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Geometrical Model to Determine Sewing Thread Consumption for Stitch Class 406

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Abstract

This study aimed at developing a geometrical model for predicting the sewing thread consumption of stitch class 406. Stitch class 400 is a multi-thread chain stitch which consumes a less amount of thread as compared with stitch class 500 but more thread as compared with stitch class 300. Sewing thread calculation plays a significant role in determining the exact amount of thread for completing a garment and predicting the right quantity of thread for bulk production. The geometrical model developed was used for predicting sewing thread consumption by using different factors like stitch density (8 and 12 SPI), material thickness (2, 4 and 6 layers of fabric), and type of material (denim, knitted and fleece). The model was validated with a total of 18 samples sewn with different kinds of fabric, SPI, and material thickness. It was concluded that the model could predict sewing thread consumption with more than 97.18% accuracy.

Key words: *sewing thread consumption, stitch class, stitch density, geometric model.*

Introduction

The quality of garments can be assessed through different attributes like physical features, dimensions, and performance characteristics. As far as physical features are concerned, it involves using different techniques for proper assembling of the different parts of garments. However, performance can be evaluated through functional requirements, visual characteristics [1], and other factors like proper stitch formation, appropriate sewing thread and seam selection, absence of differential shrinkage, along with good colour fastness properties [2, 3]. Seams and stitches are the two basic elements of a garment. A seam can be defined as a continuous row of stitches that is used for functional as well as aesthetic purposes [4]. Seam performance and appearance are amongst several factors which positively impact the performance of a garment [5, 6]. Seam performance depends on several factors like stitch density, proper selection of the needle, consistency of stitch formation, and proper selection of sewing thread [7, 8].

According to ASTM standard D-6193, stitches have been classified into six different classes, which are further divided into different subclasses of which stitch class 400 represents a multi-thread chain stitch. This stitch class is stronger, possesses higher elasticity than class 300, and can be employed effectively for the sewing of heavier fabrics and more force bearing areas in garments. Class 400 has different subclasses, of which 406 is a bottom cover stitch. Besides being a stitch class, 406 is also used for finishing inside a garment to avoid the unraveling of the fabric. Due to its better finishing technique, subclass 406 is a preferred choice for a flat seam in the neck line as well [9].

Nowadays, the biggest concern in the apparel industry is to reduce the manufacturing cost and maximise profit margins. The right estimation of sewing thread for a particular product helps in the calculation of garment cost [10]. Furthermore, because of higher competition, apparel manufacturers are trying to explore different dimensions for a reduction in expenses and maximising of profit margins. In this context, the exact calculation of the sewing thread is very important as it will help in inventory management for smooth working during operations [11]. On the other hand, lower thread estimation will cause a shortage of sewing thread, resulting in stoppages or delays in production lines, which can increase the lead time. Due to these reasons, it is clear that accurate thread estimation is vital for smooth working in apparel manufacturing units. Thread consumption depends on different factors like the type of sewing machine, stitch length, and thread composition [11]. In manual sewing machines, the consumption of sewing thread is higher because the operator draws more thread to cut after performing an operation. However, on automatic sewing machines, the thread trimmer automatically cuts the sewing thread and causes a reduction in sewing thread usage. Although sewing parameters have significant impact on the sewing thread, there are other factors which also have a crucial effect on sewing thread usage, like different shop floor practices, frequent sewing thread breakage, machine repairs, and operator working style, which causes a 10-15% loss in sewing thread [12].

The most common method for sewing thread calculation is to calculate thread consumption for a unit length of stitch, which is multiplied by the total length of the seam [13]. However, by using this method, different allowances are also given while using manual and automatic sewing machines. Jaouadi described this mechanism in a different way which states that the unravelling of a seam is very accurate method of thread consumption estimation [11]. However, these measuring techniques are not only time consuming but also require skilled operators and equipment for the exact measurement of sewing thread. These factors have pushed researchers to explore other techniques, like nowadays more focus is shifting towards analytical modelling techniques for the calculation of sewing thread. For the calculation of sewing thread consumption, different researchers have proposed different models, which include geometrical modeling, fuzzy logic, mathematical modelling, artificial neural networks etc. [12, 14].

