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Computer Simulation of Needle and Take-up Lever Mechanism Using the ADAMS Software Package

Abstract
A knowledge of the interactions between a sewing machine's mechanisms and the sewing thread in the stitch formation process should help us to understand thread loadings in the sewing process. The aim of this work is to analyse the needle bar's kinematics with the thread take-up lever by using computer simulation. A cyclogram was drawn on the basis of modelling and kinematic simulation of a needle bar with a thread take-up lever, and measurements of the thread tension forces in the sewing process. This cyclogram enables analysis of the interactions between the thread and the elements of the sewing machine. The results of these simulations are curves that describe the movements at characteristic points on the mechanism. These give the possibility of pinpointing the exact positions of the mechanism's elements with respect to the main shaft rotation in the sewing machine.

Key words: *computer simulation, stitch formation process, cyclogram, sewing thread loading.*

Introduction

Knowledge of the mechanisms' kinematics in the sewing machine and interaction with the thread in the characteristic parts of the stitch formation process is important in order to obtain the best possible insight into the stitch formation process. Exact data concerning the time-dependent movement of sewing machine mechanisms cannot be obtained by observation alone. The use of computer programs is necessary to obtain quality information about thread dynamics and loadings in the stitch formation process. These programs enable kinematic simulations of the mechanisms.

The stitch formation process has not changed much throughout the history of the sewing machine. The cycle of the straight lockstitch sewing machine is as follows:

- The needle with the sewing thread penetrates the fabric and leads the thread through the stitch plate to the lower dead point (LDP). This point is about 8-10 mm below the stitch plate.
- As the needle moves up, the thread in the long groove slides down.
- The part of the thread in the needle short groove moves up with the needle. Because of the friction between the thread and the needle, and because the thread is no longer tensioned when the needle moves up, the movement of the thread on the short groove side of the needle is slower than the needle, so the thread forms a loop.
- The thread take-up lever moves down and reaches the LDP. It supplies the necessary length of thread to widen the loop. The point of the hook catches the needle thread loop close to the needle eye and starts to enlarge the loop. In the meantime the needle moves to the upper dead point (UDP).
- The needle reaches the UDP and starts to move down, the thread take-up lever moves up and tugs the unused thread from the stitch plate and fabric.
- The loop of the needle thread slides down from the hook and interlaces with the bobbin's thread.
- The thread take-up lever moves to the upper position and pulls both threads through the stitch hole into the fabric.
- At the moment when the thread take-up lever reaches its UDP and the tension in the thread becomes greater than the friction force in the thread tension regulator, the needle thread is pulled over the tension regulator and the bobbin thread from the bobbin, ready for the next stitch.
- The needle moves down and before it penetrates the fabric again the material feeder pushes the fabric forward for the next stitch.

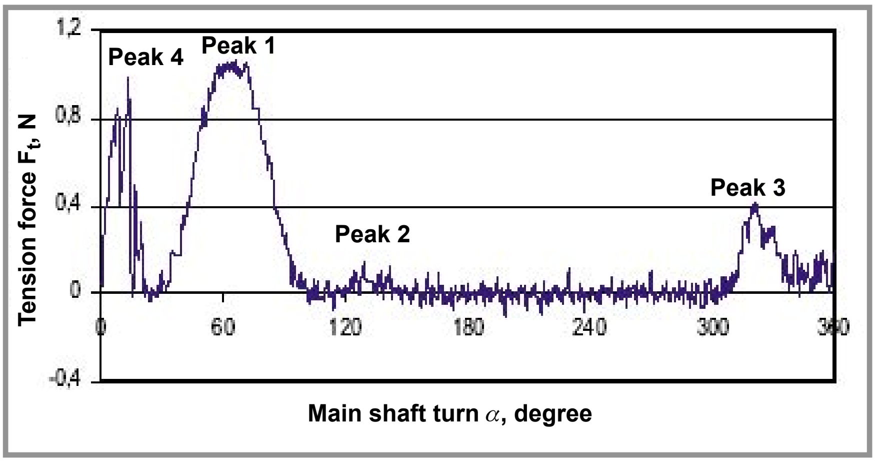

Figure 1. Thread tension force in the stitch formation process.

