A geometrical model of stitch length for lockstitch seam

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Received 16 July 2012; revised received and accepted 19 September 2013

A geometrical model has been proposed for prediction of thread consumption based on original cross-section of lockstitch seam for woven fabric. The developed model has been used to calculate the thread consumption during the process of stitching. The stitch length equation is obtained in terms of feed rate, thickness of fabric, machine rpm, thread diameter and position of the cross-over point between needle and bobbin thread in a stitch. Some experiments are carried by changing the parameters such as thickness, tension of needle thread and feed rate with high gsm denim fabric on JUKI lockstitch machine. The needle and bobbin threads length per stitch is also calculated. A new model is therefore proposed for the calculation of stitch length in seam balance as well as in any other conditions, depending on the position of needle and bobbin thread cross-over point. To predict the thread consumption in a lock stitch seam, a dynamic analysis of the stitching process is needed.

Keywords: Interlacing point, Lock stitch, Seam balance, Stitch length

1 Introduction

Prediction of the quality of seam and thread consumption from the given parameter like feed rate, thickness of fabric, tension and speed of machine is of importance to avoid defective sample production and to decide quantity of thread required for stitching. The parameters have to be adjusted in such a way that seam balance condition is obtained. The needle thread form the top surface and bobbin thread forms the bottom surface of lock stitch seam, the length of stitch depends on the feed rate, whereas height of seam depends on the thickness and compression of fabric, and the position of cross over point is decided by the flow of yarn due to tension development in the threads.

Different kinds of lock stitch models have been proposed by number of researchers to study the lock stitch seam and the mechanism of seam formation. The different types of proposed models are rectangular stitch model\(^1\), elliptical stitch model\(^2\), 3D rectangular stitch model\(^3\) and lock stitch model\(^4\).

Out of these models, recent model by Jaouadi\(^4\) is successful in predicting thread consumption for lock stitch machine but only for seam balance condition which may not be the case for all the time during stitching. The amount of the sewing thread \(Q_{301}\) needed for the 301 lock stitch, is estimated by the following formula:

\[ Q_{301} = 2L \left[ 1 + 2ne + nd \left( \pi - 1 \right) \right] \]  \( \cdots (1) \)

where \(L\) is the sewing length; \(n\), the stitch density (stitch number per centimeter); \(e\), the fabric thickness; and \(d\), the thread diameter.

A new model is therefore proposed for the calculation of stitch length in seam balance as well as in any other conditions, depending on the position of needle and bobbin thread cross-over point.

2 Materials and Methods

A thick nonwoven fabric is taken as these stitched fabrics can be photographed easily to observe seam configuration and interlacing point. Fabric is stitched using red coloured needle thread and yellow coloured bobbin thread. The fabric is cut across the stitched line to observe the seam configuration.

Figure 1 indicates the actual seam configuration and the positions of interlacing point formed by needle and bobbin threads. Figure 2 indicates a stitch configuration of a lock stitch seam with repeating unit. A unit cell of a seam is having spacing of ‘\(p\)’, The thread length of an unit cell is assumed to be same throughout the seam length for all the repeating unit.

The needle and bobbin thread each having diameter ‘\(d\)’ is stitched on a fabric having thickness ‘\(t\)’ and the threads interlacing point distance is ‘\(y\)’ from the lower surface of fabric or from the surface of bobbin thread. (Fig. 2).
As shown in Fig. 3 the needle thread length in repeating unit of lock stitch seam is \( A'H' \) and bobbin thread length is \( AH \) which consists of curved and straight length of yarn. In a lock stitch seam 301 the needle thread and bobbin thread make an contact angle of 90\(^\circ\) with fabric while going in and coming out of the fabric with an arc \( B'C' \), \( F'G' \) and \( BC, FG \) for needle and bobbin threads. At interlacing point, needle thread crosses over the bobbin thread and vice-versa. Here, the needle thread having an angle of wrap of 180\(^\circ\) around the bobbin thread the bobbin thread also makes an angle 180\(^\circ\) wrap around the needle thread. The thread length present in a repeating unit or in stitch is \( 'L_B' \) for bobbin thread and \( 'L_N' \) for needle thread. It is assumed that the yarn is circular and incompressible in nature. The diameters of needle and bobbin thread are equal; these are also equal to yarn present in a given fabric. The fabric is also incompressible in nature. The model is two dimensional in nature.

