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MODELLING OF THE SEWING THREAD CONSUMPTION OF 602 COVER-STITCH BASED ON ITS GEOMETRICAL SHAPE

MOUNA GAZZAH, FAOUZI KHEDHER, BOUBAKER JAOUACHI*

TEXTILE ENGINEERING LABORATORY, UNIVERSITY OF MONASTIR-TUNISIA

ABSTRACT

This study deals with a geometrical model of 602 cover-stitch plain used to seam decorative and esthetical parts of garments such as T-Shirts, denim pants, jackets etc. For industrials, the consumed sewing thread, as one of the most important components of sewed garments, remains a difficult problem for different reasons. First, the unsuitable used method to calculate the needed thread length value to seam garment regards different hypothesis. Second, the high waste percentage caused during different seam steps, which allows us to obtain the uncertain consumption value. Based on 602 cover-stitch's geometrical shape, a geometrical model to calculate the relative consumed sewing thread length has been derived. This developed geometrical model is successfully established mathematically considering different significant parameters such as stitch length, stitch density, sewing thread thickness and fabric thickness and interlacing. To improve findings, the proposed model was verified for 30 samples by comparing actual thread consumption value with predicted one. In fact, this model predicts the thread consumption with 97.96% accuracy. The consumed amount to seam garment part using 602 cover-stitch can be widely predictable and useful in the experimental area of interest.

KEYWORDS

Consumed thread; 602 cover stitch; geometrical model; sewing thread, influential parameters.

Abbreviations

$C_{st\,(602)}$(cm): Total consumption value of coverstitch type 602
C_{Sti1} : Consumption value of the first sewing thread
C_{Sti2} : Consumption value of the second sewing thread
C_{cs} : Consumption value of the third covering sewing thread
y_1 : First part of length surrounding the second sewing thread of needle above the assembly
y_2 : Second part length surrounding the first sewing thread of needle above the assembly
C_{lo} : Consumed looper thread length
Th_{f1} : Thickness of one fabric
Th_{f2} : Thickness of 2nd fabric
Th_f : Thickness of all assembled fabrics
α : The second angle stitch thread inclination
β : The first angle stitch thread inclination
B_r : Breadth of stitching seam equal the distance between needles

* : Corresponding author. Email : boubaker.jaouachi@gmail.com

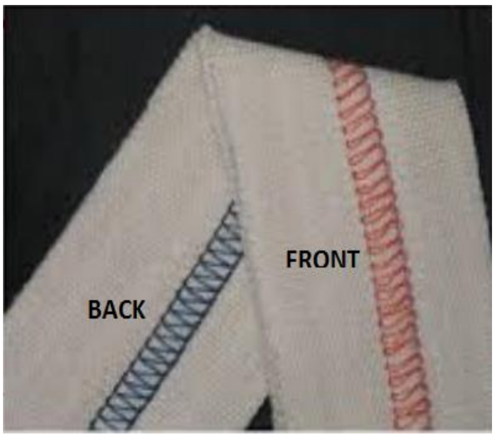
$\boldsymbol{d}$: Diameter of the sewing thread
$\boldsymbol{d_1}$: Diameter of the first sewing thread
$\boldsymbol{d_2}$: Diameter of second sewing thread
$\boldsymbol{L_{Sea}}$: Seamed length expressed in centimetre. If the seamed part of garment have a length equals to 10 cm, then the$\boldsymbol{L_{Sea}}$=10cm
$\boldsymbol{l_s}$: Length value of one stitch determined by dividing 1cm (or$\boldsymbol{L_{Sea}}$) by the N number of seamed stitches.
$\boldsymbol{l_i}$: Length of consumed thread of the looped for the second stitch
$\boldsymbol{N}$: Number of stitches along $\boldsymbol{L_{Sea}}$equals to 10 cm length.
$\boldsymbol{\delta}$: Looped thread angle inclination between two consecutive needle stitches
$\boldsymbol{\gamma}$: Angle of looped thread part inclination to tie the two developed chainstitches.