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In one study Abher successfully investigated the effect of different sewing parameters on thread calculation for stitch class 301 by using sensitivity analysis [15]. Furthermore, he developed another geometrical model for the calculation of thread consumption for stitch class 504 [16]. In another study the linear regression technique was applied, which more precisely explained the impact of different input parameters on thread calculation [11]. Boubaker calculated thread consumption by using the fuzzy model, according to whom this technique gives accurate calculation of sewing thread as compared with regression analysis, but the accuracy of this method depends on the selection of input parameters [12].

The literature shows that geometrical modelling gives high accuracy of results, but there is no geometrical model available for the thread calculation of stitch class 406. Hence, there is a need to develop a mathematical model for more precise and exact measurement of sewing thread in stitch class 406. In this context this study is in fact the continuation of previous work in which the thread consumption for stitch class 504 was calculated using the same modelling technique. Geometric modelling of stitch class 406 is important due to its vast usage in knitted garments, such as the attaching of elastics in undergarments and the hemming of T-shirts. Moreover, this stitch is also used in the loop making of five pocket denim jeans.

Figure 1. *Denim, knitted and fleece fabric.*

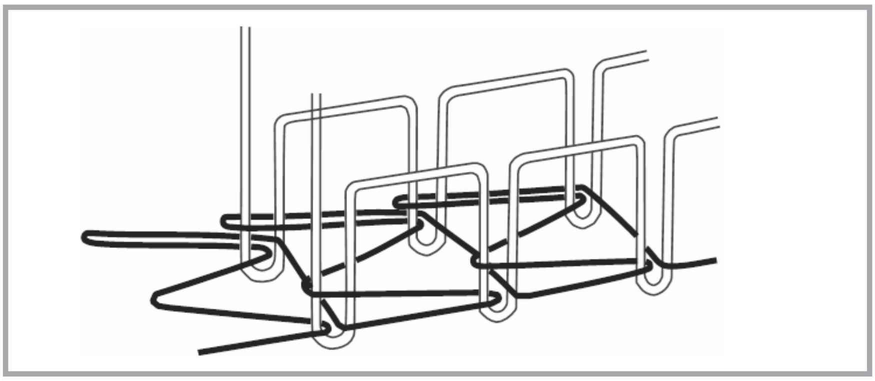

Figure 2. *Geometry of stitch class 406.*

Table 1. *Fabric specifications.*

Sr. No.	Fabric type	Fabric description	Fabric GSM
1	Denim	3/1 twill	386
2	Knitted	Polo PK (Single)	315
3	Fleece	3 Fleece double side raised	297

Experimental set-up

The modelling of stitch class 406 is the main research area during this work. Initially, the stitch geometry was analysed and a geometric model developed for determining thread consumption for stitch class 406. Since fabric was the main part of sampling for this experiment, three different types of fabrics i.e. denim, pique knit, and fleece were used for verification of the geometric model developed, shown in ***Figure 1***. Flat seams were applied on different fabric samples by varying the number of plies.

The fabric types and their corresponding GSM can be seen in ***Table 1***.

In the second step sewing samples were made by stitching according to the design of the experiment. A Pegasus high-speed, flat-lock two needle (three thread) industrial sewing machine was used for stitching the samples. Three different coloured threads of 40 Tex were used. Sewing threads of Coats plc® (Astra PC) were used because they are lubricated and have a uniform construction, which ensures fault-free stitching. Moreover, a digital thickness meter was used for measuring the thickness of the fabric. The weight used for determining fabric thickness was 8.6 ounces (ASTM D-1777). Initially, a 10 cm seam was stitched, then 2 cm from both sides was cut, and the remaining 6 cm of the stitched sample was unraveled to determine the actual sewing thread consumption. Resultantly, the unit length of sewing thread consumption was calculated. Five replicates were taken for increasing the accuracy of results. In order to validate the model developed, actual thread consumptions were compared to the corresponding sewing thread consumptions calculated.