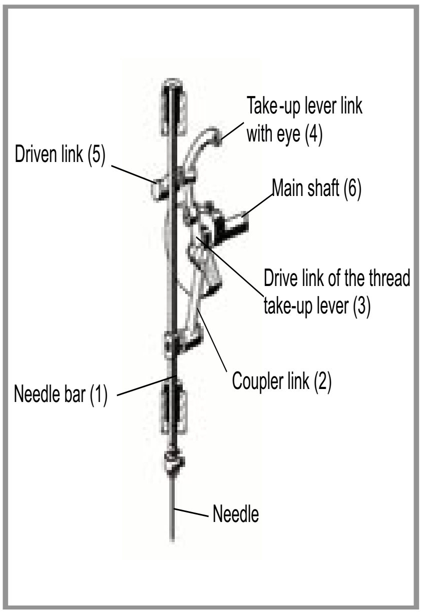

Figure 2. *Needle bar and thread take-up lever mechanism.*

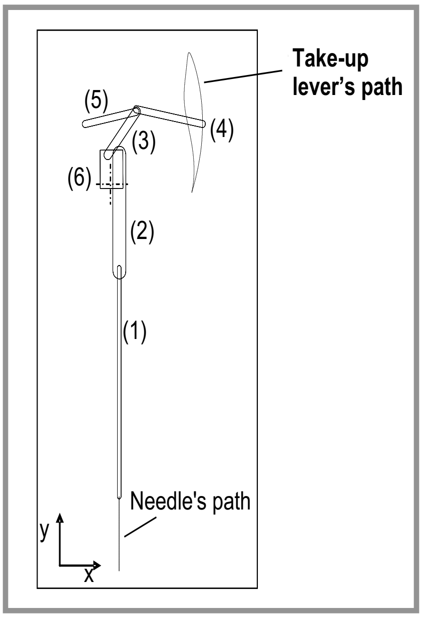

Figure 4. *Needle bar and take-up lever mechanism model; 1 - needle bar, 2- coupler link, 3 - drive link of the thread take-up lever, 4 - take-up lever link with eye, 5 - driven link, 6 - main shaft.*

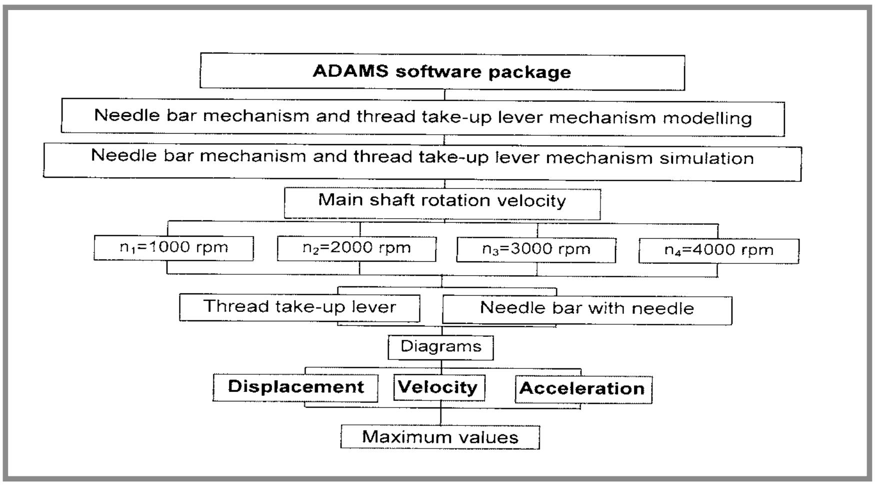

Figure 3. *Modelling process and simulation of the needle bar and thread take-up lever mechanism.*

Dynamic Thread Loadings

The thread is exposed to different forces during the stitch formation process. Dynamic thread loadings are caused with technologically dependent forces, or the so-called functional constrained forces [1]. These forces act on the thread throughout the sewing machine mechanism, the thread take-up lever, needle and hook, and they are dependent on the stitch cycle. The needle thread tension force in the stitch formation process can be seen in Figure 1 [2].