Introduction

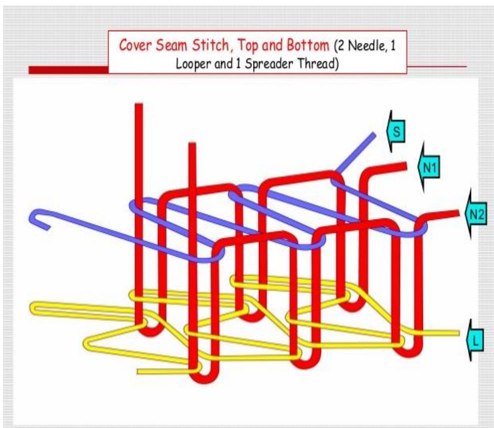
Sewing thread is an essential component material required for garment manufacturing. It is useful for overall seaming steps to stitch and decorate garment purposes such as embroidery. Sewing thread consumption affects not only the quality and the appearance of seamed garments but the manufacturing's productivity also (Abher R, Sheraz A, Mohsin M, Ahmad F & Afzal A, 2014). Buzov et al. (Buzov, Modestova, &Alymenkova, 1978) considered that poor sewing thread can greatly increase production costs, as they cause frequent stoppages of sewing machines. Furthermore, at the industrial's point of view, there is no accurate technique which can quantify the suitable number of sewing bobbins per garment. Several reasons can explain this difficulty of carrying out the suitable amount of seamed thread. First, some used hypothesis can widely help researchers to find estimative values of consumption only. Second, some significant and influential parameters seem not considered to determine the suitable sewing thread amount such as the compressibility of seamed materials, thread extensibility, etc. (O'Dwyer & Munden, 1975, Ukponmwan, Mukhopadhyay & Chatterjee, 2000, Webster, Laing &Niven, 1998). Finally, the complexity of the sewing thread consumption presents different variables which should be considered simultaneously to widely determine the consumed length. Recently, the problem of excessive thread consumption in sewing operations has become more critical and has occur a high interest due to the increases in sewing speeds and the advent of both synthetic fabrics and threads (Jaouachi & Khedher, 2013). Moreover, to provide a better-quality of sewing thread and high appearance of seaming fabrics some researchers used different techniques were conducted. Based on a statistical analysis, Fan & Leeuwner (Fan & Leeuwner, 1998) identified the important physical and mechanical properties of sewing threads related to seam appearance. Their results showed that a quantitative relationship between these properties and the performance rankings of sewing threads in terms of seam appearance was established. Behera et al. (Behera, Chand, Singh &Rathee, 1997) determined and analysed the sewing thread performance in terms of seam efficiency, pucker, slippage and needle cutting index in the light of the dimensional and mechanical properties of the fabric, thread and seam itself. Indeed, the breaking strength and elongation of the fabric and sewing thread had an excellent correlation with seam efficiency. However, Miyuki et al. (Miyuki Mori & Masako Niwa, (1994) reported and discussed the importance of the mechanical properties of sewing thread and its interaction with the sewing process. It was reported that seam strength depends on the sewing thread properties (Prabir, 2011,Jonaitiene&Stanys, 2005). Most of the researchers considered that the tensile strength of the sewing threads reduces after stitching (Ajiki&Postle, 2003; Geršak&Knez, 1993; Midha, Kothari, Chatopadhyay, &Mukhopadhyay, 2009; Sundaresan, Hari, &Salhotra, 1998). Several reasons are reported in the literature such asthe structural disintegration, the loss in fibre strength and the surface wear (Sundaresan, Hari, &Salhotra, 1997; Sundaresan, Salhotra, &Hari, 1998). Therefore, it was reported that the tensile properties of sewing thread have a bearing with the fabric characteristics (Midha, Kothari, Chattopadhyay, &Mukhopadhyay, 2010). Some of the researchers tried to find out the relationship between sewing thread properties and other factors such as seam pucker and seam strength (Dobilaite&Juciene, 2006; Jonaitiene&Stanys, 2005; ZerventÜnal, 2011). In fact, to achieve a good appearance as well as the seam properties, different parameters tied to sewing machines, stitching plain geometries, fabric characteristics and yarn structures are investigated in the literature surveys.Alagha, J. Amirbayat& I. Porat(Alagha, Amirbayat&Porat, 1996) are compared the effect of sewing variables and fabric parameters on the shrinkage of chainstitch (ISO 401) seams sewn by two different thread feeding systems: conventional method and positive feed. Besides, properties of sewing thread composition affect the consumption behaviours. Cotton threads were found to be most suitable for sewing denim from a seam puckering point of view. On the other hand, polyester threads were more prone to develop seam pucker.Behera et al. (1997). The effect of fabric tightness and certain thread properties like its size, coefficient of yarn-metal friction, twist direction, number of piles, type of fibre and fibre denier on strength reduction has been studied and found to influence the severity of strength reduction of the thread (Sundaresan, Salhotra&Hari, 1998). The evaluation of sewing thread consumption value has been a subject of interest for some studies during the last few years. Indeed, different mathematical models have developed regarding the consumed sewing thread calculations of different stitch classes (301, 401, 504 and 516) by using different techniques such as geometrical modelling, fuzzy logic theory, regression analysis, artificial neural networks, and Taguchi design method (Chen, Zou& Du, 2001, Jaouadi, Msahli, Babay & Zitouni, 2006; Jaouachi, Khedher & Mili, 2012; Jaouachi & Khedher, 2013; Rashed, Sheraz, Mohsin, Ahmad & Afzal, 2014).Recently, geometrical models for lockstitch class 301, the simplest type of stitch, aredesigned and derived by Rashed et al. (Rashed, Sheraz, Mohsin, Ahmad & Afzal, 2014) and Ghosh & Chavhan, (Ghosh & Chavhan, 2014). Similarly, as this previous stitch kind the coverstitch type 602 is very commonly used in garment manufacturing. In the present work, a geometrical model has been proposed for prediction of thread consumption based on original cross-section of chainstitch seam for woven fabrics.

Materials and Methods

Stitch types are classified into six classes ranged from Class 100 to Class 600 depending on the configuration and the mechanism of entanglement and interlacement of threads. The most commonly used stitch types are lockstitch (Class 300) and chainstitch (Class 400). However, other important classes are used for clothing are overlock (Class 500) or top and bottom cover stitch (Class 600). In fact, the various stitch types differ from each other in terms of the strength, extensibility or elasticity and security offered. However, a judicious and suitable selection of type has to be made based on the requirements of the seam achieving one or many performance goal(s) previously mentioned. This study was focused on cover stitch type 602 (Figure 1a) which used to offer elastic, decorative and secure seam of specific parts of garments.



(a) :The front and back part of the 602 stitch.



(b): The cover stitch threads (Lauriol,1989)

Figure 1: The coverstitch type 602

Class 602 is a 4 thread stitch with 2 needle threads, 1 looper thread, and 1 top covering thread (Figure 1b).

Cover stitches 602 is very strong and elastic stitches used extensively by manufacturers of knit garments to cover raw edges and prevent raveling. They may be used for attaching flat knit (Figure 2) or ribbed knit collars (Figure 3). When the upper spreader thread is removed from these stitches they become 406 and 407 types, respectively.

Figure 2: Flat knit collars

Figure 3: Ribbed knit collars

. A coverstitch offers stretch behaviour of garment parts with the maximum extensibility of the fabric such as think arobic wear, fleece, sweatshirt fabric, elastane (Lycra, Spandex, Dorlostane, etc.) and super stretchy knit fabric.

A sewing chainstitch machine type Brother 252-F was used for stitching woven fabric samples. For this geometrical and experimental analysis, one types of sewing threads was used. Therefore, only density of stitches per unit of length as an influential factor was considered and investigated in this paper. Three stands for two first sewing needles threads, covering system thread and the third one is for looper thread. The linear density or count of all mentioned thread (100 PES) is 60tex. In addition, samples were prepared and 10 cm seam length of each sample was cut and sewn within suitable adjustments requested by the Brother 252-F manufacturer's sewing machine. Overall experimental conditions are kept constant to obtain the similar seamed samples. Then, the seam was unravelled to get the needle, the covering and looper threads consumed in 10 cm length. After that, the thread was weighted and its diameter as well as its length was determined by calculation.
The woven fabric used for this study was 100% cotton woven fabric. There are two parts of this research. First of all a geometric model for the sewing thread consumption calculation was derived. The model was based on the geometric shape of the 602 stitch. Second, samples were prepared by varying the most influential input (stitch density) only. The other parameters such as material thickness (equals 1mm) and sewing thread count, number of plies (2 plies only) are kept constant as previously mentioned. Overall samples were conditioned for 24 h in standard atmospheric conditions. The sewing thread was, then, unravelled carefully for a specific seam length (100mm). After that, the unravelled sewing thread was weighted or measured to quantify experimentally the consumed length used during seam process. Finally, the consumption was determined by using the weight and count of the thread.

