Mathematical modeling of stitch formation process in lockstitch machine

Roopam Chauhan[1], Subrata Ghosh[2]
1,2 Department of Textile Technology, Dr. B.R. Ambedkar National Institute of Technology, Jalandhar, Punjab (INDIA)- 144011

Abstract: *A coordinated needle and bobbin thread tension is a major requirement of a balanced seam in lockstitch. Thread tension varies cyclically during a stitch cycle due to upward and downward movement of take up lever and needle head. This paper gives an approach of the theoretical investigation on the process of development of thread tension during stitching process of lockstitch. The path of sewing thread is divided into three different zones. The tension developed in each zone will be estimated for every minute rotation of bottom shaft. A model is to be developed based on the dynamic nature of sewing thread and possible thread flow from one zone to another. The output of the model and experimental values of yarn tension developed will be compared to check the validity of the model.*

Keywords: Lockstitch machine, thread tension, tension variation, mathematical model

1. Introduction

The stitch formation process in lockstitch sewing machine presents a cycle of consecutive stages. The performance and efficiency of a stitching machine depends on the quality of stitch and thread breakage rates. It is indispensable to understand the generation mechanism of needle thread tension for an excellent sewing. During the process of stitching, sewing thread moves over a number of yarn and metal surfaces which ultimately leads to the continuous change in the needle and bobbin thread tension in a stitching cycle [1]. The developed peak tension value of bobbin and needle threads will decide the final stitch length and seam balance. It is known that the balance of seam is a function of both the needle and bobbin thread tension and is regarded as the ratio between both thread lengths. In an ideal balanced seam, the ratio is 1:1 [2].

The tensions generated in the needle and bobbin threads during stitching cycle are an important factor in determining the quality of a lockstitch seam. Improper tensions development in needle and bobbin thread may cause various problems such as puckered seams, thread breakage and unbalanced seams [3]. However, thread tension is cyclically varied during a sewing cycle due to pulling action of the take up lever and reciprocating motion of needle bar which are responsible for dynamic tension variation within the cycle [4]. Earlier investigations into the formation of the lockstitch seams have been studied by the number of researchers using tension transducer in the thread path between the take up lever and needle [2, 5-9]. This gives a dynamic tension measurement and its variation in a complete stitch cycle. A computer simulation model has also been proposed to predict the yarn tension value by considering a simulated thread path instead of the actual path of the yarn in stitching machine and predicted the needle thread tension [5]. This model gives an idea how the thread tension can be predicted for simulated lock stitching process. Number of research work has been carried out by various researchers to see the effect of various machine, material and process parameters on thread tension development during the stitch formation process [2, 5, 10-11].

The theoretical stitch length value can only be calculated accurately from the geometrical model of the stitch after knowing the point of intersection between bobbin and needle threads. However, this point is decided on the basis of interaction between thread, machine, fabric and process variable during the process of stitch formation. So, this work will be aiming for the formulation of lock-stitching process model by studying yarn movement and predict stitch length and yarn tension during stitching process.

2. Methodology

2.1 Machine used

This study is carried out in BROTHERS S-7000 DD-403 Single needle Lockstitch machine. The needle thread tension was measured using a tension sensor. Bobbin thread tension was measured by pulling the thread through bobbin case by using dead weight.

2.2 Plotting of stitch cycle

The movement of take up lever and needle eye for a given stitch cycle with respect to wheel rotation is plotted. For this, the wheel is marked with 0^o to 360^o with an interval of 10^o with the starting point when needle is at its top position and this position of wheel is marked as 0^o with respect to reference point, then after the displacement of take up lever and needle is noted down after each 10^o wheel rotation using travelling microscope. The stitch cycle is plotted by taking wheel rotation from 0-360 degree on X-axis and displacement of stitching elements on Y-axis.

3. Theory of development of thread tension in lockstitch machine

Lockstitch machine consists of four basic mechanisms: a take up mechanism, needle motion, material feeding and a bobbin thread supply unit. Out of these, take up arm movement is responsible for supplying yarn when needle moves downward. The balance between the thread supply and thread requirement and the variation of yarn tension during stitch cycle is mainly governed by the up down movement of take up arm. This paper covers the approach to the development of thread tension during stitching process, so, only the portion completed has been included in this paper.

3.1 Thread path of Lockstitch Machine

Figure 1 illustrates the thread path of the machine used. There are 7 guide elements and one tension regulator which gives the squeezing force to increase the thread tension. The yarn comes from a stationary package and is passed through tensioning device and check spring to fixed guide. Then the yarn is passed through take up lever eyelet and another fixed guide. This will form an imaginary triangle by joining a line between two fixed guides with the varying apex of take up lever position. From this fixed guide, the yarn passes through another fixed guide and a moving guide. Finally the yarn moves through the needle eye to form the stitch in the fabric whereas the bobbin thread comes directly from the bobbin case and take part in stitch formation process.