Geometric Model of Stitch Class 406

A digital microscope was used to study the three-dimensional geometry of stitch class 406. Analysis of the stitch geometry revealed that stitch class 406 is made by the interlacing of two needle threads and one looper thread. A 3D view of the stitch can be seen in ***Figure 2***.

The total consumption of sewing thread per centimeter can be calculated by adding individual consumptions of needle threads and looper thread, shown in ***Equation (1)***.

$$Ct = SPC \times (Cn + Cl) \qquad (1)$$

Where Ct, SPC, Cn, and Cl represent the consumption of total thread per centimetre of seam, the stitch density (number of stitches per centimetre of seam), the consumption of needle threads and looper thread, respectively. Needle thread consumption can be calculated using ***Equation (2)***.

$$Cn = 2 \times (SL + 2MT) \qquad (2)$$

Where Cn, SL and MT are the consumption of needle threads, the stitch length, and material thickness under the stitch, respectively. Material thickness was found using a digital thickness meter as per ASTM D1777-96. The geometry of stitch class 406 can be seen in ***Figure 3***.

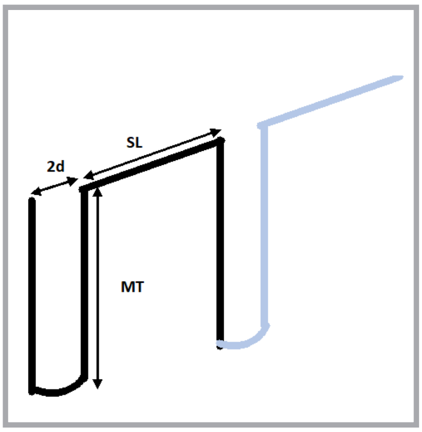

Figure 3. *Geometry of needle thread.*

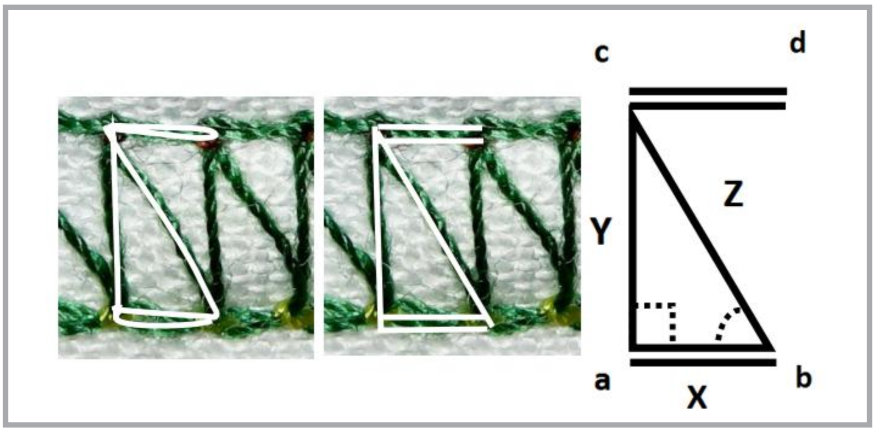

Figure 4. *Geometry of looper thread.*

Stitch length is the length covered by needle thread on top of the stitch, which is dependent on the stitch density (SPC) and yarn diameter (d). Stitch length can be calculated using ***Equation (3)*** [15].

$$SL = \left(\frac{1}{SPC}\right) - 2d \qquad (3)$$

Where '*SPC*' is the stitches per centimeter, which can be counted physically, while '*d*' represents the diameter of sewing thread, which can be calculated using ***Equation (4)*** [17].

$$d = \frac{1}{28\sqrt{N}} \qquad (4)$$

The value of 'N' in ***Equation (4)*** can be calculated using ***Equation (5)*** [18].

$$Ne = \frac{590.5}{Tex} \qquad (5)$$

To determine the sewing thread consumption of looper thread, first the geometry of looper thread was analysed, shown in ***Figure 4***.