Geometric Model of 602 Coverstitch

By investigating the shape of 602 coverstitch, it was remarked that this shape can be geometrically modelled. Different parts can be separately investigated to successfully calculate the total amount of the stitch during seaming. A double stitch consists of complex interlacing of looper and needle threads. Figure 1 represents the different parts of a 602 coverstitch.
So, sewing thread consumed to make a single stitch can be calculated by using Equation (1):

$$\boldsymbol{C_{st\,(602)}} = \sum_{i=1}^{i=4} \boldsymbol{C_{sti}} \quad 1$$

$$\boldsymbol{l_s} = \boldsymbol{L_{Sea}}/\boldsymbol{N} \quad 2$$

Consumed Needle Thread Length of Coverstitch Seam type 602

Figure 4 shows the stitch configuration of cover stitch seam type 602 ensured similarly by the two needles threads. According to Figure 3, it can be remarked that the needle thread seamed ($\boldsymbol{C_{Sti}}$) is equals to the sum of two needle lengths, $\boldsymbol{C_{Sti1}}$and$\boldsymbol{C_{Sti2}}$. Indeed, the same configuration is repeated per unit simultaneously by the two needles used.

Figure 4 represents the looper thread trajectory. This view presented how it is enveloped the needle threads using right or left side of stitch.

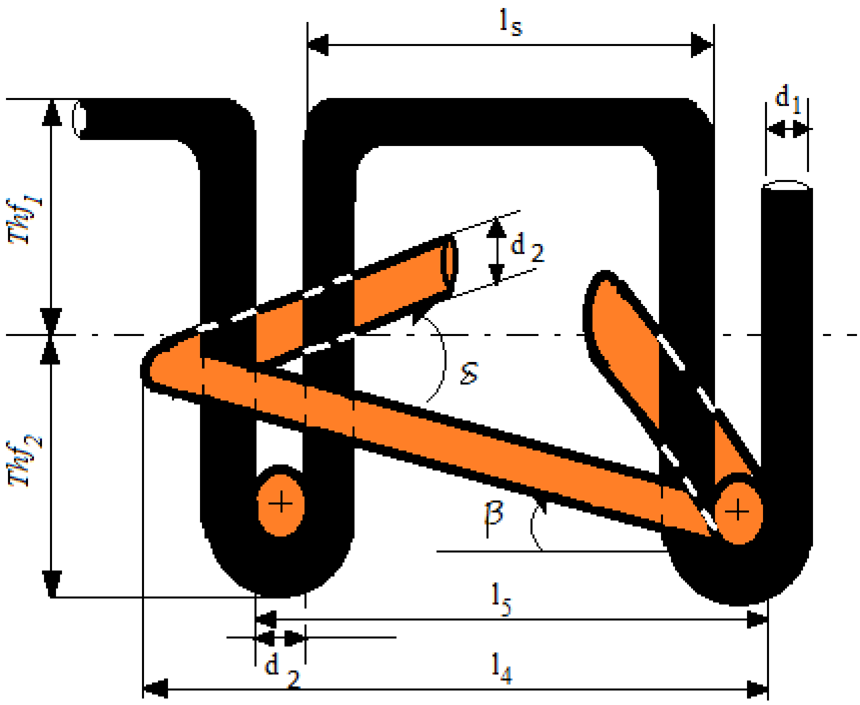


Figure 4: Geometric shape of the needle stitching according to the coverstitch type 602.

Thus, when $d_1 = d_2 = d$, the calculation of the needles consumption is given as mentioned in Equation 3.

$$\boldsymbol{C_{Sti} = N \times [4 \times (Th_{f1} + Th_{f2}) + 2 \times l_s + 6\pi d]} \qquad 3$$

Where:

$\boldsymbol{d}$**:** Diameter or thickness of sewing thread. It is expressed in centimetre and determined by Seyam and El Sheikh, (1994) as function of linear density ($\boldsymbol{tex}$) of the sewing thread as follow:

There are always some conditions of constants used by Seyam and El Sheikh, However, in our case of interest, we have used the same conditions as well as in some other literature of survey. The yarns used are ranged inside the same one used by Seyam and El Sheikh in their study based on some hypothesizes. That is why; the formula or equation 5 is adopted to solve the geometric shape consumption used coverstitch type 602. The constant 251.37 is available for some yarn densities compositions, diameters, etc.

To calculate a circular yarn diameter, the following general equation suggested in literature (Seyam and Sheikh, 1994) was used:

$$\mathrm{d(inches)} = \frac{1}{29{,}30\sqrt{\varphi \rho_f N}} \qquad 4$$

Where φ; yarn packing fraction (ration of yarn density to fiber density), ρ_f, fiber density; N, yarn count in cotton system.

The yarn packing fraction is a function of yarn structural paramerters (twist level, fiber diameter, spinning method,…).

The yarns used are ranged inside the same one used by Seyam and El Sheikh in their study.

That is why the equation 5 is available for the yarn diameter or thickness of sewing thread. It is expressed in centimetre and determined by Seyam and El Sheikh, (1994) as function of linear density (tex) of the sewing thread as follow:

$$\mathrm{d(cm)} = \frac{1}{251{,}37} \times \sqrt{\mathrm{tex}} \qquad 5$$

$$\boldsymbol{N} = \frac{\boldsymbol{l_{sea}} \times \boldsymbol{n_b}}{\boldsymbol{l_b}} \qquad 6$$

$\boldsymbol{l_{sea}}$:Length of seamed part of cloth;
$\boldsymbol{n_b}$**:** Number of basic stitches regulated along basic length equals 1 cm
$\boldsymbol{l_b}$**:** Basic length (1cm)

Geometrical Calculation of Consumed Cover Sewing Thread, $(\boldsymbol{C_{cs}})$of Coverstitch Seam Type 602
Figure 4 indicates the actual seam configuration and the positions of interlacing point formed by needle and covering system threads. Even though, Figures 4 depicts cross sections of the interlacing point of 602 coverstitch to cover the realized seam between needle and the covering system threads.

