: 200 min^{-1}, 550 min^{-1}, 900 min^{-1}, 1250 min^{-1}, 1600 min^{-1}, 1950 min^{-1}, 2300 min^{-1}, 2650 min^{-1} and 3000 min^{-1}. The sewing was performed by a UNICORN one-needle lockstitch sewing machine.

The effect of fabric tensile stiffness upon the stitch length

For the investigation, 14 mm-width specimens were prepared from a twill weave fabric. This width of specimen was chosen in accordance with the width of the investigated garment part in the sewing machine. The initial zones of the force-elongation curves are shown in Figure 10. The dependencies of the fabric tensile stiffness coefficient (c=P/Δl) development (Figure 11) were determined on the basis of the force-elongation curves given in Figure 9.

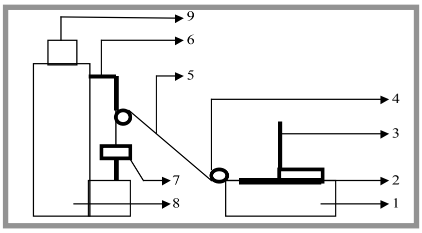

***Figure 15.** The arrangement of friction force determination: 1 - sewing machine, 2 - specimen, 3 - pressing foot, 4 - pulley, 5 - fixing rope, 6 - upper jaw, 7 - lower jaw, 8 - tensile testing machine, 9 - recording device.*

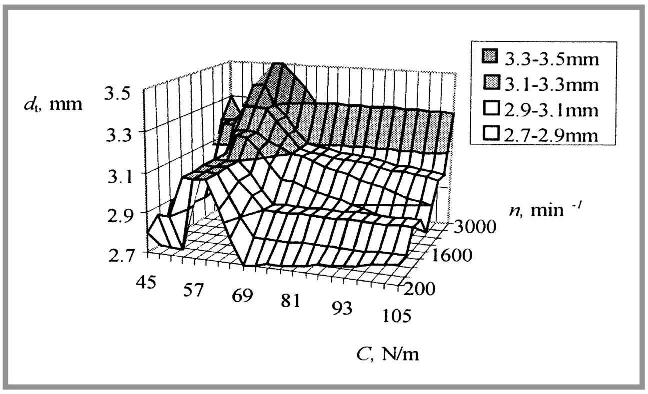

***Figure 13.** The mean stitch length (d_t) dependence versus fabric tensile stiffness coefficient (c) at various rotational speeds (n) of the main shaft.*

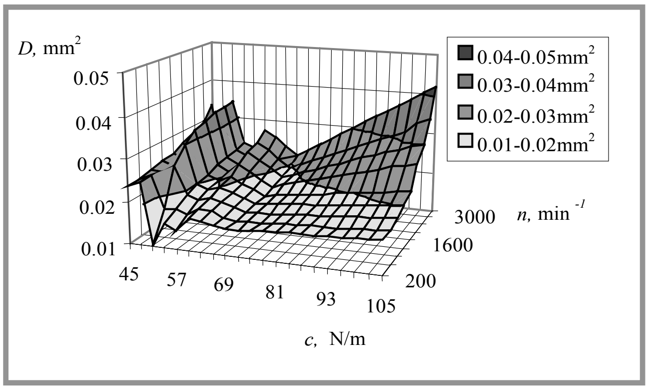

***Figure 14.** The stitch length variance (D) dependence versus fabric tensile stiffness coefficient (c) at various rotational speeds (n) of the main shaft.*

