A Model of Seam Pucker and Its Applications
Part I: Theoretical

by

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Abstract

This paper considers a simple model of the lock stitch (301) seam, and uses it to derive a measure of the severity of puckering in the seam. The numerical value of the measure depends on the bending properties of the fabrics and thread in the seam, together with the tensions in the threads. How the latter may be estimated is discussed.

Keywords

Seam deformation, pucker severity, garment appearance, garment manufacturing.

Introduction

In garment manufacturing, the fabrics and the threads used to sew pieces of fabric together are highly flexible and easily deformed. If the balance between the various elements of a seam, the threads and the tensions in them, the mechanical properties of the threads and fabrics etc. is not right, the seam will often display an unacceptable deformation known as pucker, i.e. a “waviness” of the seam that is unsightly. Much research has been carried out to try to understand this phenomenon (Dorkin 1961; Zorowski and Patel 1970; O'Dwyer 1975; Amirbayat 1990; Stylios 1990; Amirbayat 1991; Inui, et al. 2001; Jin Lian, et al. 2006; Suzaini and Faizul 2013; Fernando, et al. 2014) but an objective method of calculating the extent of pucker that attempts to balance the above mentioned elements has not emerged.

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The present papers develop such a method by considering a simplified model of the situation when two fabrics are joined by means of a lock stitch (301) seam, one of the most commonly used in the garment industry.

Part I describes the development and theory of the model, while Part II describes its verification and application.

A Lock Stitch Model

The basic lock stitch (301) is illustrated in Figure 1.

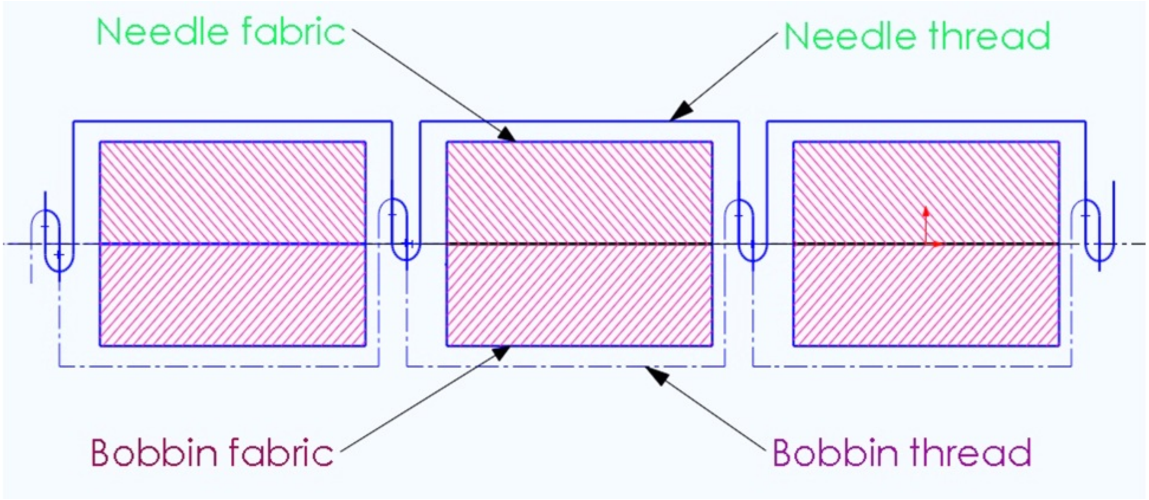


Figure 1. Lock stitch (301) seam profile

The two fabrics are joined by means of two threads, the “needle” thread and the “bobbin” thread, that are locked or interlaced together as shown in the diagram. The two threads generate a normal pressure on the two fabrics, which hold the latter together. A simple idealization of a single stitch of the seam, of length l, is shown in Figure 2.