Some characteristic peaks are identified in the diagram (Figure 1). Peak 1 is dependent on the tension force in the thread at the moment when the interlaced threads are pulled into the fabric. This peak depends on a tension regulator adjustment which at that moment, through the thread take-up lever, gives the amount of thread needed for the next stitch. The force responsible for stitch pulling influences the correct interlacing between the needle's and bobbin's thread [1]. Peak 2 depends on the thread tension force when the needle penetrates the fabric. The needle pushes the thread down, which causes friction between the needle and the thread, and also between the thread and the fabric being penetrated. After the hook catches and widens the needle thread loop around the bobbin case, the take-up lever tugs the needle thread upwards, and the tension force becomes greater, which can be seen as peak 3. This peak can spread into more peaks. When the needle thread loop slides from the hook and the thread take-up lever pulls it up, the needle thread interlaces with the bobbin thread, thus causing greater tension force, as shown at peak 4.

The shapes and heights of the peaks change depending on certain sewing machine parameters: rotation velocity, pre-tension on the tension regulator, needle thickness, as well as on material parameters: thread linear density, thread twist, and others [3,4].

Sewing Machine Mechanisms

In the stitch formation process, the thread slips around or through sewing machine guides of different shapes. It slips over a stick guide, flat guide, pre-tensioner, tension regulator, tension spring, angular guide, thread take-up lever, a hole in the needle bar, and through the needle eye. The movements of the sewing machine mechanisms cause thread movement. The guides, which are moving, form paths with respect to the main shaft rotation. Exact representations of the thread take-up lever and the needle bar are given in the next chapter.

The needle bar and the needle

The function of the needle, which is fixed to the needle bar, is to penetrate the fabric and carry the thread under the stitch plate where the loop is formed. Transformation of the main shaft rotation into the translation of the needle bar is done using the slider-crank mechanism, which is connected to the main shaft bolt at one end and to the slider block and needle bar at the other. The needle bar is guided in linear bearings.

The displacement of the needle bar is assigned as s_i and depends on the rotation of the main shaft from 0° to 360°. This movement rises to its maximum value at φ=180°. The value of the movement s_i decreases during the rotation of the main shaft from 180° to 360°, and at 360° reaches its minimal value. The movement of needle bar s_i is a function of length of the driven link, the main shaft's rotation angle and the coupler link's length [5,6]. The displacement of the needle bar is highly non-linear. Velocity and acceleration of the needle bar are functions of the driven link's length, the main shaft's rotation angle, the coupler link's length and the link's angular velocity [5,6].

Thread take-up lever

The function of the thread take-up lever in the stitch formation process is to ensure appropriate thread feeding. In some parts of the stitch formation process, more thread is available than is needed for loop forming.

The mechanism (the four-link mechanism) is connected to the eccentric bolt on the main shaft where the coupler link of the needle bar mechanism is also connected (Figure 2). The kinematic equations describing the motion of such a mechanism are complicated. The coupler link path is a complicated curve, and it is hard to define a mathematical formulation to describe it.

Methodical Approach

To ensure the quality of stitch, it is important to know:
- the interaction between the elements of the sewing machine and the sewing thread, and
- the influence of the sewing machine parameters and the thread properties on thread loading.

The following measurement equipment is used for measuring thread loading and the simulation of the sewing machine mechanism's kinematics:
- a Brother EXEDRA DB2-B737-913 sewing machine,
- ADAMS computer software for motion simulation [7], and
- a measuring system for thread tension force measurement.

