Ryszard Przytulski

Department of Mechanics of Textile Machines
Faculty of Material Engineering and Textile DesignTechnical University of Łódź
Ul. Zeromskiego 116, 90-543 Łódź
E-mail: rprzytul@p.lodz.pl

Influence of Technological Loads on the Dynamic of the Driving System of an Overedge Sewing Machine

Abstract
This article concerns the evaluation of the influence of technological loads caused by mechanism elements of a three-thread overedge sewing machine on the dynamic of its driving system concerning the cycle of steady-state motion conditions. On the basis of a physical model of such a machine with an elastic belt drive, a system of dynamic movement equations was elaborated and completed by a differential equation of the driving motor moment. The system of these equation was numerically soluted. The characteristics of the dynamic changes of forces in the particular threads, which take part in the process of creation of the stitch and are known from literature publications, were considered in the calculations. The results of a computer simulation of the sewing machine dynamic were graphically illustrated.

Key words: *overedge sewing machine, technological loads, dynamic of mechanisms, computer simulation.*

Description

$R_m R_w$ – radii of belt wheels,
Φ_1 – angle of main shaft position,
Φ_m – angle of instantaneous position of the motor rotor,
α_i β_i – angles of mechanism elements' position,
m_{ig} – mass of needle unit elements,
u_{ig} – needle unit displacement,
B_i – mass inertia moments of mechanism's links reduced to a selected point i,
N_{ig} – forces caused by thread action on the needle unit,
N_T – transportation force of the connected fabrics,
N_P – needle unit load caused by thread tension,
$N_3 N_5$ – forces of technological action of threads on grippers,
$e_3 e_5$ – radii of action of forces N_3 and N_5,
M_i – moments caused by forces in relation to a particular joint i,
L_i – geometrical parameters of the mechanism,
F_p – instantaneous force in a belt,
S_p – belt rigidity,
D_p – dumping coefficient,
M_m – moment of the motor shaft,
ω_m – angular speed of the rotor,
T – time constant,
C_m – rigidity of the motor characteristic,
i – index that describes by letters the mechanism joints or by numbers the number of a link.

Introduction

The aim of this work was to establish by computer simulation the influence of reverse motion of the elements of spatial lever mechanisms of a three-way overlock machine on the dynamic of its elastic driving system. The evaluation of the influence of dynamical technological loads of the machine's working elements over one machine cycle on the dynamic of the drive was also interesting.

The generation of forces in the threads and needles of a sewing machine, as well as their analysis, has been the subject of several works [2, 3]. The oscillograms recorded and discussed in the literature indicate that the dynamic tensions in sewing threads during the sewing process have a periodical changing character over one working cycle of the machine. A row of factors, such as the kind and properties of the threads and connected fabrics, as well as the number and thickness of the particular fabric layers, are decisive about the value and character of the tensions generated in the threads during the sewing process.

This was the reason that the elaboration of an analysis of the driving system of an overlock – type sewing machine, which would consider the loads of the technological process, should be beneficial for the knowledge of the sewing machine working conditions. The subject discussed in this article is a continuation of work [1] devoted to an analysis of the spatial mechanisms of such a sewing machine with the use of computer simulation.

The basic features of the mechanisms and dynamic motion equations

A GN-1 three-way overedge sewing machine was used for the analysis. The structure of this machine, the mutual interaction of its mechanisms and a kinematic analysis were presented in work [1]. The basic configuration system of the machine elements in a planar projection is presented in ***Figures 1*** and ***2*** (see page 54) together with the description necessary for the elaboration of the dynamic equations of motion. The scheme in ***Figure 1*** includes the designations of parameters connected with the elastic main

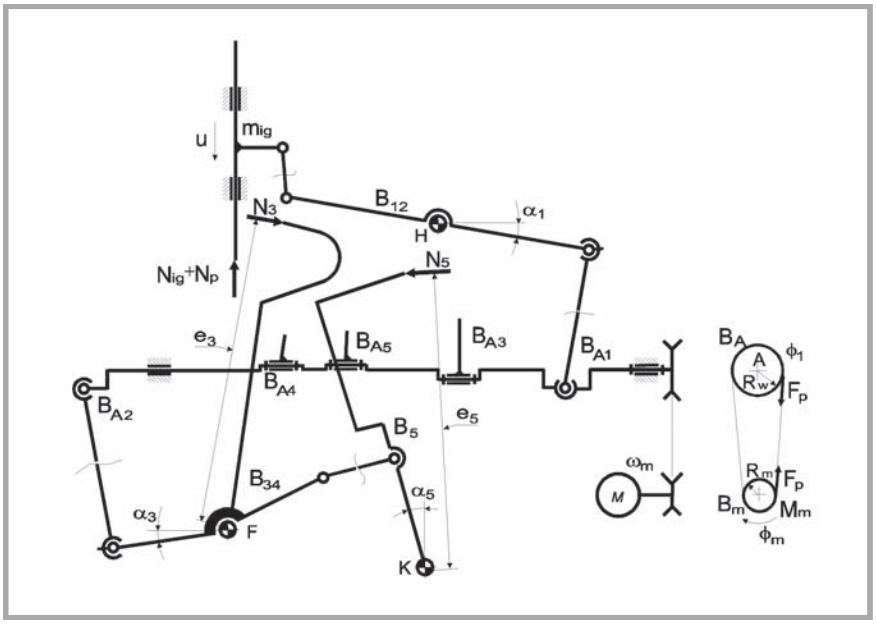

Figure 1. *Scheme of the main machine elements and the designations accepted. All the designations are listed in the first chapter.*