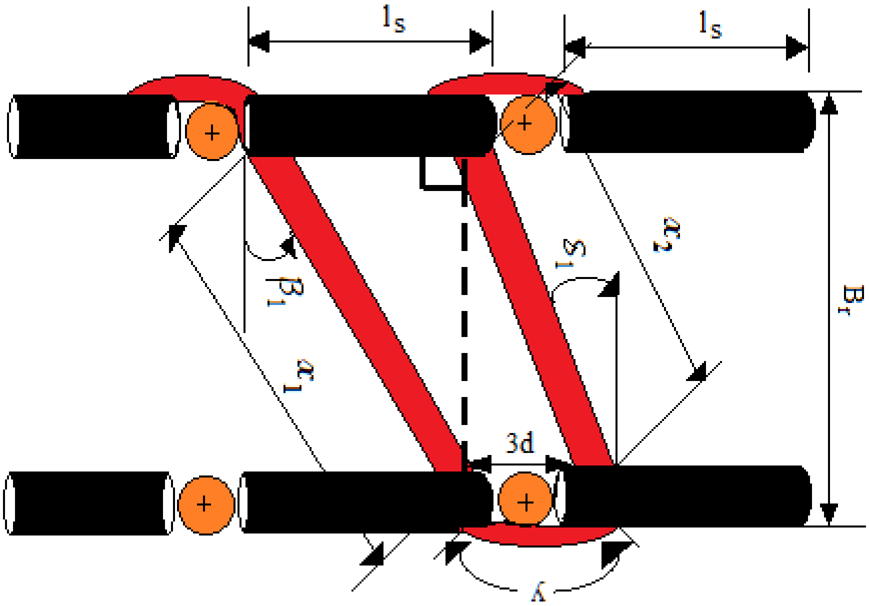


Figure 5: Geometric interlacing of needle and covering system threads in coverstitch type 602: Covering configuration along the breath seam.

Stitch breadth will depend on the thickness of the sewn material (Rasheed et al., 2014). To calculate the thread consumption per unit length, this equation was multiplied with the stitch density. So, Equation (5) can also be written as:

$$\boldsymbol{N_{(602)}} = \frac{\boldsymbol{l_{sea}} \times \boldsymbol{N_{bs}}}{\boldsymbol{BSL}} \qquad 7$$

Where:
$\boldsymbol{N_{(602)}}$: Number of stitches calculated to carry out the theoretical consumption value of sewing thread using coverstitch type 602 regarding the sewn garment part length,
$\boldsymbol{l_{sea}}$: Length of the seamed part in garment,
$\boldsymbol{N_{bs}}$: Stitch density along basic length or number of stitch per unit of length (equal to 1cm) adjusted voluntary by user in cover sewing machine (class 600),
$\boldsymbol{BSL}$: Basic seam length which equals 1centimeter.

Based on geometric shape of 602 coverstitch type, the calculation of the consumed thread per unit to cover the seamed parts can be easily carried out.Indeed, consumed amount relative to the cover part on chainstitch type 602 is made up of two sewing threads. One of them comes from the needle and the other from the covering system. Sometimes threads having same count are used, while in some cases, threads having different counts are also used. Thread consumed in covering can be calculated by using the following Equation 6. Furthermore, to calculate the thread consumption per unit length (relative to 10 cm) to cover seamed parts, Equation 6 can also written as follow:

$$\boldsymbol{C_{CS\,(2stitches)} = 2y + 2x_1 + 2x_2} \quad 8$$

Where$\boldsymbol{y}$(see Equation 7) represents the lateral length of interlacing cover thread with needle in the board of seam configuration. $\boldsymbol{x_1}$is the first part of one stitch cover length per unit as mentioned in Equation 8. However, $\boldsymbol{x_2}$ represents the second part of cover length per unit. This length value is totally different($\boldsymbol{x_1 \neq x_2}$) for the first part one (see Equation 8).

$$\boldsymbol{y = 3 \times \pi \times d_1 = 3 \times \pi \times d_2 = 3\pi d} \quad 9$$

$$\boldsymbol{x_1^2 = \left(l_s^2 + B_r^2\right) \Rightarrow x_1 = \sqrt{\left(l_s^2 + B_r^2\right)}} \quad 10$$

$$\boldsymbol{x_2^2 = \left((3d_1)^2 + B_r^2\right) \Rightarrow x_2 = \sqrt{\left((3d)^2 + B_r^2\right)}} \quad 11$$

Incorporating known these previous expressions determining the covering parts (along two stitches) and putting the all equations (Equations 7-9) in Equation 6, the consumption value of the sewing thread to cover seam using coverstitch type 602 can be as follow:

$$\boldsymbol{C_{cs(2\,stitches)} = 2 \times \left[\sqrt{\left(l_s^2 + B_r^2\right)} + \sqrt{\left((3d_1)^2 + B_r^2\right)} + 6\pi d\right]} \quad 12$$

Stitching is also used on some incompressible or relatively less compressible materials (e.g. leather). In that kind of materials, the thickness of materials can be measured with the help of a micrometer or vernier callipers. For seamed part measuring$\boldsymbol{l_{sea}}$, N stitches are depicted and the cover thread consumed in interlacing when $d_1 = d$ can be calculated by using the following Equation:

$$\boldsymbol{C_{cs} = N \times \left[\sqrt{\left(l_s^2 + B_r^2\right)} + \sqrt{\left((3d)^2 + B_r^2\right)} + (6\pi d)\right]} \quad 13$$

This equation can be available for different diameters of threads having the same linear density value. In case of the different used linear densities, the expression of the consumption part should consider this detail to carry out the suitable amount. Similarly, when the breadth and the length of stitch per unit changed, the consumed thread length varied.

Geometrical Calculation of looper Sewing Thread Consumption, $(\boldsymbol{C_{lo}})$ of Coverstitch Seam Type 602

Regarding the interlacing of looper thread within those of needles, the configuration reflects that the consumed thread increases widely the total consumption of the coverstitch type 602. Moreover, this part of work, Figure 5 tackles the different and repetitive geometric shapes that have a bearing on the high consumed amount realized by the looper system during seaming process.

