Sewing needle penetration force study

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Introduction

The penetration force of the sewing needle is the quantitative measure of the damage which appears in the garment as the result of the sewing process[1-3]. To get a better look at this process, knowledge of the fabric, the used thread, the sewing needle and the sewing machine mechanisms is important. In this work a mathematical model for the determination of the sewing needle penetration force is developed and the results are compared with measured values[4] for the chosen fabric, sewing needle and sewing machine.

The fabric model

The fabric was modelled as a plain weave fabric. It is a simple combination of parallel warp and parallel weft threads with no friction in the crossings of the threads. For this fabric model we need the thickness of each thread and the distance increment in the warp direction and in the weft direction of the threads. These data are easy to obtain from the fabric with a stereo microscope. The image of such plain weave fabric with one perforation of a sewing needle is shown in Figures 1 and 2. To find the mechanical behaviour of each thread in the fabric a standard tear experiment of the thread was done. The first derivative of the stress-deformation function of the thread measured at the tear experiment gives the Young's module of the thread. For simplification reasons we assume that the material of the thread is just elastic deformed. This means that the thread can be modelled as an ideal Hook's material. The first derivative of the stress-deformation function, for the thread from the plain weave fabric shown in Figure 1 and 2, is shown in Figure 3.

The sewing needle model

The sewing needle tip is modelled as a cone. The geometric data are identical with a normal sewing needle with the number 80. For modelling reasons the sewing needle is simplified. In the study we are looking for the maximum sewing needle penetration force. This force appears when the needle has its eye in the fabric. The cone was geometrically modelled with the correct dimensions from the tip of the sewing needle to the eye.

The model of the mechanism for the sewing needle movement

For the mechanism simulation, for the motor torque transformation into the sewing needle penetration force, a model of a slider-crank transformation

International Journal of Clothing
Science and Technology,
Vol. 9 No. 3, 1997, pp. 241-248.

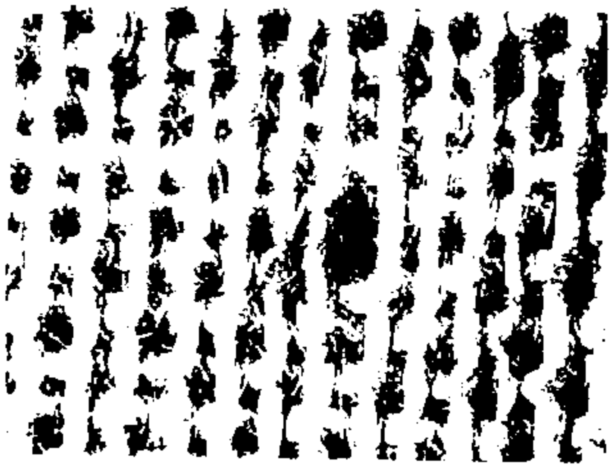

Figure 1.
The plain weave fabric stereo microscope picture with a sewing needle perforation in the warp direction

Figure 2.
The plain weave fabric stereo microscope picture with a sewing needle perforation in the weft direction

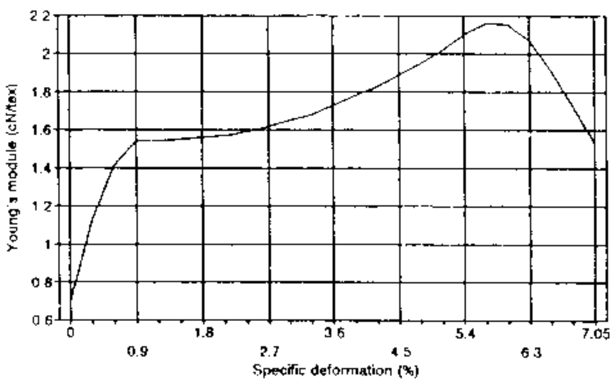

Figure 3.
The Young's module of the thread from the fabric from Figures 1 and 2

mechanism[5] which is built into the sewing machine, is developed (Figure 4). The equations which describes the transformation of the motor torque into the sewing needle penetration force are:

$$\begin{Bmatrix} F_x \\ F_y \end{Bmatrix} = [J]^{-1} \begin{Bmatrix} M \\ 0 \end{Bmatrix} \quad (1)$$

$$[J]^{-1} = \begin{bmatrix} \dfrac{\cos\varphi_3}{r_2.\sin(\varphi_3-\varphi_2)} & \dfrac{\sin\varphi_3}{r_3.\sin(\varphi_3-\varphi_2)} \\ \dfrac{-\cos\varphi_2}{r_2.\sin(\varphi_3-\varphi_2)} & \dfrac{-\sin\varphi_2}{r_3.\sin(\varphi_3-\varphi_2)} \end{bmatrix}. \quad (2)$$