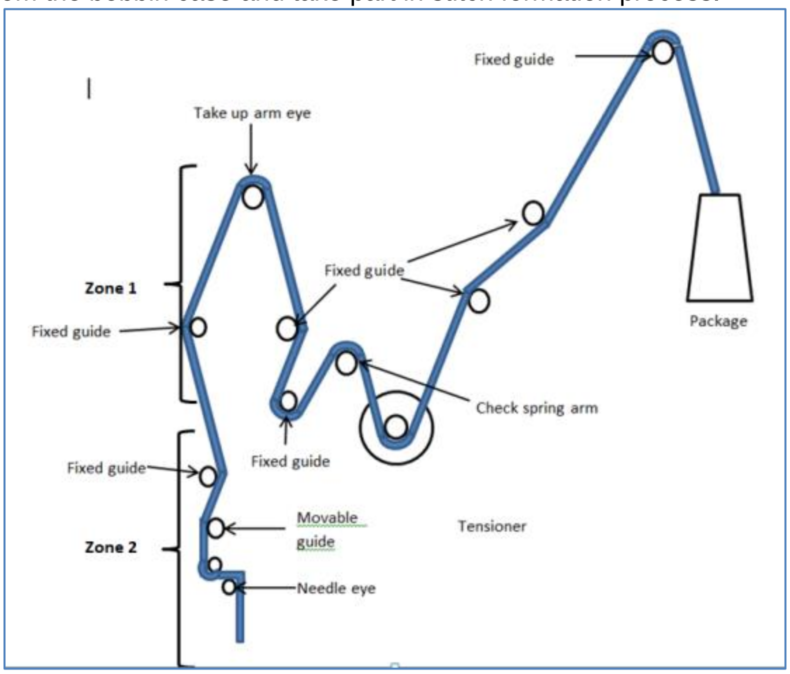
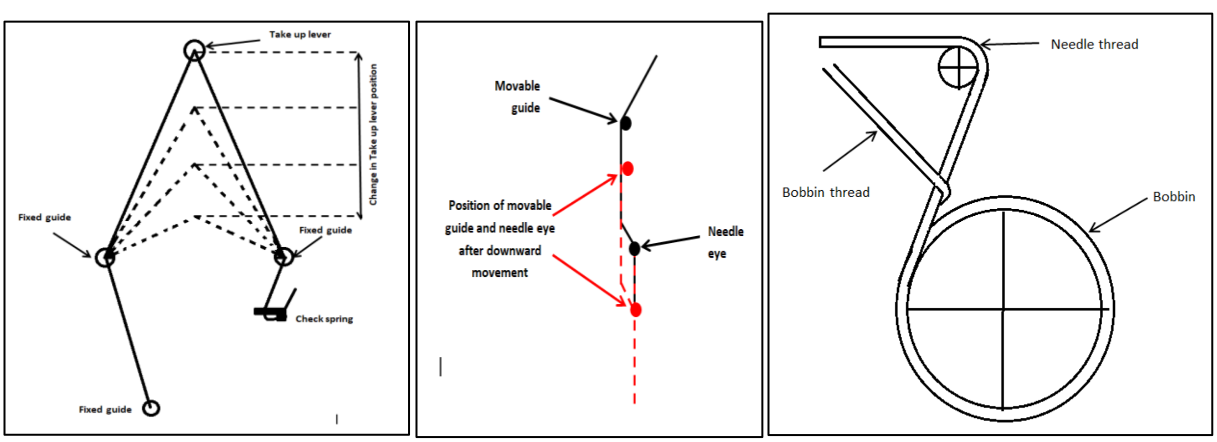


Figure 1: Thread path of lockstitch machine

3.2 Approach for theoretical model of thread tension

In order to develop theoretical model of thread tension in lockstitch machine, the path of needle and bobbin thread in a lockstitch machine is divided into three zones as shown in Fig.2. Zone 1 represents the movement of take up lever, Zone 2 represents the movement of needle and Zone 3 represents the bobbin thread path.