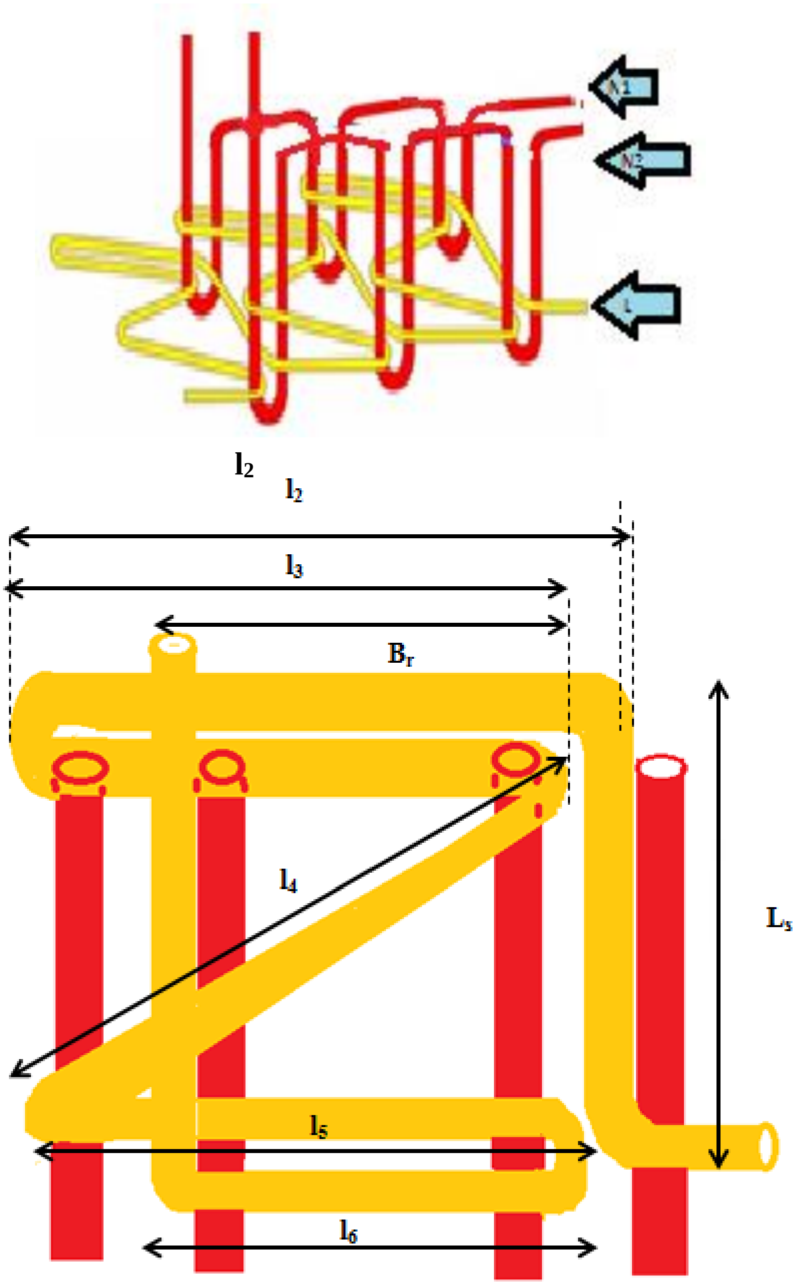


Figure 6: Geometric shapes simulating the interlacing threads between those of needles and looper systems.

Based on the two stitches length used, the consumption value of the lower looper $\boldsymbol{C_{lop}}$ can be given by the Equation below:

$$\mathbf{C}_{\boldsymbol{lo}} = 2 * \sum_{\mathrm{i=1}}^{\mathrm{i=6}} \mathbf{l_i} \qquad 14$$

Therefore, Equations 15-20 depict the all expressions of the individual lengths $\boldsymbol{l_i}$. They are differently measured due to their different shapes determining the consumed thread. As shown in Figure 5, they are interlaced by looper and needles along two consecutive stitches.

$$\boldsymbol{l}_2 = \boldsymbol{4d} + \boldsymbol{B}_r \qquad 15$$

So, the expression of $\boldsymbol{l}_3$ is given by Equation 16 as following:

$$\boldsymbol{l}_3 = (\boldsymbol{l_2} - d) = \boldsymbol{B}_r + 3d \qquad 16$$

$$\boldsymbol{l}_5 = \boldsymbol{l_3} = \boldsymbol{B}_r + 3d \qquad 17$$

$$\boldsymbol{l}_6 = \boldsymbol{l_3} - 3d = \boldsymbol{B}_r \qquad 18$$

Nevertheless, Figure 7 shows the geometric shape of the interlacing oblique part ($\boldsymbol{l_4}$) of looper thread mentioned above. To determine the value of the consumed thread in this zone, the schematic distances are given in Figure 7 allowing exactly the geometrical calculation of the correspondent amount.

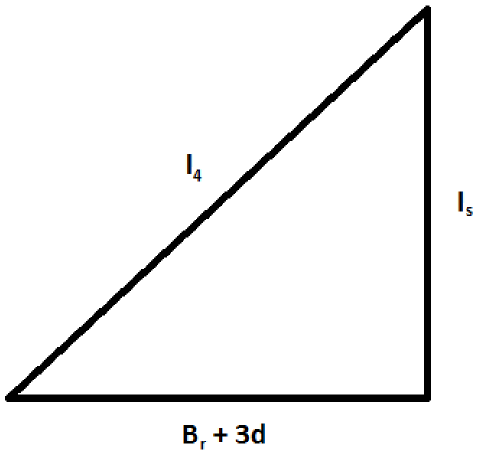


Figure 7: Geometric configuration to determine l_4 value.

Incorporating known of the breadth and the diameter of the contributed lengths, the $\boldsymbol{l_3}$part can be easily founded. The relative equation of seaming breadth using coverstitch type 602 as function of geometrical parameters along two stitches when $d_1 = d_2 = d$ can be depicted as following:

$$\boldsymbol{l_4} = \sqrt{(\boldsymbol{3d} + \boldsymbol{B_r})^2 + \boldsymbol{l_s}^2} \qquad 19$$

Regarding Equation 12 mentioned above, the expression of the consumed thread during two stitches can be written (see Equation 20) as follow:

$$\mathrm{C}_{lo\,(2stitches)} = \mathbf{2} \times \left[\boldsymbol{l_s} + \mathbf{8}\,\boldsymbol{B_r} + \mathbf{10}\,\boldsymbol{d} + \sqrt{(\boldsymbol{3d} + \boldsymbol{B_r})^2 + \boldsymbol{l_s}^2}\right] \quad 20$$

For N stitches along seamed length,$\boldsymbol{l_{sea}} = \mathbf{10cm}$,the amount of looper thread using 602 coverstitch type is derived using Equation 21:

$$\mathrm{C}_{lo(N\,stitches)} = \boldsymbol{N} \times \left[\boldsymbol{l_s} + \mathbf{8}\,\boldsymbol{B_r} + \mathbf{10}\,\boldsymbol{d} + \sqrt{(\boldsymbol{3d} + \boldsymbol{B_r})^2 + \boldsymbol{l_s}^2}\right] \qquad 21$$