The looper thread was calculated using ***Equation (6)***.

$$Cl = 4X + Y + Z \qquad (6)$$

Where *Cl*, *X*, *Y*, and *Z* represent the consumption of looper thread, stitch length (*SL*), stitch width (*SW*), and the length of diagonal thread, respectively. It was observed that *X* and *Y* in ***Equation (6)*** were equal to *SL* and *SW*, respectively. Hence, this equation was converted into ***Equation (7)***.

$$Cl = 4SL + SW + Z \qquad (7)$$

From ***Figure 4***, it can be noted that the looper stitch geometry makes a perfect right-angled triangle. Furthermore, *Z* represents that the diagonal of this triangle, whose length can be found by using the Pythagoras theorem, and can be written as ***Equation (8)***.

$$Z = \sqrt{(SL)^2 + (SW)^2} \qquad (8)$$

Therefore, ***Equation (8)*** can be rewritten in the form of ***Equation (9)***.

$$Cl = 4SL + SW + \sqrt{(SL)^2 + (SW)^2} \qquad (9)$$

Consequently, the total thread consumption can be found by putting the values of *Cn* from ***Equation (2)***, and *Cl* from ***Equation (9)*** into ***Equation (10)***.

$$\begin{aligned} Ct = SPC \times \big(6\mathrm{SL} + 4MT + SW +& \\ + \sqrt{(SL)^2 + (SW)^2}\big)& \qquad (10) \end{aligned}$$

The stitches per centimetre (SPC) can be adjusted from machine setting and can be verified by physical counting. Stitch length (*SL*) can be determined using ***Equation (3)***. Stitch width (SW) can be established from the given distance between two needles of the flat-lock machine (gauge of the machine), which can also be verified physically. Thus, Equation 10 can be used for the calculation of sewing thread (per centimetre) for stitch class 406 by putting the value of different input variables which influence thread consumption.

Model Validation

To validate the geometric model developed, stitched samples were prepared. A full factorial design was used for deciding the number of samples required for model validation. Three factors: material thickness, stitch density and fabric type were considered. The material thickness was varied by using a number of plies and the stitch density by adjusting the machine setting. Three types of fabric i.e. denim (woven), pique and fleece (Knitted) with areal densities of 386, 315

Table 2. *Design of experiment.*

Sr. No.	Type of seam	Stitch density (SPI)	Fabric type	Number of plies	Thickness, cm
1	Flat seam	8	Denim	2	0.15
2	Flat seam	8	Denim	4	0.29
3	Flat seam	8	Denim	6	0.36
4	Flat seam	8	Knitted	2	0.14
5	Flat seam	8	Knitted	4	0.27
6	Flat seam	8	Knitted	6	0.35
7	Flat seam	8	Fleece	2	0.18
8	Flat seam	8	Fleece	4	0.38
9	Flat seam	8	Fleece	6	0.45
10	Flat seam	12	Denim	2	0.14
11	Flat seam	12	Denim	4	0.29
12	Flat seam	12	Denim	6	0.43
13	Flat seam	12	Knitted	2	0.14
14	Flat seam	12	Knitted	4	0.29
15	Flat seam	12	Knitted	6	0.40
16	Flat seam	12	Fleece	2	0.20
17	Flat seam	12	Fleece	4	0.33
18	Flat seam	12	Fleece	6	0.57

and 297 GSM, respectively, were used. A total 18 stitched samples with dimensions of 20 cm x 5 cm were prepared with the application stitch class 406 on a Flat Lock sewing machine. Machine adjustment was made before stitching each specimen because of the variation in the number of plies and fabric type. A 10 cm seam length was marked on the stitched specimens, leaving almost equal spaces on both sides of the seam, and individual threads were taken out carefully. Details of the design of the experiment (DOE) can be seen in ***Table 2***.