(a) (b) (c)

Figure 2. Different zones in lockstitch machine: (a) Zone 1; (b) Zone 2; (c) Zone 3

Take-up lever, sewing needle and check spring arm are the three moving elements in the path of sewing thread from package to stitch formation point. The movement of check spring arm is very little so we can ignore its effect on sewing thread tension. With the change in the position of take up arm and sewing needle, the needle and bobbin thread tension goes on changing over a stitch cycle. The tension on the needle thread during a stitch cycle was measured on the thread line between the take-up lever and the needle. But the tension indicated in this zone may be much lower than the actual thread tension developed during stitching process because of high level of strain imposed on the thread. The tension developed in the sewing thread at different positions is different. It is possible to measure thread tension at positions where there is no movement of machine element. In order to understand the theory of the development of yarn tension along this path, it is required to predict thread tension in all zones through which yarn is moving as well as to predict the location of needle and bobbin thread cross-over points i.e. y-value.

So, a theoretical model is needed to predict the thread tension during stitching for every minute changes in displacement of the moving elements. The displacement of moving elements (take-up lever and needle) is measured for each 10 degree of wheel rotation. For this a coordinate system is to be developed such that the displacement of moving elements is given on Y axis corresponding to the wheel rotation in degrees as represented on X axis.

To calculate needle thread tension it is required to know:

- Position of the elements of sewing machine at any point of time
- Wrap angle around each element
- Thread length between elements in each zone

The flow chart for prediction of the developed thread tension in stitching zone is illustrated by Figure 3.

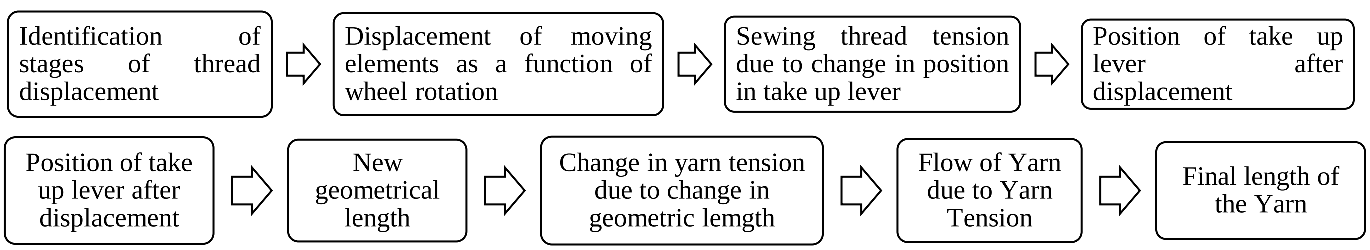


Figure 3: Flow chart for formulation of model for development of thread tension during stitching process

3.3 Formulation of the model:

1. *Position of needle and take up arm after displacement:*
   Take up lever is moved upward or downward due to wheel rotation (θ), then the position of take up arm and needle eye will be a function of θ:
   $$y = f(\theta)$$
2. *New geometrical length due to change in position of needle and take-up arm:*
   As the take up arm moves to a new position, its vertical distance with respect to imaginary line between fixed guides also changes. This would result in change in geometrical length as well as wrap angle.
   $d_i = f(h, \theta)$ where, h is change in height
3. *Change in tension in yarn segment due to extension:*
   Change in geometrical length of yarn in various zones by movement of different machine elements develops strain in yarn which increases yarn tension. It will either allow the flow of yarn or extension in the yarn. If there is no flow of yarn from one zone to another, then, only extension of yarn is considered for increase in yarn tension. The original unstrained length of yarn (l) would change by the amount d. So change in yarn tension due to yarn extension will be:
   $$T = \frac{E(d-l)}{l}$$
   Where, l – Length of yarn at zero tension
   d – Geometrical length of yarn after the displacement of element
   E – Rigidity of yarn
4. *Change in yarn tension due to flow of yarn*
   The possibility of yarn flow and its direction can be calculated by using Amonton's equation of friction:
   $T_1 > T_2\, e^{\mu\theta}$, where, μ is the coefficient of friction of yarn
   Then the yarn will flow from arm 2 to arm 1 till tension in the arm 1 is as follows:
   $T_1 = T_2\, e^{\mu\theta}$ and vice versa.
   But when $T_1 > T_2$ but $T_1 \le T_2\, e^{\mu\theta}$, or $T_2 > T_1$ but $T_2 \le T_1\, e^{\mu\theta}$, then there will be no flow of yarn from one zone to another zone.

5. *Final length of yarn segment:*
If a state of balance is achieved in any zone through drop in tension from T_i to $\overline{T_i}$ and increase in length from l to $\bar{l}$, then,

$$\bar{l} = \frac{E \times d}{E + \overline{T_2}}$$ where, $\bar{l}$ is the new geometrical length after the flow of yarn.