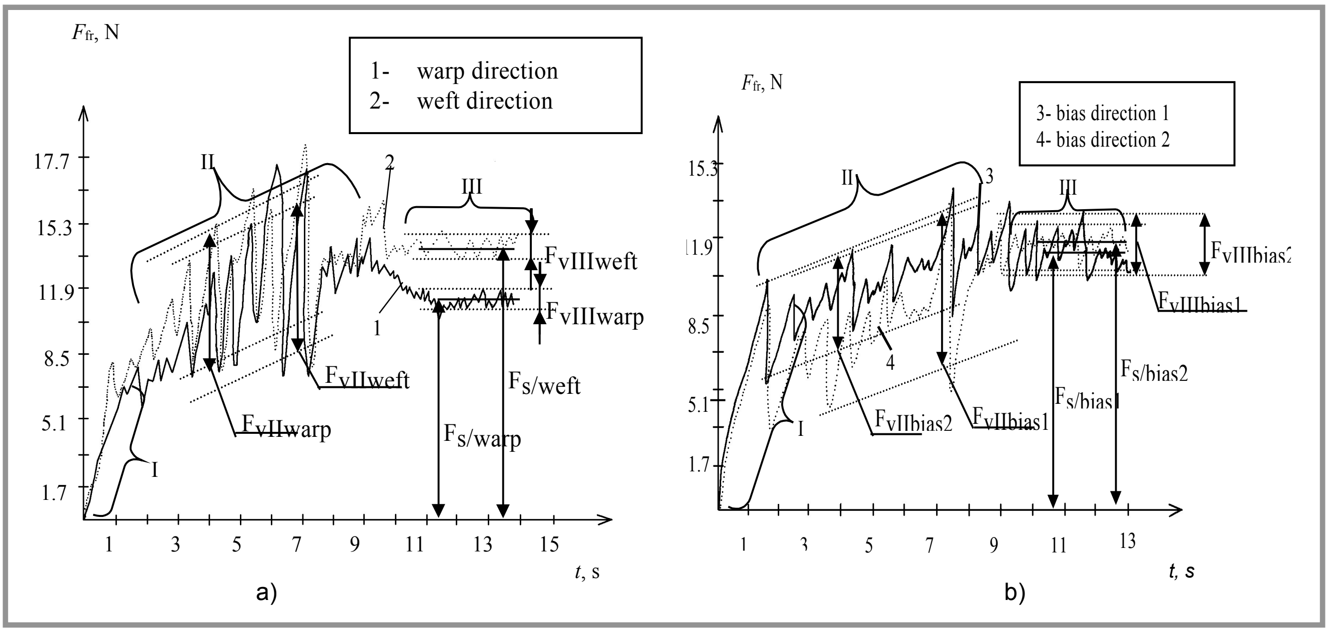

***Figure 16.** The development of fabric friction force F_{fr}: I - start of pulling, II - start of specimen slide, III - specimen slide; F_v - variable friction force, F_s- slide friction force a) 1 - in warp, and 2 - in weft directions, b) 3 - in bias 1, and 4 - in bias 2 directions.*

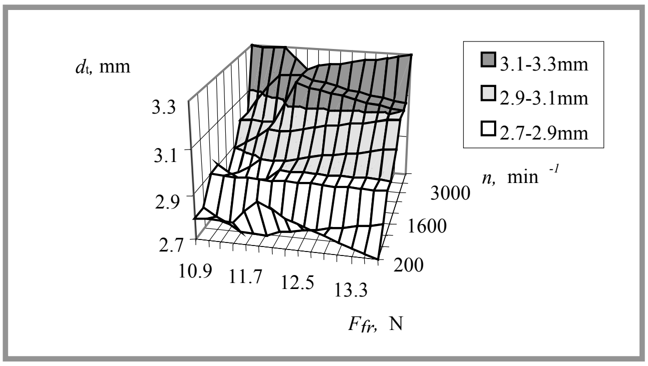

Figure 18. The mean stitch length (d_t) dependence versus the friction force (F_{fr}) at various rotational speeds (n) of the main shaft.

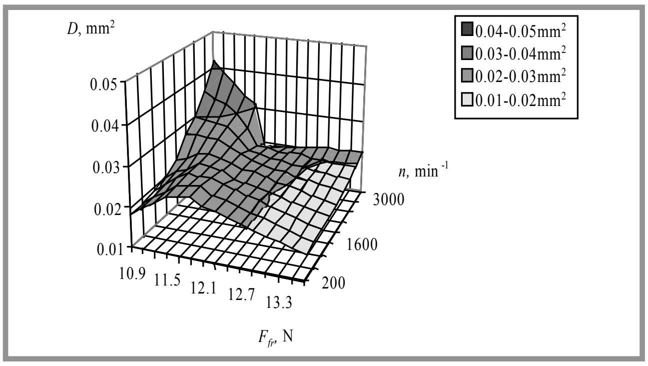

Figure 19. The stitch length variance (D) dependence versus the friction force (F_{fr}) at various rotational speeds (n) of the main shaft.

Experimental results proved that the tested fabric was stiffer in the warp direction. The values of the fabric tensile stiffness coefficient in weft and in both bias directions were almost the same, and rather low compared to the value in warp direction. The initial zones of the development of fabric tensile stiffness are shown in Figure 12.

The investigated fabric was stitched up. Stitch length measurement, determination of length mean value and variance etc. was performed according to the method described above. The stitch length dependence versus fabric tensile stiffness coefficient at different sewing speeds is shown in Figure 13. The plot clearly shows that the tensile stiffness coefficient value of 40-70 N/m significantly affects the stitch length. Besides, the stitch length shows no clear tendency to alteration. The stable decrease in stitch length is observed starting from the tensile stiffness coefficient value 70 N/m.