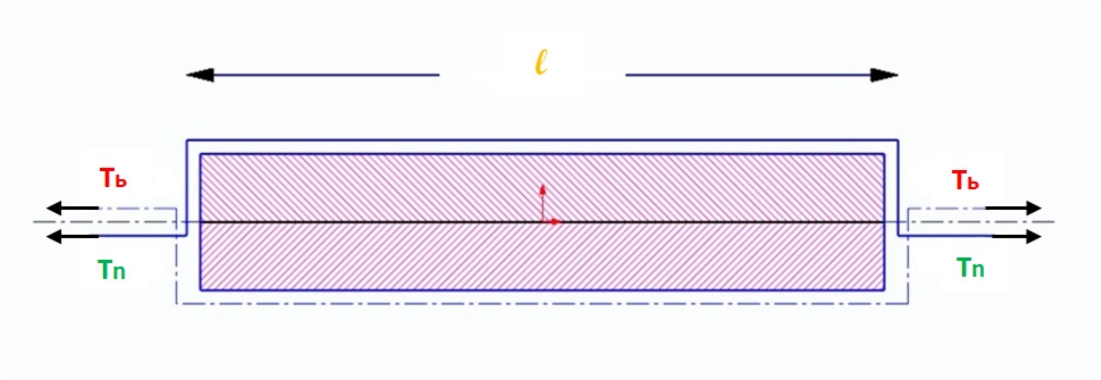


Figure 2. Idealized single stitch

In this diagram T_n and T_b are the tensions in the needle and bobbin threads respectively. As they lie in the formed seam. During the stitching operation the threads are subjected to considerable tension, but once the seam has been formed the tensions decrease in the relaxed seam. We shall regard the seam as a beam of width equal to the diameters of the threads, as shown in Figure 3.

If B_n and B_b are the bending rigidities per unit width of the two fabrics l which; for convenience, we shall refer to as the “needle” and “bobbin” fabrics, the bending rigidities of the parts of the fabrics in the beam are $B_n' = B_n d_n$ and $B_b' = B_b d_b$, where d_n and $d_b$are the diameters of the threads.

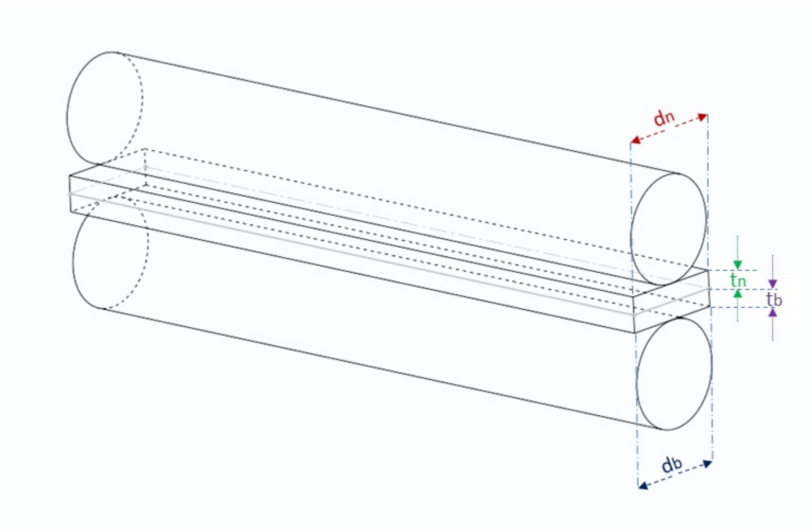


Figure 3 Thickness of the stitched assembly

If $b_n$and $b_b$are the bending rigidities of the needle and bobbin threads and we assume that all members of the beam in Figure 3 bend independently, the bending rigidity of the "equivalent beam" B_e is

$$B_e = B'_n + B'_b + b_n + b_b$$

$$= B_n d_n + B_b d_b + b_n + b_b \dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

When the seam is in equilibrium, this beam will be defined by the pressures generated by the tensions in the threads, as shown in Figure 4.