In the equations (1) and (2) F_x is the needle penetration force and F_y is the perpendicular force which acts on the guides, $[J]^{-1}$ is the inverse Jacobian matrix (the transformation matrix between the motor torque M and the needle penetration force F_x). r_2, r_3, φ_2, φ_3 are the geometric and kinematic data of the slider-crank mechanism in Figure 4.

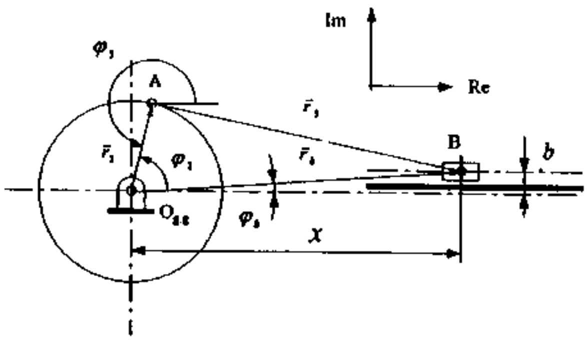

Figure 4. The slider-crank mechanism

The sewing needle penetration force study

For the model being developed, the fabric penetration of the fabric with the sewing needle, some restrictions must be done. As mentioned earlier the fabric is a combination of parallel warp and weft threads with no friction in the connections. The sewing needle is a simple geometric cone which penetrates into the fabric in such a way that the threads are not damaged but just elastic deformed Figure 5.

The threads are treated as pure Hook's material. This means that just elastic deformations in the thread, when it is deformed, appear. The elastic deformation in each thread causes a force which then causes the normal force between the deformed thread and the sewing needle. This normal force produces the friction force of one thread because of the friction between the thread and the sewing needle.

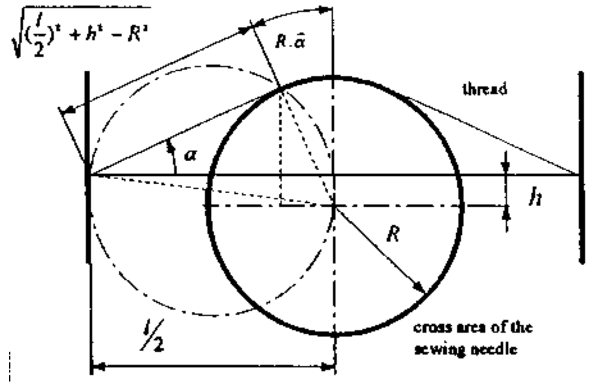

Figure 5.
The sewing needle penetration model

The force in the thread when it is deformed is:

$$F = A.\varepsilon.E = A.E.\frac{2.(R.\hat{a} + \sqrt{(\frac{1}{2})^2 - h^2 - R^2}) - l}{l}. \tag{3}$$

The normal force produced in the thread (Figure 6) is:

$$F_N = \frac{F.l}{\frac{1}{2} + \frac{\Delta l}{2}}. \tag{4}$$

If more threads in the penetration process are deformed, the total normal force is:

$$F_N = \sum_{i=1}^{N_R} F_{Ni}. \tag{5}$$

The total sewing needle penetration force as a function of the friction coefficient is:

$$F_T = F_N.\mu. \tag{6}$$

The coefficient of friction was measured with the friction meter for the combination threadsteel (sewing needle material).