The total consumed thread value relative to$\boldsymbol{l_{sea}}$can be expressed geometrically using Equation 22:

$$\boldsymbol{C_{st\,(602)}} = [\boldsymbol{C_{sti}}] + [\boldsymbol{C_{cs}}] + [\boldsymbol{C_{lo}}] \qquad 22$$

If $\boldsymbol{Th_{f1}} \neq \boldsymbol{Th_{f2}}$, the expression to calculate geometrically the consumed amount of sewing thread using coverstitch 602 can be given by Equation 23.

$$\boldsymbol{C_{st\,(602)}} = [\boldsymbol{N} \times [\mathbf{4} \times (\boldsymbol{Th_{f1}} + \boldsymbol{Th_{f2}}) + \mathbf{2} \times \boldsymbol{l_s} + \mathbf{6\pi d}]] + \left[\boldsymbol{N} \times \left[\sqrt{(\boldsymbol{l_s^2} + \boldsymbol{B_r^2})} + \sqrt{((\boldsymbol{3d})^2 + \boldsymbol{B_r^2})} + (\mathbf{6\pi d})\right]\right] + \left[\boldsymbol{N} \times \left[\boldsymbol{l_s} + \mathbf{8}\,\boldsymbol{B_r} + \mathbf{10}\,\boldsymbol{d} + \sqrt{(\boldsymbol{3d} + \boldsymbol{B_r})^2 + \boldsymbol{l_s}^2}\right]\right] \qquad 23$$

However, when all assembled fabrics present the same thickness values ($\boldsymbol{Th_{f1}} = \boldsymbol{Th_{f2}} = \boldsymbol{Th_f}$), the consumed amount of thread using 602 coverstitch seam can be geometrically calculated as following (see Equation 24):

$$\boldsymbol{C_{st\,(602)}} = \boldsymbol{N} \times \left[\mathbf{8}\boldsymbol{Th_f} + \mathbf{6}\boldsymbol{l_s} + \mathbf{12\pi d} + \left(\sqrt{(\boldsymbol{l_s^2} + \boldsymbol{B_r^2})} + \sqrt{(\mathbf{9}\boldsymbol{d}^2 + \boldsymbol{B_r^2})}\right) + \left[\boldsymbol{l_s} + \mathbf{8}\,\boldsymbol{B_r} + \mathbf{10}\,\boldsymbol{d} + \sqrt{(\boldsymbol{3d} + \boldsymbol{B_r})^2 + \boldsymbol{l_s}^2}\right]\right] \qquad \mathbf{24}$$

Results and discussion

The value of needle thread, covering system thread and looper thread are plotted in Figure 8. It is observed from the Figure 6 that with the rise in feed rate both the looper as well as needle and covering thread length per stitch changes differently.

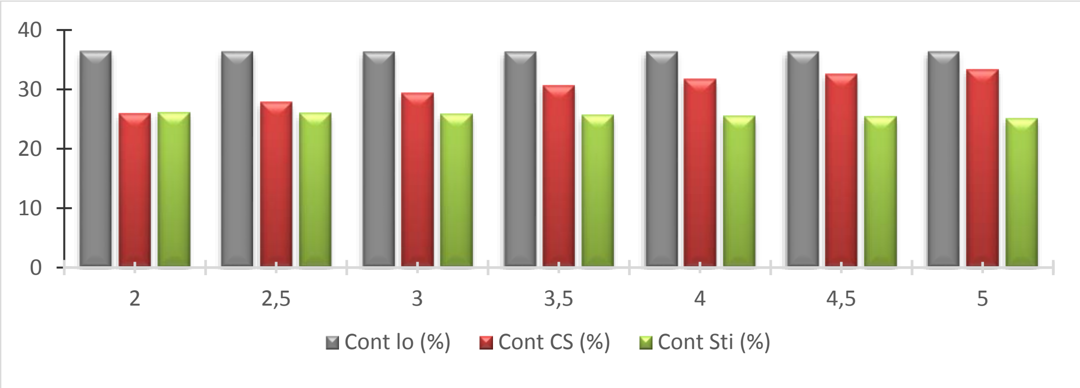


Figure 8: Different contributions of sewing thread systems on the consumption using Coverstitch 602 type.

Equation 29 illustrates the expression of the absolute contribution ($\overline{C_k}$) of each sewed thread on the total amount value of seamed thread based on 602 coverstitch type.

$$\overline{C_k}(\%) = \mathbf{100} \times \left| \frac{C_{st\,(geo)} - C_{st\,(exp)}}{C_{st\,(geo)}} \right|_k \qquad 25$$

Where:

$C_{st(geo)}$and$C_{st\,(exp)}$are the predicted theoretical and actual consumption values of the sewing thread relative to sewing system $\boldsymbol{k}$ along basic seam using coverstitch 602.

Although Figure 6 shows unchangeable contributions on the value of consumption based on the point of seam 602 relative to the variation of the number of stitches per centimetre, however, there are small variations that ranged from 0,02% to 0,10%. This variation of the relative contribution values of needle threads ($\overline{C_n}$) which cannot appear clearly in Figure 6 is obtained by varying the number of stitches per centimetre from the lowest value (equal to 2 stitches/cm) to that highest (equal to 5 stitches/cm). These low contributions of needle thread amounts can be justified by the variation of the lengths of stitch seamed and the rise in feed rate given during seam process. However, regarding the covering system thread, consumed along the basic seam length, the increase of the number of stitches/cm contributes positively on the consumption value using the coverstitch type 602. Based on the findings obtained, the consumed thread length of covering system contributes enormously on the total amount of thread ($\overline{C_{cs}}$). Hence, its relative contribution represents 25,98% from the hole consumption value when the number of stitches per centimetre equals 2 stitches only and 33,38% when this parameter equal to 5 stitches/cm (see Table 1).