The forces that act in the stitch formation process on the thread are measured on the Brother EXEDRA DB2-B737-913 sewing machine. This is a one-needle basic sewing machine for straight lockstitch, stitch type 301. The needle bar mechanisms with a thread take-up lever are modelled using the ADAMS software package in accordance with the data of this sewing machine.

Analyses of the acting forces show that the thread take-up lever and the needle have major influence. With respect to rotation of the main shaft, these two elements influence the thread movement and cause loading in it. To obtain insight into the movements, velocities and accelerations of these two elements, they were modelled and their movements simulated using the ADAMS (Automatic Dynamic Analysis of Mechanical Systems) software package. This software enables model verification and automatic development & solving of motion equations for kinematics, quasi-static or dynamic simulation. The ADAMS/View program enables graphical modelling and visualisation. The modelling process consists of the forming and assembling of parts connected to different kinds of joints and motion generators. Analysis of the model in the ADAMS/Solver package was carried out after modelling. The model's behaviour in the ADAMS/Solver is described by six dynamic and six kinematic equations for each body, with algebraic equations for joints between the bodies and user-defined equations.

Model verification must verify whether the model moves accurately, as desired, and whether the forces have the appropriate values. Kinematic analysis using path generation and calculation of the velocity and acceleration were all carried out after verification. The fundamental movement of the system can be verified on the basis of these values. When using ADAMS/View, the movement is first animated and then the results are shown in graphic form. A flow chart showing the use of the ADAMS software package is shown in Figure 3.

Measuring system for thread tension force measurement

To obtain an insight into the stitch formation process, the correlation between the moving mechanisms of the needle bar, thread take-up lever and thread must be investigated. A measurement system was built up for force measurements. This system consists of a tension force sensor, a DMC-plus amplifier from HBM

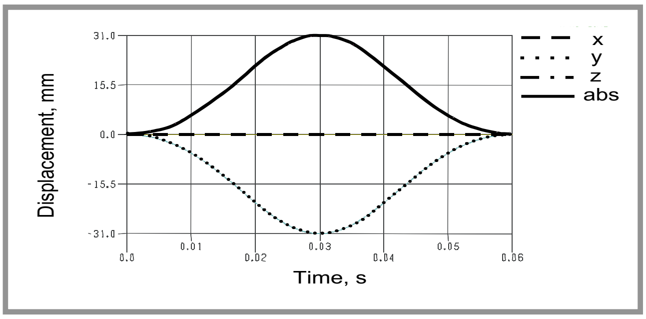

Figure 5. Diagram of needle movement at stitch velocity n_1=1000 rpm depending on main shaft turn.

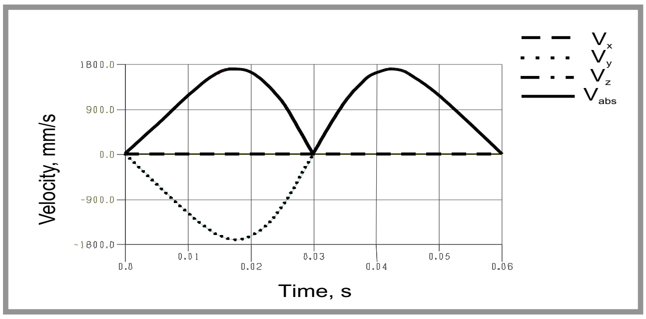

Figure 6. Diagram of needle velocity at stitch velocity n_1=1000 rpm depending on main shaft turn.