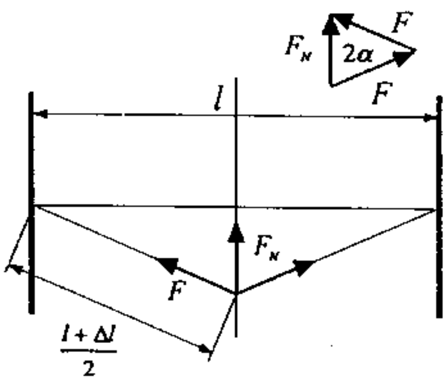

Figure 6.
The force system and the normal force F_N on the elastic deformed thread

In the equations (3) to (6) are: ε is the specific deformation of the thread, A is the cross area of the thread, E is the Young's module of the thread, R is the actual sewing needle radius, h is the distance increment between the parallel warp threads and parallel weft threads, l is the length of the thread which is in the penetration process deformed, F_N is the normal force of the deformed thread and μ is the friction coefficient.

Example

As mentioned earlier the fabric is a plain weave fabric with 295 warp threads per 10cm and 270 weft threads per 10cm. The thread (warp and weft threads) are spun from 100 per cent cotton. The Youngs module for the mentioned thread as a function of the specific deformation is shown in Figure 3. The friction coefficient is measured on the friction meter. The value of this coefficient, for very slow movements of the thread around the guides, is

$$\mu = 0.12. \qquad (7)$$

The penetration force, the friction force between the sewing needle and the fabric is as the function of the needle penetration shown in the Table I and in Figure 7.

Sewing needle penetration force measuring

The sewing needle penetration force was measured on the Brother EXEDRA DB2-B737-913 Mark II sewing machine. The measuring device, with strain gauges, is our own construction. The results are shown as a print from the HP

Sewing needle penetration (mm)	Actual sewing needle radius (mm)	Number of elastic deformed threads	Total frictional force between the needle and the fabric (cN)
0.0	0.000	0	0.000000
0.2	0.025	0	0.000000
0.4	0.050	0	0.000000
0.6	0.075	0	0.000000
0.8	0.100	0	0.000000
1.0	0.125	4	0.002627
1.2	0.150	4	0.010948
1.4	0.175	4	0.025282
1.6	0.200	4	0.065920
1.8	0.225	4	0.107460
2.0	0.250	4	0.187298
2.2	0.275	4	0.274123
2.4	0.300	4	0.357381
2.6	0.325	4	0.456901
2.8	0.350	4	0.574037
3.0	0.375	8	0.713514
3.2	0.400	8	0.908502
3.4	0.425	8	1.111404
3.6	0.450	8	1.409497

Table I. The sewing needle penetration force (the total frictional force between the sewing needle and the fabric) as a function of the needle penetration into the fabric

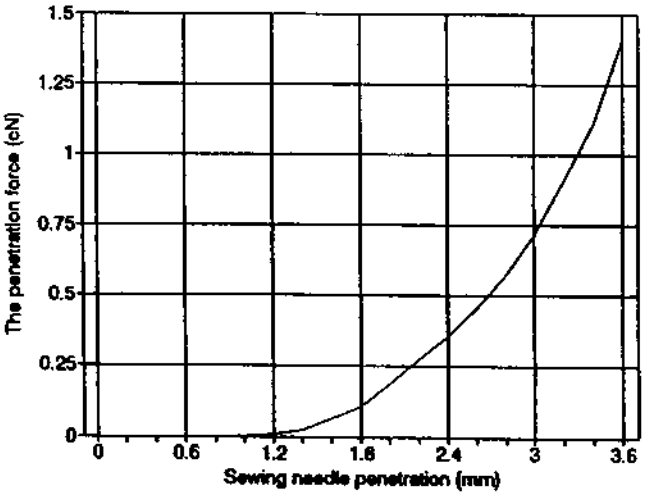

Figure 7. The sewing needle penetration force with respect to the sewing needle penetration into the fabric

54501A digital oscilloscope with the printer HP 2225. The measuring was done with the sewing machine shaft speed $\omega = 47.59\ rd/s$. The print of the measured sewing needle penetration force as the function of time (the rotation of the sewing machine shaft) is shown in Figures 8 and 9.