3.4 Motion Mechanism of moving elements

The up-down movement of take-up lever and needle is recorded with every 10 degrees of wheel rotation. The displacement curve of take up lever and needle eye is depicted in figure 4. From this figure, the displacement equation of take up lever and needle eye is found and is given below by eq. 1 and eq. 2.

$$y_t = -1E\text{-}06x^3 + 0.0007x^2 - 0.0914x + 3.5839 \quad (1)$$
$$y_n = -4E\text{-}09x^4 + 3E\text{-}06x^3 - 0.0006x^2 + 0.0199x + 1.9628 \quad (2)$$

Where y_t represents take up lever displacement (cm) and y_n represents needle eye displacement w.r.t. wheel rotation angle. A coordinate system is developed where the displacement of moving elements is given on Y axis corresponding to the wheel rotation in degrees on X axis.

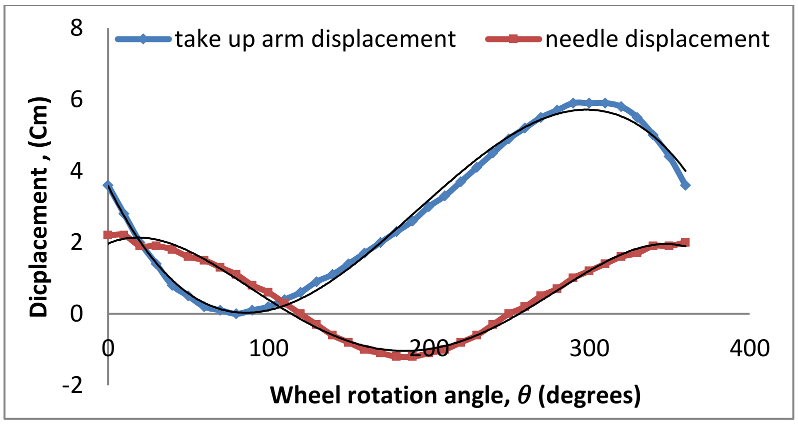


Figure 4. Displacement curve of moving elements

3.5 Wrap angle of machine elements at any point of time

Sewing thread passes over different elements during its passage in lockstitch machine. The wrap angle around each element depends on the position of element and configuration of thread path i.e. it is over/under the guide. To know the flow of yarn from one zone to other, there is a need to know the wrap angles at each contact point in the thread path of lockstitch machine. To find the wrap angles, the configuration of sewing thread at each contact point is drawn to know all the possible configurations. It was found that there are three basic configurations of the wrapping of sewing thread around different elements. The equations for the calculation of wrap angles and thus, thread length for different configurations are derived and are given in Table 1.

Table 1. Wrap angle and thread length equation of different thread configurations

Configuration	Wrap angle	Thread length
 Case 1	$\alpha_1 = \alpha_2 = \alpha$ $\alpha = 90^0 - \left[\tan^{-1}\left(\frac{\sqrt{y^2 + x^2 + {k_1}^2}}{k_1}\right) - \tan^{-1}\left(\frac{y}{x}\right)\right]$ Where, $k_1 = r_1 + 2r_y + r_2$	$l_1 = k_1\alpha + \sqrt{y^2 + x^2 + {k_1}^2}$
 Case 2	$\alpha_1 + \alpha_2 = 90^0$ $\alpha_1 = \tan^{-1}\left(\frac{x}{y}\right) - \left[\tan^{-1}\left(\frac{k}{\sqrt{y^2 + x^2 - k^2}}\right)\right]$ Where, $k = r_2 - r_1$	$l_2 = (r_1 + r_y)\alpha_1 + (r_2 + r_y)\alpha_2 + \sqrt{y^2 + x^2 - k^2}$
 Case 3	$\alpha_1 = \alpha_2 = \alpha$ $\alpha = 180^0 - \left[\tan^{-1}\left(\frac{\sqrt{y^2 + x^2 - {k_3}^2}}{k_3}\right) + \tan^{-1}\left(\frac{y}{x}\right)\right]$ Where, $k_3 = r_1 + 2r_y + r_2$	$l_3 = k_3\alpha + \sqrt{y^2 + x^2 - {k_3}^2}$

The symbols used in the formulas refer to: α_1: half of wrap angle around 1st element; α_2: half of wrap angle around 2nd element; x: horizontal distance between 1st and 2nd element; y: vertical distance between 1st and 2nd element; r_1: radius of 1st element; r_2: radius of 2nd element; r_y: yarn radius; l: length of yarn in any zone

3.6 Expected Tension Profile

The tension profile of needle and bobbin thread in lockstitch machine has been studied previously by few researchers. The general pattern of needle and bobbin thread tension variations during a complete cycle is illustrated in figure 5.