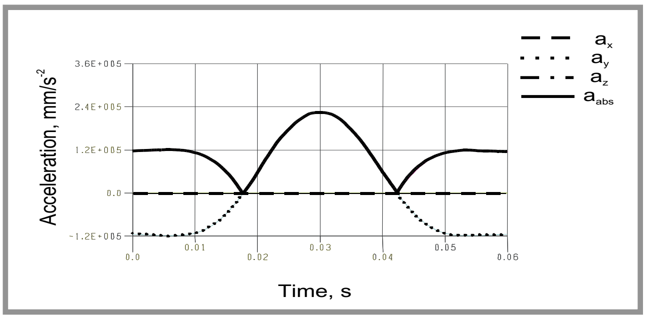

Figure 7. Diagram of needle acceleration at stitch velocity n_1=1000 rpm depending on main shaft turn.

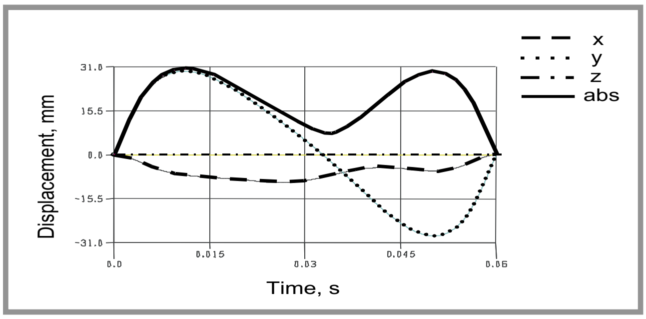

Figure 8. Diagram of take-up lever eye movement at stitch velocity n_1=1000 rpm depending on main shaft turn.

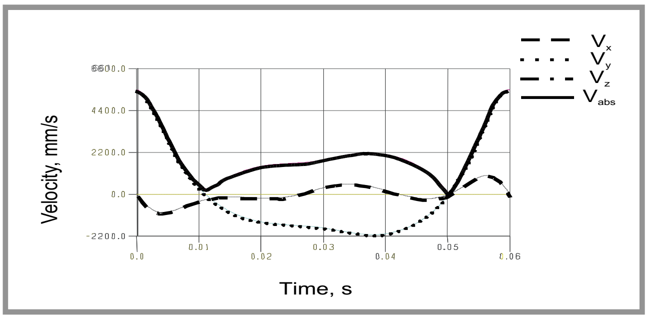

Figure 9. Diagram of take-up lever eye velocity at stitch velocity n_1=1000 rpm depending on main shaft turn.

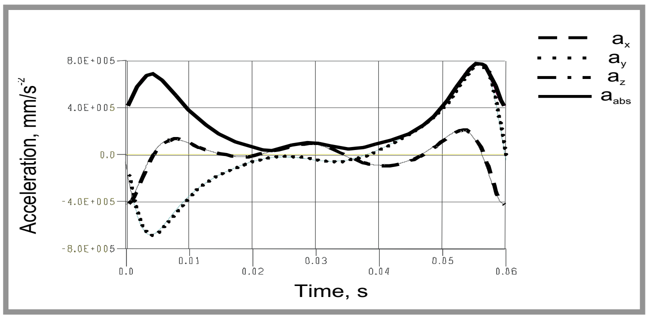

Figure 10. Diagram of take-up lever eye acceleration at stitch velocity n_1=1000 rpm depending on main shaft turn.

with CATMAN software, and a personal computer. This measurement system enables measurements and visualisation of thread tension force in numerical or graphical forms.

Results

The result of the modelling and simulation of a needle bar mechanism and the take-up lever using the ADAMS software package are presented in Figure 4. The paths of the needle and the take-up lever eye are also in this figure.

When the needle moves, the displacement s_i is 31 mm; its upper position is defined at 0° and its lower position at 180° of the sewing machine's main shaft turn. Common movement of the take-up lever s_n is 58.14 mm. The upper position in the y direction is reached at 66° of the main shaft turn, and the lower position at 302°. The rotation angle is calculated using the time needed for one turn of the sewing machine's main shaft.