Table 1. Different theoretical contributions of the consumed sewing thread types forming the coverstitch 602 along basic seam length (10 cm)

Stitch density	$\overline{C_k}$			$C_{st\,(602)}$predicted value (cm)	***Total (%)***
	$\overline{C_n}$ (%)	$\overline{C_{cs}}$ (%)	$\overline{C_{lo}}$ (%)		
2	26,139	25,982	36,417	124,24	88,538
2,5	25,994	27,865	36,356	144,94	90,215
3	25,84	29,397	36,335	165,94	91,572
3,5	25,692	30,661	36,332	187,17	92,685
4	25,556	31,718	36,337	208,52	93,611
4,5	25,431	32,613	36,347	229,98	94,391
5	25,319	33,38	36,358	251,51	95,057

Undoubtedly, due to the rise in feed rate of the covering system per stitch the correspondent consumed thread increases accurately which seems in good agreement with Ghosh & Chavhan (Ghosh &Chavhan, 2014). Incorporating known that the covered part of garment using coverstitch 602 had a bearing on decorative and esthetical appearance, a high needed number of strands to form this stitch type encourages to cover particularly the seamed zones. So, it seems reasonable to obtain more consumed thread amount than the needle ones to flawlessly envelope these specific garment areas.

Therefore, compared to both needles and covering system threads, the relative contribution of looper thread ($\overline{C_{lo}}$) during seaming process based on 602 type seems high when the number of stitches per centimetre increases. By analysing results shown in Figure 6 and Table 1, it can be concluded that a remarkable decrease of the consumed thread value relative to looper system was obtained especially when the length of stitch increases. In spite of the high value of the contributions given by the looped threads, a notable decrease is saved when the stitch length decreases. Indeed, looper thread contributions are ranged from 36,33% to 36,41% (for 2stitches/cm). These contributions remain the highest compared to those consumed by both needles and covering system threads. This finding seems in a good agreement within its tackled by Ghosh &Chavhan (Ghosh &Chavhan, 2014, O'Dwyer, &Munden, 1975). But, according to literature surveys, the looper threads lengths per stitch is always higher than the needle thread length per stitch, the same remark was also saved in the coverstitch type 602. Moreover, contrary to other extensible stitch types such as chainstitch (classes 100 and 400) and over edge stitch (class 500) which giving adequate stretch for sewing comfort stretch fabrics and providing the maximum attainable consumption values, the coverstitch 602 gives high contributions (Alaghaet al., 1996, Lauriol, 1989). This result may be explained by the high number of needle threads, complicated geometrical shapes and the covering threads used to envelop the secure zones. In addition, the esthetical garments parts are covered using the coverstitch class 600 in order to decorate seamed zones by the interlocking of the threads together encouraging a high amount of threads.

Nevertheless, Figure 9 shows the relationship between the actual and the predicted consumed thread using the coverstitch type 602, as function of the increase of the stitch density value. For the verification of the derived geometrical model, 70 specimens were prepared by varying the number of stitches per centimetre only because it is one of the most important parameters (Rasheed et al., 2014) which affecting the consumed thread. Each sample was repeated 10 times to obtain mean and representative value of the consumed amount of thread using 602 coverstitch types.

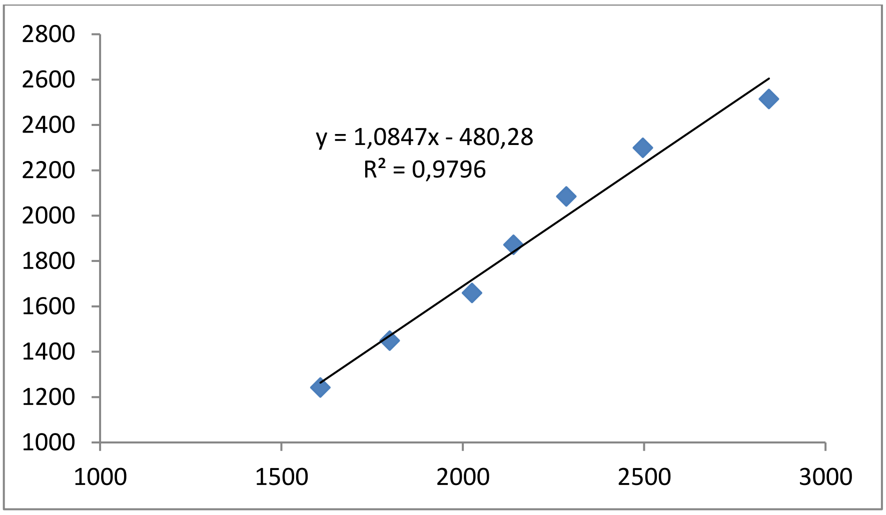


Figure 9: Relationship between experimental ($C_{st\,\exp(602)}$) and geometrical consumptions ($C_{st\,theo(602)}$).

Sewing thread consumption has a direct relationship with the stitch density and this result seems in a good agreement with Rasheed's study (Rasheed et al., 2014) in the case of lockstitch type 301.

Similarly, based on other studies (Rasheed, et al., 2014, Rengasamy, Kothari, Alagirusamy, &Modi, 2003, Ghosh &Chavhan, 2014) the stitch length or stitches per centimetre affects the thread consumption, but compared to other studied parameters (thickness, number of assembled plies, tension, etc.) its effect stilled influential and significant on the final consumed thread.
It is found that the relationship reaching the experimental and the geometrical consumption values using 602 coverstitch type is given by the Equation 26:

$$\boldsymbol{C_{st\,theo(602)}} = \mathbf{1,084} \times \boldsymbol{C_{st\,\exp(602)}} - \mathbf{480,28} \qquad 26$$

Equation 26 is a regression equation that relates the theoretical consumption as a function of the practical consumption which facilitates the estimation of of the sewing thread the consumption on the stitching operation before its industrial realization. The equation is reliable since the value of R2 (0.9796) is very close to 1. The implementation of this equation gives a range of error between -1.413% and 5.720%. This error is minimal which can't exceed 6 mm in a seam of 10 cm.
To predict and calculate the thread consumption per unit length, this equation was multiplied with the stitch density or the calculated number of stitch ($\boldsymbol{N}$). The stitch density relative to the new garment part length can be also found using the number of stitch per centimetre or per unit of length ($\boldsymbol{N}$) used in the developed geometrical model (given previously by Equation 23).
So, according to Equation 2, previously presented can give the conversion from basic seam length to the desired garment part length which will be seamed using $\boldsymbol{N}$ stitches of coverstitch type 602.
Out of the basic variables, consumed thread amount based on 602 coverstitch and stitch length are dependent on each other. Indeed, it may be concluded that changing the value of one automatically changes the value of the other accordingly. Besides, it is clearly remarked that the developed geometrical model considers not only the stitch density but the thickness of fabrics to be sewn, the diameter or the linear density of sewing threads and the breadth of needles. Hence, in this work we have studied one parameter whereas the others can be changed either changing automatically the results. This geometrical model can be used to depict the predicted values of the consumed sewing threads using the coverstitch 602 as function of the geometrical and structural variables investigated.
Table 2 illustrates a comparative analysis between the actual and predicted thread consumption along with their relative error (R_E) values. The average relative error was calculated and its range value is extended from 7,88% to 22,71%. The fitted line between actual and predicted values showed that actual values were in good agreement with predicted thread consumption values with R^2 value of 0,9796.