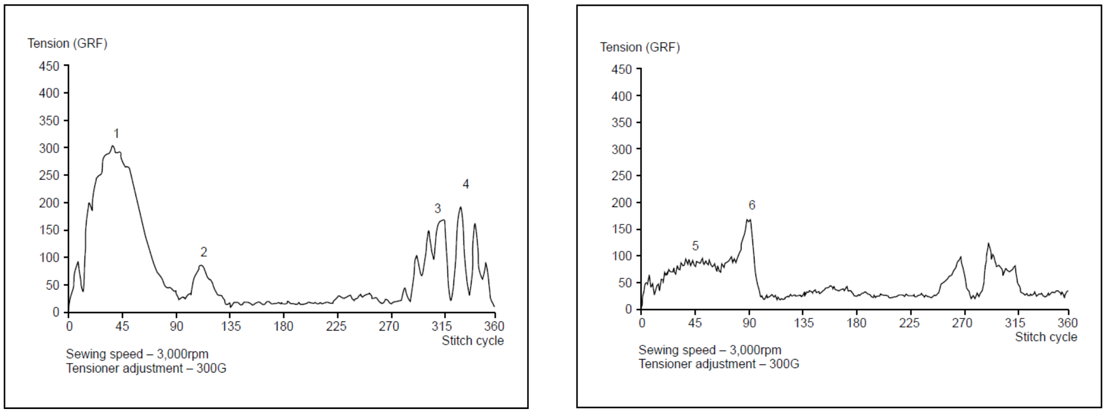


Figure 5: Tension profile of needle and bobbin thread in lockstitch machine

Typically, the graphs show four significant peaks of tension on the needle thread tension trace and two significant peaks of tension on the bobbin thread tension trace. The tension values calculated from theoretical modeling and that traced from tension sensor will be compared to find out the error%.

References

1. Ferreira F.B.N., Harlock S.C., Grosberg P (1994), "A Study of Thread Tensions on a Lockstitch Sewing Machine (Part 1)", *International Journal of Clothing Science and Technology*, Vol. 6, No.1, pp. 14-19.
2. Ferreira F.B.N., Harlock S.C., Grosberg P (1994), "A Study of Thread Tensions on a Lockstitch Sewing Machine (Part 2)", *International Journal of Clothing Science and Technology*, Vol. 6, No.5, pp. 26-29.
3. Ferreira F.B.N., Harlock S.C., Grosberg P (1994), "A Study of Thread Tensions on a Lockstitch Sewing Machine (Part 3)", *International Journal of Clothing Science and Technology*, Vol. 6, No.5, pp. 39-42.
4. Weizlak, W. & Bochenska J.E.:Process of Lockstitch tightening and optimization of thread working conditions. Part 2. The trial of optimizing the Interlacement Location in the Stitch Link, *Fibres and Textiles in Eastern Europe*, Vol. 15(1), 62-65
5. Randima, L.M.L., Sandaranga, D.M.B.C., Design and Fabrication of an Automatic Tension Monitoring and Regulation System for needle thread, Moratuwa Engineering Research Conference 2019
6. Kamata Y, Sakai T, Onogami M, Chanaya Y (1986), "Analysis on Tightening Tension Wave in s Lockstitch Sewing Machine Part 1: A Computer Simulation Technique", *Journal of the Textile Machinery Society of Japan*, Vol. 39, No. 1, 7-15
7. Kamata Y, Sakai T, Onogami M, Chanaya Y (1986), "Wave Analysis of the Tightening Tension Wave for Single-Needle Lockstitch Sewing Machine Part 2: Examination by Computer Simulation", *Journal of the Textile Machinery Society of Japan*, Vol. 39, No. 6, 86-96
8. Zunic Lojen D and Gersak J (2005), "Thread Loadings in Different Measuring Positions on the Sewing Machine", *Textile Research Journal*, Vol. 75(6), 498-506
9. Rengasamy RS and Samuel Wesley D (2014), "Study on Dynamic Needle Thread Tensions in a Single Needle Lockstitch Machine. Part 1- Effect of Stitch Length, Check Spring Tension, Fabric Feed Timing and Needle Thread in-take Length", *Fibers and Polymers*, Vol. 15, No. 8, 1766-1772
10. Amirbayat, J., & Alagha, M. J. (1993), "Further Studies on Balance and Thread Consumptions of Lock-stitch Seams", *International Journal of Clothing Science and Technology*, 5(2), 26-31.
11. Arai N and Akami (1999), "Simulataneous Measurement of Tightening Tensions of Needle and Bobbin Thread in a Lockstitch Sewing Machine", *Journal of Textile Institute*, Vol. 90, No. 3, 428-444