The results of needle eye movement depending on the sewing machine's main shaft turn at stitch velocity n_1=1000 rpm are presented in Figures 5 to 7. The results of the take-up lever movement analyses are presented in Figures 8 to 10. In the diagrams the paths, velocities and accelerations in the x, y and z directions (the directions x, y and z are shown in Figure 4) are given for the points defined on the take-up lever eye. The values in the diagrams are defined as:

$$abs = \sqrt{x^2 + y^2 + z^2}$$

$$v_{abs} = \sqrt{v_x^2 + v_y^2 + v_z^2}$$

$$a_{abs} = \sqrt{a_x^2 + a_y^2 + a_z^2}\,.$$

The maximum values of sewing needle and take-up lever velocity and acceleration obtained from the ADAMS analyses are given in Tables 1 to 3 for particular positions of the main shaft, depending on stitch velocity.

The influence of the sewing needle and take-up lever velocity and acceleration on the calculated maximum values is shown in Figures 11 to 14. The cyclogram (Figure 15) shows the sewing needle and take-up lever displacement diagram together with thread tension force at stitch velocity n_1=1000 rpm, depending on main shaft turn.

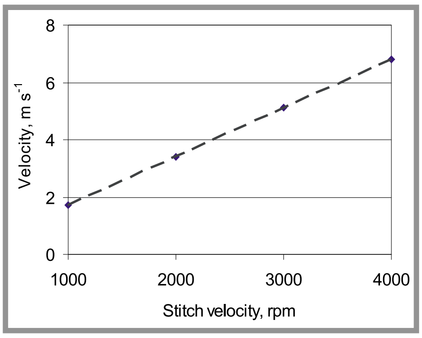

Figure 11. Velocity of needle bar or sewing needle v_{max1} (α=106°) depending on stitch velocity.

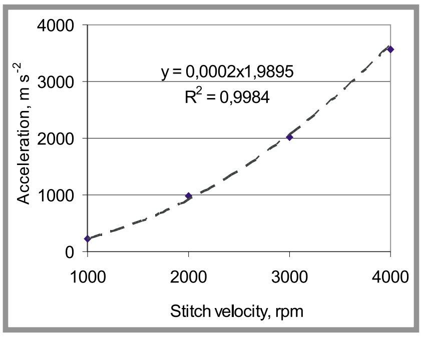

Figure 12. Acceleration of needle bar or sewing needle a_{max2-y} (α=180°) depending on stitch velocity.

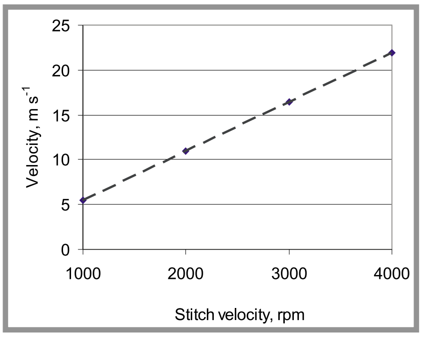

Figure 13. Velocity of take-up-lever eye v_{max1-y} (α=0°) depending on stitch velocity.

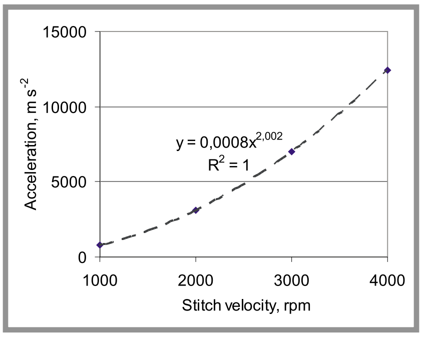

Figure 14. Acceleration of take-up-lever eye a_{max2-y} (α=334°) depending on stitch velocity.

Discussion

Data regarding the movement of the observed point at the take-up lever eye and sewing needle, respectively of the needle bar (Figure 4), can be obtained from a needle bar and take-up lever displacement simulation. The results enable exact analyses of these two sewing machine elements depending on the sewing machine's main shaft turn and the determination of any interaction between the mechanism analysed and the sewing thread.