The results showed that the increase in the rotational speeds of the sewing machine's main shaft affected the stitch length; in other words, the mean stitch length considerably increased in all directions starting at sewing speed 1600 min^{-1}. Some of the stitch length alterations could be noticed visually, because in certain cases the difference reached up to 0.5 mm; for example, the mean stitch length in warp direction increased from 2.8 mm to 3.3 mm. The dependence of stitch length variance versus fabric tensile stiffness coefficient and the rotational speeds of the main shaft is shown in Figure 15.

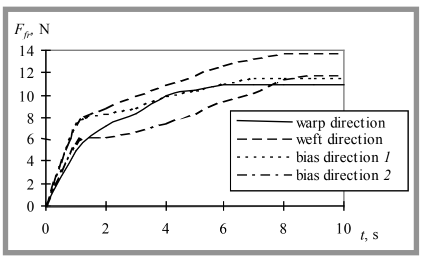

Figure 17. The approximated development of friction force F_{fr}.

As shown in Figure 14, a low fabric tensile stiffness coefficient (c=40-70 N/m) has an influence not only on the mean stitch length value but also on the stitch length variance . It is obvious that the increase in stitch length variance is stable at the increased rotational speed of the main shaft and fabric coefficient (starting from c=70 N/m).

The effect of friction force upon the stitch length

Curves of the friction forces acting on the sewing machine pressing foot and on the needle plate in all the directions mentioned of the tested fabric were obtained using the arrangement given in Figure 15. The fabric specimen 2 is pressed by the pressing foot 3 of the sewing machine 1. The specimen 2 is fixed by one edge to the rope 5 and is pulled out from under the pressing foot 3 over the pulleys 4 and 6 with the help of the lower jaw 7 of the tensile testing machine 8. The development of the friction force is registered by the recording device 9.

The development of the friction force versus testing time for all directions mentioned of the tested fabric is given in Figure 16. It is evident that the character of friction force development is diverse in different fabric directions. In the initial part of the development, the friction force increases sharply for all fabric directions. With time, the character of the friction force changes and it starts to gradually increase. Oscillations of friction force are especially distinct in warp and weft directions, where they reach the value of 10.9 N. In the bias direction 2, the maximum oscillation of friction force is lower (9 N), and 1 is 5.1 N in the bias direction. The character of the development becomes stable. The plot of the approximated development of friction force (Figure 17) shows that the stable friction force reaches its maximum value in weft direction, and its minimum value in warp direction.

To determine the effect of friction force upon the stitch length the tested fabric was stitched up. The dependence of mean stitch length at various rotational speeds of the main shaft upon the friction force is shown in Figure 18.

It is obvious that friction force has a significant effect upon the mean stitch length. The latter decreases at the lowest rotational speed of 200 min^{-1} and greater friction force. At the higher rotational speeds (n>550 min^{-1}), the mean stitch length remains more stable in the range of acting friction force. With an increase in both the rotational speed of the main shaft and friction force, the mean stitch length also increases. At the maximum speed of 3000 min^{-1}, the stitch length tends to increase only at a higher friction force. The dependence of stitch length variance versus the sewing speed and magnitude of friction force is shown in Figure 19.

It is evident that the highest stitch length variation is at the lowest friction force and highest rotation frequency of the main shaft. With the increase in friction force, the stitch length variance decreases, but with the increase of rotational speed of the main shaft, the stitch length variance increases also.

Conclusions

- The automatic algorithm presented saves time in quality estimation in the sewing process.

- The reliability of the automatic algorithm was similar to manual estimations, and mostly depended on the scanner or video camera resolution.
- The mean stitch length decreases as the fabric tensile stiffness coefficient grows. Stitch length is very unstable at low fabric tensile stiffness coefficient.
- The influence of the fabric tensile stiffness coefficient on the stitch length variance manifests analogically. With an increase in the fabric tensile stiffness coefficient, the stitch length variance increases also.
- In general, the mean stitch length increases and the stitch length variance decreases with an increase in friction force.
- At the higher sewing speed, both the mean stitch length and the stitch length variance reach maximum values.
- In order to create a good-looking seam, it is very important to evaluate the forces acting in the stitch formation process. The value of these forces and the character of their development is determined by fabric properties, sewing speed etc.
- These results can be applied for research purposes or quality control in laboratorial and industrial conditions.

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The University of Bielsko-Biała

the Youngest Polish University with a Textile Faculty

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Dean of the Faculty of Textile Engineering and Environment Protection and Director of the Institute of Textiles and Polymer Materials: Professor Stefan Boryniec, Ph.D., D.Sc.

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