2.1 Calculation of Bobbin and Needle Thread Length in a Repeating Unit of Lockstitch Seam

As observed in Fig. 2, the bobbin thread length in a repeating unit \( (L_B) \) is equal to
\[
L_B = AB + \text{Arc } BC + CD + \text{Arc } DE + EF + \text{Arc } FG + GH
\]
\[
\text{Arc } BC = \text{Arc } DE = \pi (d/2 + d/2) = \pi d
\]
\[
CD = FE = y - d
\]
\[
AB = GH = (p/2 - d/2 - d - d/2) = (p/2 - 2d)
\]
\[
L_B = 2\pi d + 2(y-d) + 2(p/2 - 2d)
\]
\[
L_B = 2\pi d + 2(y-d) + (p - 4d) \quad \ldots (2)
\]
Similarly,
\[
L_N = 2\pi d + 2[t-(y+d)] + (p - 4d) \quad \ldots (3)
\]
where \( L_B \) is the bobbin thread length per stitch; \( y \), the position of interlacing point from fabric; \( d \), the diameter of the yarn (needle thread, bobbin thread, warp and weft); \( p \), the spacing of a stitch; and \( L_N \), the needle thread length per stitch.

At seam balance condition for lock stitch seam, needle thread length and bobbin thread length in a stitch are equal, i.e. \( L_N = L_B \). From Eqs (2) and (3), following relationship can be obtained:
\[
2\pi d + 2 \{t-(y+d)} + (p - 4d) = 2\pi d + 2 (y-d) + (p-4d)
\]
or \( t - (y+d) = (y-d)\)
or \( y = t/2\)

Therefore, at seam balance condition the interlacing point position is at middle of seam. Putting this value into Eqs (2) and (3), the equations become \( L_N = L_B = 2\pi d + t + p - 6d \), the same for both needle and bobbin threads.

If the yarn diameter is very small and can be neglected, the above equation will be simplified and the bobbin thread and needle thread length in seam balance condition will be same for both the model and its expression is given below:
\[
L_N = L_B = p + t \quad \ldots (4)
\]

2.2 Expressing Needle and Bobbin Thread Length in terms of Fabric Feed and Machine Speed

The number of stitches per unit length (i.e. stitch density) is decided by rpm of machine and fabric feed rate. To observe the effect of fabric feed on thread
consumption for a given rpm of machine, the needle and bobbin thread Eqs (2) & (3) can be modified.

If ‘F’ is the fabric feed rate in centimeter per minute and the machine is having ‘N’ rotation per minute then the number of stitches per cm is given by the following relationship:

\[ \text{Stitches/cm} = \frac{N}{F} \]

Hence, spacing of a stitch (p) = \( \frac{F}{N} \)

Putting the value of stitch spacing in Eqs (2) & (3), we will get

Bobbin thread length (\( L_B \)) = \( 2\pi d + 2(\frac{F - 4d}{N}) \) ... (5)

Needle thread length (\( L_N \)) = \( 2\pi d + 2[(t - (y + d)) + (\frac{F - 4d}{N})] \) ... (6)

It is clear from Eqs (5) and (6) that for a given fabric and stitching yarn, the needle threads and bobbin threads per stitch increase with the increase in feed rate and reduce with the reduction in feed rate; reverse is true for machine rpm.

The needle and bobbin threads also depend on position of needle and bobbin threads crossover point (y). If y is increases the bobbin thread length increases and needle thread length reduces and vice-versa.

2.3 Preparation of Stitched Samples

Some experiments were carried out on stitching machine using a denim fabric. The fabric having the specifications 322 gsm, threads density 28 × 16 threads/cm, warp count 102 tex and weft count 76 tex, with fabric thickness of 0.92mm was used. The sewing thread of double yarn with final tex value of 23.34 and diameter of 0.0172cm is taken for stitching the fabric on JUKI Lockstitch machine. The same thread is used as needle and bobbin thread for stitching. The fabric is stitched by varying the parameter like tension on needle thread (45g and 130g), feed rate (slow, medium and fast) and the thickness (by stitching with single, double and triple layer of the same fabric) of stitched layers.

For the stitched fabric sample the needle and the bobbin threads length per stitch is measured experimentally. The number of stitches presents in 10 cm stitched fabric is counted and the needle yarn length and bobbin yarn length for the same 10 cm stitched sample is marked. The sewing threads are unraveled from the stitched fabric sample. The needle thread and bobbin thread length are measured by applying 0.1 g/tex load at the end.

Needle/ bobbin thread length per stitch = total length of yarn/ total number of stitches.