We can see from the needle bar and take-up lever displacement simulation (path, velocity and acceleration diagrams of the observed point) that the needle makes a displacement of s_i=31 mm and the take-up lever of 58.14 mm in the vertical direction. The upper needle's position is defined at 0° and the lower position at 180° main shaft turn. Furthermore, the upper take-up lever's position in the y-direction is defined at a main shaft turn of 66° and a lower position of 302° (Figure 8). The diagrams in Figures 6, 7, 9 and 10 show where the maximum velocities and accelerations are reached. The highest values of needle velocity were achieved at main shaft turns of 106° and 254° (Table 1), and for the take-up lever at 359° (Table 2). Furthermore, the highest values of needle acceleration were achieved at main shaft turn of 180° (Table 1), and for the take-up lever at 333° (Table 3).

The simulations of the needle and take-up lever movement were made at four stitch velocities, from which the influences of stitch velocity on needle and take-up lever eye velocity and acceleration were determined. The results show that, with increasing stitch velocity from 1000 rpm to 4000 rpm, the maximum needle velocity increases from 1.70 m·s^{-1} to 6.80 m·s^{-1} (Table 1), and the maximum take-up lever velocity from 5.48 m·s^{-1} to 21.88 m·s^{-1} (Table 2). This increase is linear (Figures 11 and 13).

The increase in stitch velocity also influences the acceleration changes: the needle acceleration increases from 224.0 m·s^{-2} (n_1=1000 rpm) to 3573.7 m·s^{-2} (n_4=4000 rpm) (Table 1), and take-up lever eye acceleration from 780 m·s^{-2} (n_1=1000 rpm) to 12444 m·s^{-2} (n_4=4000 rpm) (Table 3). Acceleration increases with increasing stitch velocity by non-linear function (Figures 12 and 14).

In the cyclogram (Figure 15), the sewing thread tension force and the particular movements of the sewing machine's elements are presented, depending on the sewing machine's main shaft turn. From this special combined diagram, it can be seen how the movement of the take-up lever and the movement of the needle influence the thread tension force peaks. Peak 1 appears in the area where the take-up lever moves upwards and reaches its UDP, while peak 2 is located in the area where the needle moves down and penetrates into the fabric. Peak 3 is connected with the next movement of the take-up lever from the LDP upward, when it starts to tug the needle thread upwards. Peak 3 depends also on the bobbin's rotation; however, this is not taken into consideration within this contribution. Peak 4 is the result of the

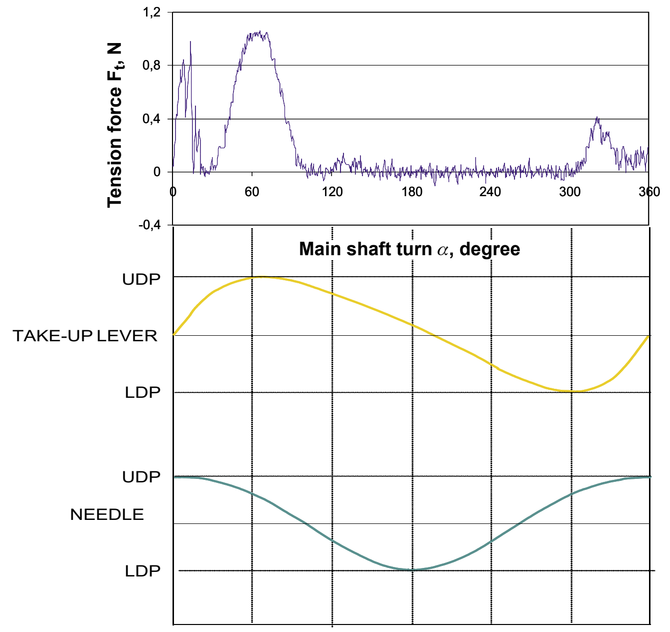

***Figure 15.** Cyclogram of sewing machine mechanism displacement in connection with sewing thread tension force depending on main shaft turn.*