Different stitch densities (stitches per inch) are used in joining different layers of fabric. However, mostly 8 to 12 SPI are used for most knitted and denim fabric stitching. Regarding the thickness of material, as the number of layers in the stitched samples was increased, correspondingly it increased the thickness of seams and hence consumed more thread. Therefore, the thickness of fabric also plays an important role in determining the exact quantity of sewing thread. All the stitched specimens were treated in random order, and threads recovered from the marked seam length were kept separate, with clear identification. For each specimen, the length of needle thread and looper threads were measured physically and added up to observe the actual thread consumption of the seam. The predicted consumption of each thread was also calculated for each specimen by using geometric model developed as shown in Equation 10. The results of calculated and actual thread consumptions are arranged in ***Table 3***, along with the absolute error of percentage.

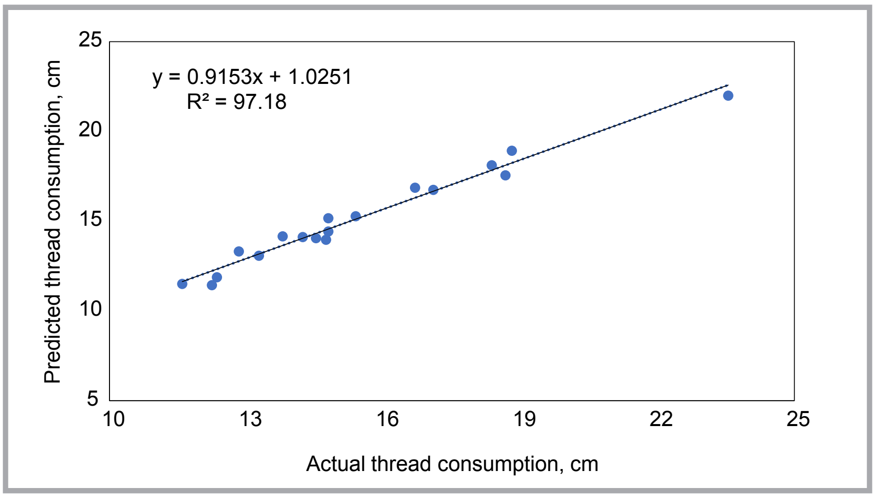

Figure 5. *Linear Regression between actual and predicted thread consumption.*

Table 3. *Comparison of actual and predicted thread consumption.*

Sr. No.	Actual thread consumption, cm	Predicted thread consumption, cm	Absolute error, %
1	11.59	11.51	0.7
2	12.83	13.32	3.7
3	13.79	14.16	2.6
4	12.24	11.44	7.0
5	13.27	13.08	1.5
6	14.23	14.12	0.8
7	12.35	11.88	4.0
8	14.79	14.43	2.5
9	15.39	15.28	0.7
10	14.52	14.06	3.3
11	16.69	16.87	1.1
12	18.37	18.12	1.4
13	14.74	13.97	5.5
14	17.09	16.75	2.0
15	18.81	18.93	0.6
16	14.79	15.17	2.5
17	18.67	17.56	5.94
18	23.55	22.00	6.58

Table 4. *Extreme and mean values of input variables.*

Sr. No.	Input variable	Minimum level	Maximum level	Mean	Predicted response by input variable
1	Stitch density (SPC)	3.15	4.72	3.94	3.81
2	Material thickness (MT)	0.14	0.57	0.35	6.7

Table 5. *Extreme levels and range of output variable.*

Sr. No.	Output Variable	Minimum Level	Maximum Level	Range
1	Thread Consumption	11.59	22.15	10.56

The results showed that the absolute error was high in the case of compressible materials, especially at a high stitch density and greater number of plies. The obvious reason for the error in such cases was the changed geometry of the looper thread, which took a curvy path and spread between two series of stitches. For further analysis, a linear regression line was plotted against the actual thread consumption (x-axis) and predicted thread consumption (y-axis), shown in ***Figure 5***. The trend line of the scatter plot between the actual and predicted thread consumption shows that the model was acceptable and near to the actual measurement. The coefficient of determination i.e. R^2 value of 0.9718, shown in ***Figure 5***, is evidence that the model developed could explain 97.18% of the variability in response data around its mean.