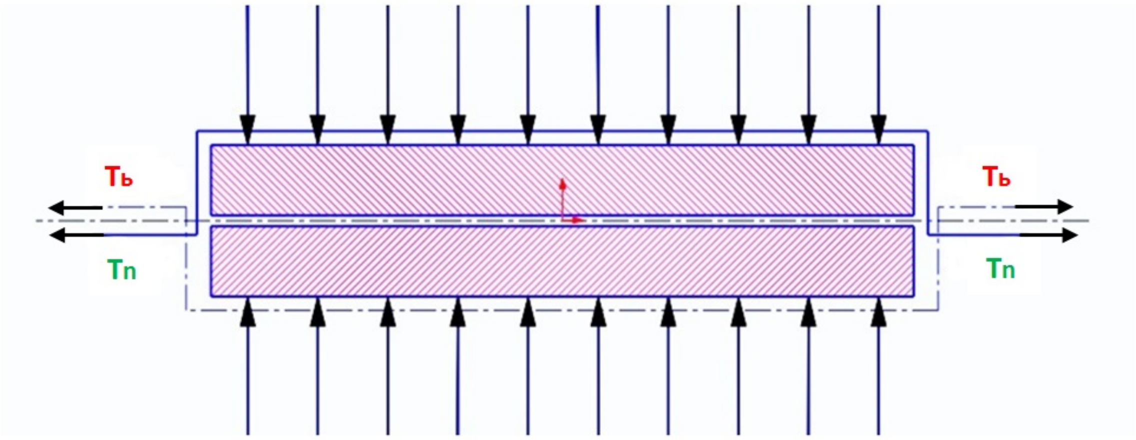


Figure 4 Thread tension produces uniformly distributed pressure

We now assume that the needle thread tension generates a uniformly distributed pressure P_n per unit length. The total downward force on the beam is therefore $P_n l$ and this is provided by the vertical tensions T_n. Thus

$$P_n l = 2T_n ,$$

and similarly

$$P_b l = 2T_b .$$

The resultant uniformly distributed pressure P_d on the beam is therefore

$$P_d = |P_n - P_b| = \frac{2|T_n - T_b|}{l} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

This pressure deforms the beam, which we assume to have built-in ends, as shown in Figure 5.

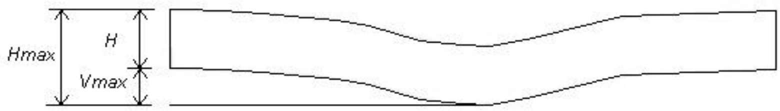


Figure 5 Total stitched fabric thickness

The maximum deflection, V_{max} , of the beam occurs at its centre and is given by (Seed 2000)

$$V_{max} = \frac{P_d l^4}{384 B_e} = \frac{|T_n - T_b| l^3}{192\ B_e} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

where B_e is given by equation (1). V_{max} can be thought of as a measure of the severity of puckering in a seam. However, the same value of V_{max} would be regarded quite differently, from a pucker point of view, if it referred to a seam involving two relatively thin fabrics as opposed to more robust ones. We therefore suggest a measure called "relative pucker" (R_p)

which is defined in the following way. The basic idea is to relate V_{max} to the thickness of the beam assembly. As can be seen from Figure 3 the total thickness of the beam is

$$H = t_n + t_b + d_n + d_b \, , \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where t_n and t_b are the thicknesses of the needle and bobbin fabrics. After the seam has been formed, Figure 5 shows that the overall thickness of the assembly becomes

$$H_{max} = H + V_{max}$$

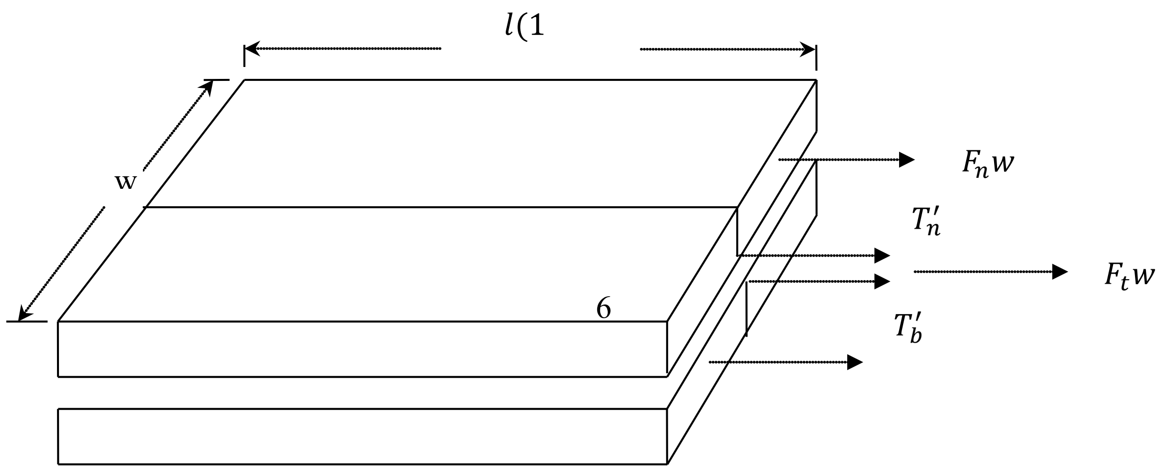
The change in thickness due to the seam is V_{max} and we define relative pucker R_p