The seam spacing is measured by using image analyzer as well as using stitch density data. The interlacing point position (y) between the needle and the bobbin threads within the fabric is theoretically calculated from the experimental data by using theoretical Eqs (2). The experimental data for the three layered stitched fabric is given in Table 1.

## 3 Results and Discussion

The value for needle thread and bobbin thread length single, double and triple layers of fabric are plotted in Fig. 4 at different feeding rates and tension values. It is observed from the figure that with the rise in feed rate both the bobbin as well as needle thread length per stitch increases. However, the bobbin threads lengths per stitch is always higher than the needle thread length per stitch. The bobbin and needle threads lengths per stitch. Increase almost linearly with the increase in feed rate from slow, medium to high. This is due to the fact that at higher feed rate the fabric is moving faster and hence the length of yarn supply from needle and bobbin per seam is increased. This can be explained with the help of Eqs (5) and (6). If everything remains same and only the F value increases, then the thread length per stitch increases.

From Fig. 4, it is clear that with the increase in number of fabric layers, the bobbin thread length per stitch is increased. However, the needle thread length per stitch is marginally changed with the increase in number of layers. As the number of fabric layer is increased, the value of total thickness (t) is increased and the cross-over position of needle and bobbin thread moves upward, resulting in high bobbin thread length in a stitch. This is probably

<table>
<thead>
<tr>
<th>Tension, g</th>
<th>Feed rate</th>
<th>Needle thread length/stitch, cm</th>
<th>Bobbin thread length/stitch, cm</th>
<th>Seam balance</th>
<th>Spacing, cm</th>
<th>Interlacing point position y, cm (from bottom)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>Slow</td>
<td>0.171</td>
<td>0.305</td>
<td>0.561</td>
<td>0.100</td>
<td>0.149</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>0.319</td>
<td>0.569</td>
<td>0.561</td>
<td>0.278</td>
<td>0.163</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>0.581</td>
<td>0.679</td>
<td>0.856</td>
<td>0.465</td>
<td>0.126</td>
</tr>
<tr>
<td>130</td>
<td>Slow</td>
<td>0.108</td>
<td>0.424</td>
<td>0.255</td>
<td>0.100</td>
<td>0.180</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>0.294</td>
<td>0.600</td>
<td>0.491</td>
<td>0.256</td>
<td>0.165</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>0.438</td>
<td>0.763</td>
<td>0.574</td>
<td>0.417</td>
<td>0.174</td>
</tr>
</tbody>
</table>
due to easy availability of bobbin thread with the rise in needle thread tension. This causes the movement of needle and bobbin thread cross-over point (y) upwards, resulting in an increase in bobbin thread length per stitch.

From Fig. 4 it is also clear that with the increase in needle thread input tension from 45g to 130g, the length of bobbin thread required per stitch is increased. As the input tension in bobbin thread is same all the time, so with the increase in needle thread input tension from 45g to 130g the peak tension in needle thread yarn is raised to very high value in the stitching area. At that condition, may be it is easy to pull yarn from bobbin to form the stitch, which is indicated through high bobbin thread length per stitch. Due to high tension in needle thread (130 g tension), the cross over point between needle and bobbin thread may be moved upward as compared to that at 45g tension. This is also indicated by the change in position y in the table. The y-value is calculated theoretically from the experimental data. Furthermore, the difference between needle thread and bobbin thread length per stitch is less for single layer of fabric and this difference goes on increasing with number of layers and at high value of needle thread tension. This may be due to rise in peak tension value of needle thread because of increase in input needle thread tension.

4 Conclusion
4.1 The proposed stitch length calculation model is generalized in nature which can predict the sewing thread consumption in a stitch for any given value of y, i.e. the position of needle and bobbin thread cross over point.
4.2 Propose model is able to predict thread consumption not only at seam balance condition but also at all other possible condition, if y is known.
4.3 The proposed model is also able to explain the effect of feed rate and fabric thickness change on needle and bobbin thread length per stitch which is confirming with practical results.
4.4 The position of y (needle and bobbin thread cross-over point) is very important for this model. This y is basically function of tension in bobbin and needle thread developed during the process of stitch tightening, which probably depends on yarn variables (yarn diameter, yarn rigidity, coefficient of friction etc.), machine variables (take-up arm, needle movement and guide dimensions etc.) and process variables (input tension, feed rate, speed of machine etc.).
4.5 A dynamic analysis of the stitching process is needed to establish the relation between tension development in yarn and location of the position of y. This will ultimately lead to the theoretical prediction of needle and bobbin thread length in a stitch and picks value of yarn tension during stitching.

References
1 Davis W, J Text Inst, 24 (1933) 361.