***Table 1.** The maximum values of sewing needle velocity and acceleration, regarding the main shaft turn and analysed stitch velocities (v_{max1-y} - the maximum sewing needle velocity -1 in y direction, m·s^{-1}; v_{max2-y} - the maximum sewing needle velocity -2 in y direction, m·s^{-1}; v_{abs} - the absolute maximum sewing needle velocity, m·s^{-1}; a_{max1-y} - the maximum sewing needle acceleration-1 in y direction, m·s^{-2}; a_{max2-y} - the maximum sewing needle acceleration--2 in y direction, m·s^{-2}; a_{abs} -the absolute maximum sewing needle acceleration, m·s^{-2}).*

Sign for velocity or acceleration	Main shaft turn α, degree	Stitch velocity n, rpm			
		1000	2000	3000	4000
$v_{max1-y} = v_{max2-y} = v_{abs}$	106; 254	1.7	3.41	5.11	6.8
a_{max1-y}	38	119	476.1	1071.3	1898.5
$a_{max2-y} = a_{abs}$	180	224	986.3	2016.6	3573.7

***Table 2.** The values of take-up lever eye velocity, regarding the main shaft turn and analysed stitch velocities (v_{max1-y} - the maximum thread take-up lever eye velocity -1 in y direction, m·s^{-1}; v_{max2-y} - the maximum take-up lever eye velocity -2 in y direction, m·s^{-1}; v_{max3-y} - the maximum take-up lever eye velocity -3 in y direction, m·s^{-1}; v_{abs} - the absolute take-up lever eye velocity, m·s^{-1}).*

Sign for velocity	Main shaft turn α, degree	Stitch velocity n, rpm			
		1000	2000	3000	4000
$v_{max1-y} = v_{max3-y}$	0; 359	5.48	10.95	16.43	21.87
v_{max2-y}	228	2.12	4.24	6.35	8.46
v_{abs}	359	5.48	10.95	16.43	21.88

***Table 3.** The values of take-up lever eye acceleration, regarding main shaft turn and analysed stitch velocities (a_{max1-y} - the maximum take-up lever eye acceleration-1 in y direction, m·s^{-2}; a_{max2-y} - the maximum take-up lever eye acceleration -2 in y direction, m·s^{-2}; a_{a-UDP} - the maximum take-up lever eye acceleration amplitude in upper position of the take up lever, m·s^{-2}; a_{a-max} - the maximum take-up lever eye acceleration amplitude, m·s^{-2}).*

Sign for acceleration	Main shaft turn α, degree	Stitch velocity n, rpm			
		1000	2000	3000	4000
a_{max1-y}	23	683	2733	6149	10912
a_{max2-y}	334	775	3102	6979	12443
a_{a-UDP}	66	312	1247	2812	4947
a_{a-max}	333	780	3121	7022	12444

interlacing of both threads and their being pulled into the sewing material. The movement of the thread take-up lever upwards causes this peak.

Conclusion

Knowledge of the interaction between sewing machine mechanisms and sewing thread, and the influence of some sewing machine parameters to alter thread loading in the stitch formation process is important for optimising the sewing process.

On the basis of this needle and take-up lever simulation, it was determined that with increasing stitch velocity the needle bar and take-up lever velocity changes linearly, but on the other hand the acceleration performs a non-linear function. At higher stitch velocities the acceleration increases, and this influences the increase of sewing thread inertial forces and through this the tension force.

The results of this simulation enable exact definition of the needle and take--up lever eye positions and a detailed description of the stitch formation process, depending on the sewing machine's main shaft turn.

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Received 12.06.2003 Reviewed 06.10.2003