$$R_p = \frac{V_{max}}{H} = \frac{V_{max}}{t_n + t_b + d_n + d_b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The estimation of $|T_n - T_b|$

A prominent feature of equation (3) is the appearance of the difference $|T_n - T_b|$ in the thread tensions as they lie in the relaxed seam. Such tensions would be extremely difficult to measure directly without introducing considerable errors of measurement. Therefore a different approach has been employed to estimate the magnitude of $|T_n - T_b|$.

Suppose a length of the joined fabrics, including the seam, is extended parallel to the seam, and let the width of the specimen be w. Consider a single stitch, as shown in Figure 6, extended from length l to length $l(1 + \varepsilon)$.



F_b w

Figure 6 Force components on an individual stitch

The total force $F_t w$ needed to produce an extension ε is made up of several components, as shown in Figure 6. They are

a) Forces $F_n w$ and $F_b w$ needed to extend the two fabrics;
b) the tensions T_n' and T_b' in the extended needle and bobbin threads.

Thus we have

$$F_t w = F_n w + F_b w + T_n' + T_b' \dots\dots\dots\dots\dots\dots\dots.\dots\dots\dots\dots (6)$$

Suppose the fabrics obey Hooke's law for small extensions, i.e.

$$F_n = E_n \varepsilon\,,\ F_b = E_b \varepsilon\,,$$

where E_n and E_b are the Young's moduli of the fabrics.

The thread tensions T_n' and T_b' in the extended seam may be found as follows. We assume that if a tension T is applied to a thread and produces an extension ε_y then

$$T = e\varepsilon\varepsilon_y$$

where e is the thread's Young's modulus. After the seam is formed the tensions in the yarns are T_n and T_b; thus the yarns are already stretched and their natural length is smaller than l. In fact, if l_0 is the natural length we have, for the needle thread,

$$T_n = e_n \varepsilon_y = e_n (l - l_{0n})/l_{0n}\,,$$

leading to

$$l_{0n} = \frac{e_n l}{T_n + e_n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Similarly

$$l_{0\mathrm{b}} = \frac{e_b l}{T_b + e_b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (8)$$

When the seam is extended and the needle thread tension increases to T_n' we find that

$$T_n' = e_n \left\{ \frac{l(1+\varepsilon) - l_{0n}}{l_{0n}} \right\}$$

which leads to

$$T_n' = (1+\varepsilon)(T_n + e_n) - e_n$$

after using equation (7).

Similarly,

$$T_b' = (1+\varepsilon)(T_b + e_b) - e_b$$

Hence in equation (6) we get

$$F_t w = (F_n + F_b)w + (1+\varepsilon)(T_n + e_n) - e_n + (1+\varepsilon)(T_b + e_b) - e_b$$

$$= (E_n + E_b)w\varepsilon + (1+\varepsilon)(T_n + T_b) + \varepsilon(e_n + e_b) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

This equation would allow the sum of the tensions $(T_n + T_b)$ to be estimated. However, we require the size of their difference $(T_n - T_b)$ to be entered in equation (3) to calculate V_{max} . To estimate this difference, consider the following.