Table 2. Comparative actual and predicted thread consumption values with their relative errors.

Stitch density (Stitch/cm)	$\boldsymbol{C_{st\,\exp(602)}}$ **(m/m)**	$\boldsymbol{C_{st\,theo(602)}}$ **(m/m)**	R_E (%)
2	16,070	12,42	22,713
2,5	17,984	14,49	19,407
3	20,253	16,59	18,068
3,5	21,397	18,71	12,528
4	22,855	20,85	8,764
4,5	24,966	22,99	7,885
5	28,441	25,15	11,568

Based on the coefficient of regression value, it seems that a high correlation was established between the experimental and the geometrical consumptions using the coverstitch 602 in the experimental area of variation. However, there are relative errors which traduce that experimental consumed thread remained an empirical value which incorporates some factors such as waste factor as tackled in our previous work (Khedher&Jaouachi, 2015). Besides, an added percentage related to seam performance, compressibility of both sewing thread and fabrics, frictional stresses and extensions and operator manipulations which can enormously affect the result (thread breaks, waste factor, the loss of thread during the threading process, etc. Moreover, the notable effect of fabric

tightness and certain sewing thread properties like its size, coefficient of yarn-metal friction, twist direction, number of piles, type of fibre and fibre denier on strength reduction which has been studied by Sundaresan et al. (Sundaresan, Salhotra&Hari, 1998, O'Dwyer&Munden,1975) can explain the origin of high consumed thread and wastage values as well as the decrease of sewn garment quality.
In the other hand, to obtain experimentally the suitable value of consumed thread, the unstitching should be carefully realized without considering the different form of wastages in seam occurring due to ends or starts of sewing operations and to shop floor conditions like machine running, threads breakage, repairs, etc.The literature suggests (Lauriol, 1989), 10-15% of sewing thread wastage should be added to carry out the experimental approximate consumption value of sewn cloths. However, this percentage of wastage is not usually preserved because it changes as function of the type of sewn garment, type of stitches seamed, structural and geometrical parameters. Besides, the industrial does not accept that the consumed amount remains unpredictable and ambiguous due to these presented factors. Thus, the need of determining the suitable quantity of sewing thread bobbins becomes an urgent and essential problem especially when the quality of produced garments is strongly recommended. In fact, in our earlier work, this wastage percentage was redefined, reviewed and is not kept the same. There is no doubt that, the calculation of the theoretical consumption value of sewing thread, does not considered the same percentage especially, when it is geometrically realized. Two reasons can be provided to explain the advantage. First, because the geometrical parameters are the main factors which are carefully defined to simulate accurately the real shapes of both yarns and fabrics structures. Second, based on geometric and mathematical relationships within minimal or no presumptions, the theoretical consumed thread derived to sew garment or part of garment decreases as possible the approximations. Nevertheless, compared to experimental value of the consumed lengths, the geometrical findings remained more effective (-1,413% $< R_E <$ 5,720%) and explained sufficiently the suitable amount of sewing thread using the coverstitch 602. In spite of its complicated shape, the coverstitch 602 is successfully modelled and accurately fitted the practical consumptions to seam a decorative and esthetical parts in garments. Therefore, further research is needed to compare experimental and theoretical effects of different thicknesses of assembled fabrics, variable tensions of threads, needles sizes and different yarn counts on the consumed thread lengths.These parameters can help to define more deeply the behaviour of the consumed thread based on coverstitch 602. According to some studies (Chen et al., 2001, Ghosh, &Chavhan, 2014, Ukponmwan, Mukhopadhyay, & Chatterjee,2000) their impactsaredifferent in case of the consumption of lockstitch type 301 and 40. In contrast with Rasheed et al. (Rasheed et al., 2014), it was evident from the obtained results of sensitivity analysis that relative effect of stitches density using coverstitch 602, were ranged from 5,34% to 12,2%. Indeed, the suggested mean effect of stitches per inch using lockstitch model type 301 is 43% but using the coverstitch 602, the average contribution of stitches per unit of length is 9,03% only. Although the difference of the studied type of stitch, it seems that the contribution values of stitch density input still significant to affect the consumption value (Webster, Laing &Niven, 1998). Even though due to some supposed factors such as stitch type, tested database, hypothesis considered in the geometrical analysis and the other influential inputs (Chen, et al., 2001, Rengasamy et al., 2003, Meric & Durmaz, 2005, Krishnan & Kumar, 2010), these different contributions can be saved.

CONCLUSION

The quantification of different stitch densities and their relative influences on sewing thread consumption using coverstitch 602 can assist for accurate prediction of sewing thread required for sewing operation in garments industry. Indeed, the developed geometrical model predicts the thread consumption with 97, 96 % accuracy. It is concluded from the results obtained that geometrical model can be successfully used for the sewing thread consumption calculation precisely. Thread consumption per unit of length for coverstitch 602 varies as function of the adjusted length of stitch. Based on the derived geometric model of the coverstitch 602 shape, influential factors that have a

bearing on the geometrical structure of sewing threads and fabrics affect enormously the behaviour of the consumed amount of thread during seaming process.
Moreover, different relative contributions of the needles, covering system and looper threads on the total value of the consumed thread length are highlighted presenting their impact rates to vary the behaviour of the consumption using the coverstitch 602. By classifying these relative effects as function of the stitches per unit of length, our findings show that the highest contribution (between 41,30% and 47,87%) is given by the looper system. However, those given by the covering system and the needles are ranged from 25,98% to 33,38% and from 25,32% to 26,14% respectively. In this paper, we have remarked that the thread consumption depends widely on the values of stitch density. Theoretical thread consumption value presented a direct relationship not only with all these input variables but also dynamic condition parameters during seaming process (tension of threads, extensibility of fabric and sewed threads, frictional stresses and elongations, needles temperature and effectiveness). However, a dynamic analysis of stitching process is needed to establish the relation between physico-mechanical parameters development in thread, needles, fabrics and the consumed amount of thread to guarantee esthetical seams using the coverstitch 602. Further work is needed to develop a compromise between dynamic behaviour of the consumed thread based on this type of stitch and the related influential inputs.

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