Conclusion

The mathematical model for the calculation of the sewing needle penetration force is an experiment which could show how it is possible to get better mathematical models of the fabric through simple experiments and

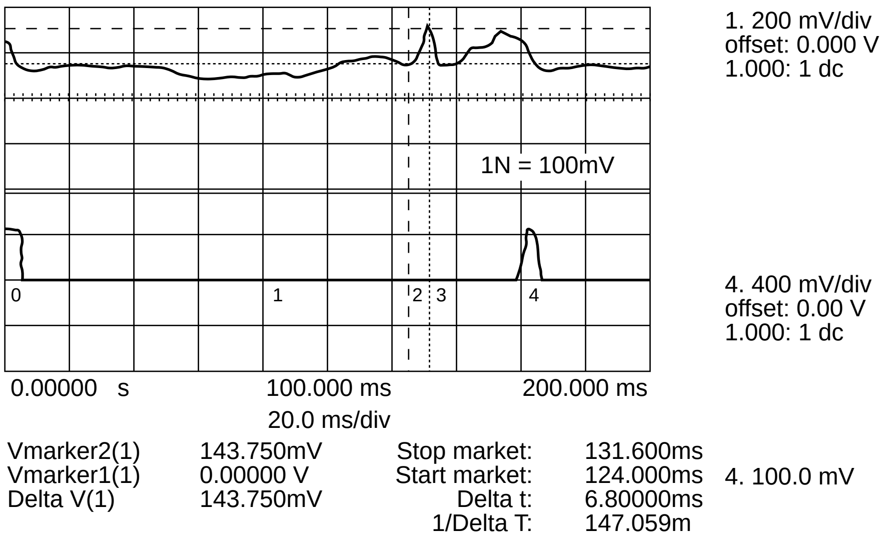

Figure 8. The measured sewing needle penetration force for the seam in the warp direction

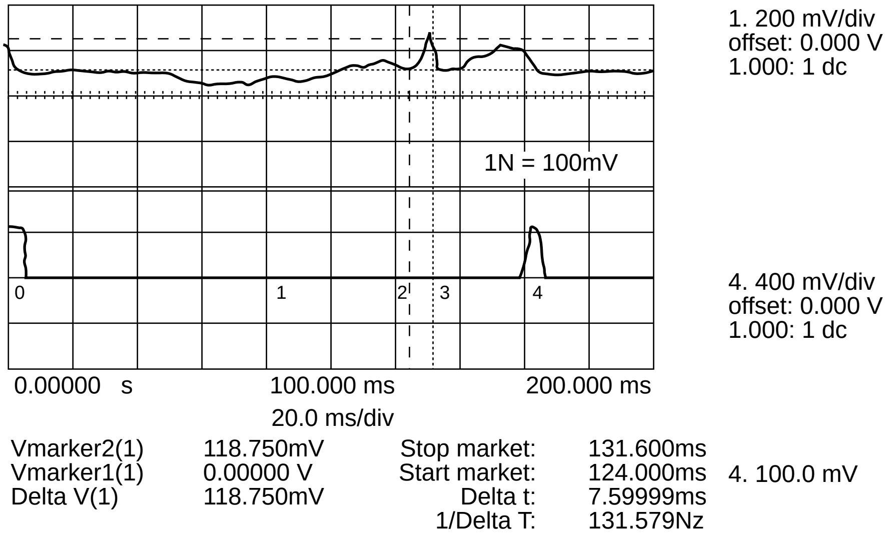

Figure 9. The measured sewing needle penetration force for the seam in the weft direction

mathematical background. The penetration force of the sewing needle could also be measured and this fact gives us the answer as to how far or how near to the correct material model of the fabric the hypotheses presented in this work are.

The comparison of the measured and calculated values shows that the values are very different. Thus means that the mathematical model must be further developed in the following directions:

- Better knowledge of the fabric and the threads in the fabric is needed.
- Better knowledge is required of the mechanical properties of the thread in the fabric and the interaction of the threads of the fabric. Figures 1 and 2 show different perforations dependent on whether the seam is in the warp or weft direction. The presented model deals with constant mechanical properties of the thread. Figure 3 shows that the rheological behaviour of the thread changes with the growth of deformation.
- A better geometrical model of the sewing needle is needed.
- The coefficient of friction is the function of the sewing needle penetration speed. So the coefficient must be determined as the function of this speed.
- The process of fabric penetration presented in this work is the simplest possible. It is also possible that the thread is damaged by the sewing needle damages the thread or a knot in the fabric. The real penetration force is then a statistical combination of these different possible modes (the deformation of the threads, the damage of one or more threads and the damage of a knot in the fabric).

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