Suppose a fairly long piece of seam of length $L = nl$ is clamped between the jaws of a tensile tester, and suppose also that the bobbin thread of a stitch close to the clamps is cut. The bobbin threads in the main part of the seam are still intact and because of friction, will play some role in opposing the seam extension. However, the tensile tester will not measure "see" the bobbin thread tension and equation (9) would apply with $T_b = 0$. The tension T_n

measured by the tensile tester may change slightly to $T_n + \Delta T_n$ say. Hence in equation (8) we get

$$F_{tn}w = (E_n + E_b)w\varepsilon_n + (1 + \varepsilon_n)(T_n + \Delta T_n) + \varepsilon_n(e_n + e_b)$$

Similarly if the needle thread were cut we would get

$$F_{tb}w = (E_n + E_b)w\varepsilon_b + (1 + \varepsilon_b)(T_b + \Delta T_b) + \varepsilon_b(e_n + e_b)$$

If it is arranged that $\varepsilon_n = \varepsilon_b (= \varepsilon_c$ say) and if we make the reasonable assumption that $\Delta T_n \cong \Delta T_b$, subtracting the last two equations leads to

$$(F_{tn} - F_{tb})w \cong (1 + \varepsilon\varepsilon_c)(T_n - T_b)$$

Where F_{tn} and $F_{tb}$are the total loads recorded by the tensile tester.

or

$$(T_n - T_b) = \frac{(F_{tn} - F_{tb})w}{(1 + \varepsilon\varepsilon_c)}$$

i.e.

$$(T_n - T_b) = \frac{(X_n - X_b)}{(1 + \varepsilon\varepsilon_c)} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots (10)$$

Where X_n and X_b are the total loads recorded by the tensile tester.

The use of stiffeners

One method used in industry to counteract puckering is by the use of a "stiffener" introduced between the two fabrics being joined Stylios 2016. The situation is shown diagrammatically in figure 7.

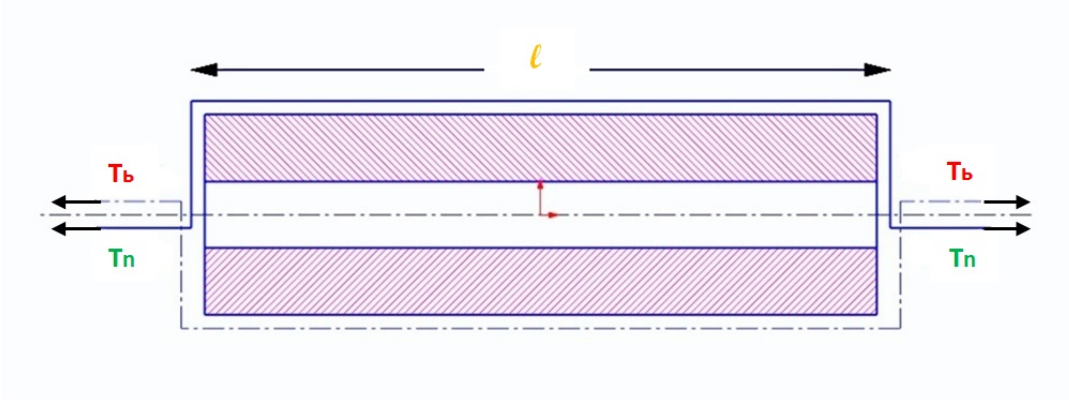


Figure 7 Model of the equivalent beam with stiffener

If the bending rigidity of the stiffener is B_s per unit width, then, if $\bar{d} = \frac{1}{2}(d_n + d_b)$ is the mean thickness of the equivalent beam, we deduce that the contribution of the stiffener to the bending rigidity of the beam is $B_s' = B_s\bar{d}$. The total rigidity of the beam becomes

$$B_{es} = B_e + B_s' = B_e + B_s\bar{d}$$

$$= B_n d_n + B_b d_b + b_n + b_b + B_s\bar{d} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

which is obviously greater than the bending rigidity of the unstiffened beam given by equation (1). Hence the value of V_{max} is reduced and therefore the severity of the puckering. The advantage of this approach is that in a practical case of puckering the properties of the stiffener needed to reduce the severity of puckering to an acceptable level can be calculated.

Conclusion

This paper has presented a simplified model of a lock stitch seam. The model was then used to derive a proposed measure of the severity of puckering in the seam. This measure depends on the bending properties of the fabrics and threads composing the seam and on the difference in the tensions in the needle and bobbin threads as they lie in the seam. A practical method of estimating this difference has been suggested. The experimental verification of the measure and its application are dealt with in Part II.

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