The experiments showed that the consumption per centimetre for stitch class 406 depends upon the stitch density, sewing thread diameter and thickness of the material. Moreover, a higher value of R^2 shows that factors such as thread consumed in interlacing during stitching are of minor significance.

Sensitivity analysis

A sensitivity analysis was made to analyse the relative effect of each input variable on the output variable. The maxi-

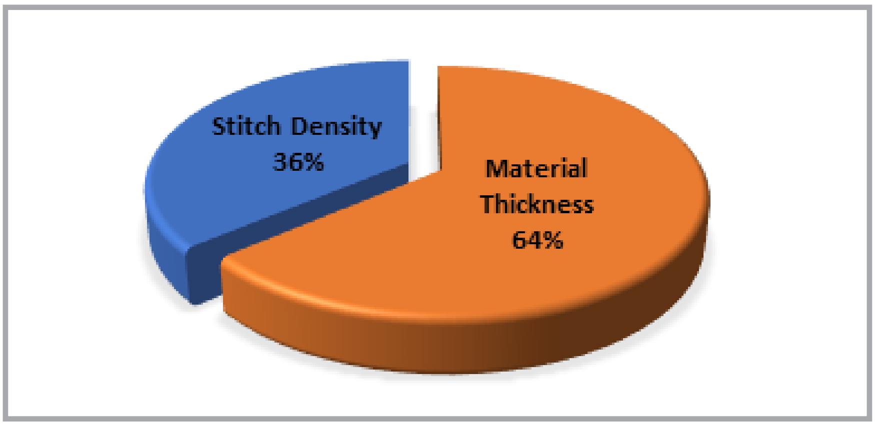

Figure 6. *Contribution percentage of input variables.*

mum and minimum values of each input and output variable are shown in ***Tables 4*** and ***5***, respectively.

The contribution ratio of each input variable was determined by using the ratio of the predicted range of the response variable, at minimum and maximum values of the input variable, to the overall actual range of the output variable according to ***Equation (11)***.

The Contribution Ratio percentage (CR %) for all input variables was calculated by dividing the CR of each input variable with the sum of all CRs of input variables, shown in ***Equation (12)***.

Contribution ratio percentages of respective input variables are presented in ***Figure 6***. The results revealed that in the case of stitch class 406, material thickness has a major impact on the consumption of sewing thread.

Upon further investigation, it was found that the contribution of material thickness also depends on the nature of fabric materials. Among the fabrics used in the present study, fleece fabrics had the highest contribution to material thickness.

Conclusions

The accuracy of the geometrical model proposed is more than 97.18%, which can be used confidently for estimation of the thread consumption in sewing factories. On average, stitch class 406 consumes thread 12 to 22 times the length of seam applied. By keeping the stitch width constant, then the consumption of thread depends upon the material thickness and stitch density. From the total, 20% of thread is consumed by each of the needles, while the looper thread contribution is 60%. Furthermore, it can also be concluded from the sensitivity analysis of input variables that material thickness has a 64% contribution in thread consumption, while stitch density accounts for 36% only. Further studies can also be conducted to study the effect of different seam widths along with the other fabric parameters (including softness and fluffiness).

$$CR = \frac{\text{Predicted range of response by input variable}}{\text{Overall actual range of output variable}} \qquad (11)$$

$$CR = \frac{\text{CR of single input variable}}{\text{Sum of CR of input variables}} \times 100 \qquad (12)$$

Equations (11) *and* ***(12)***.

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