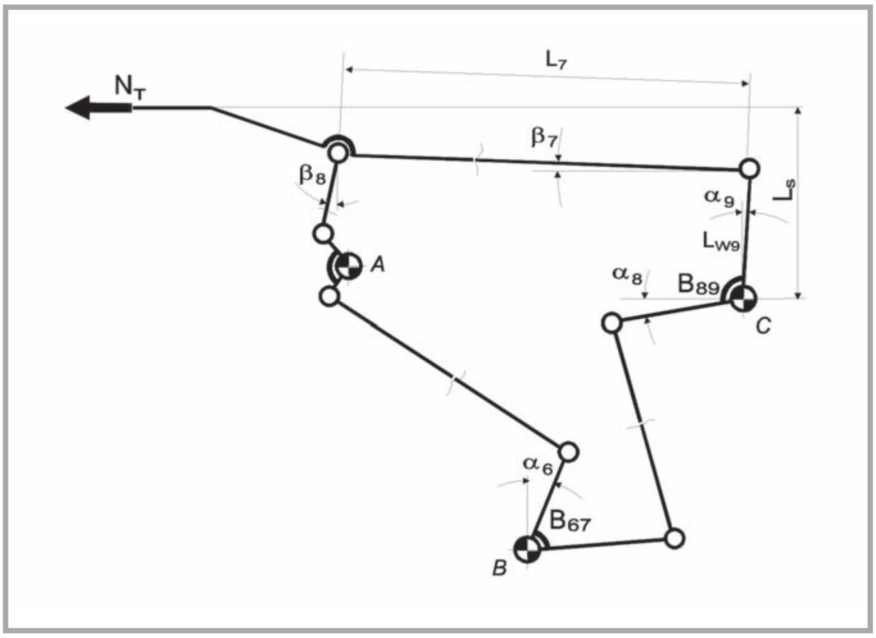

Figure 2*. Scheme of the transport mechanism of a GN-1 sewing machine; view from the driving unit. All the designations are listed in the first chapter.*

$$M_A d\varphi_1 + M_H d\alpha_1 + F_{ig} du_{ig} + M_F d\alpha_3 + M_K d\alpha_5 + M_B d\alpha_6 + M_C d\alpha_8 = 0. \quad (1)$$

$$M_{N_T} = \frac{N_T \cdot L_{W9}}{L_7 \cos(\beta_8 - \beta_7)}\left[(L_S - L_{W9}\cos\alpha_9)\sin(\alpha_9 - \beta_8) + L_7\cos(\beta_8 - \beta_7)\cos\alpha_9\right], \quad (9)$$

$$F_p = S_p(\varphi_m R_m - \varphi_1 R_w) + D_p\left(\frac{d\varphi_m}{dt}R_m - \frac{d\varphi_1}{dt}R_w\right), \quad (10)$$

$$\frac{d^2(\alpha_i)}{dt^2} = \frac{d^2\varphi_1}{dt^2}\,\frac{d(\alpha_i)}{d\varphi_1} + \left(\frac{d\varphi_1}{dt}\right)^2 \frac{d^2(\alpha_i)}{d\varphi_1^2}. \quad (11)$$

Equations 1, 9, 10 and 11.

shaft drive, the mechanism that realises the motion of the needle unit, the grippers' mechanism and the transport mechanism, which are all the objects of action of the forces N_i changing during a motion cycle of the technological process.

With the aim of characterising and evaluating the influence of the variable technological loads on the work of the drive, the rule of virtual works was used in this elaboration in order to determine the dynamic motion equations. The sum of the elementary works of the particular units of the machine element system presented (without taking the friction resistance in the joints into account in the considerations presented) can be described in the following form (Equation 1).

M_i in this equation are the moments caused by forces in relation to moveable joints of the rotary cranks and rockers. The moments are described by letters in the schemes in ***Figures 1*** and ***2***, and take the following form:

$$M_A = -B_A \frac{d^2\varphi_1}{dt^2} + F_p R_w, \quad (2)$$

$$M_H = -B_{12}\frac{d^2\alpha_1}{dt^2}, \quad (3)$$

$$F_{ig} = -m_{ig}\frac{d^2 u_{ig}}{dt^2} + N_{ig} + N_p, \quad (4)$$

$$M_F = -B_{34}\frac{d^2\alpha_3}{dt^2} + N_3 e_3, \quad (5)$$

$$M_K = -B_5\frac{d^2\alpha_5}{dt^2} + N_5 e_5, \quad (6)$$

$$M_B = -B_{67}\frac{d^2\alpha_6}{dt^2}, \quad (7)$$

$$M_C = -B_{89}\frac{d^2\alpha_8}{dt^2} + M_{N_T}, \quad (8)$$

where M_{nt} is described by Equation (9) and the instantaneous force in the belt of the main drive is described in Equation (10).

The particular angles α_i are described by the second derivative of the angles presented in equation (11):

The Equations (2, 3, … and 10) were substituted to Equation (1) of the sum of virtual works, and at the same time the derivatives of the complex function for the variables ($\alpha_i = \alpha_1$, α_3, α_5, α_6, α_8 and u_{ig}, respectively) were used. After the appropriate transformation, we obtain Equation 12 in the following form:

$$\begin{aligned}&-\frac{d^2\varphi_1}{dt^2}\left[B_A+B_{12}\left(\frac{d\alpha_1}{d\varphi_1}\right)^2+m_{ig}\left(\frac{du_{ig}}{d\varphi_1}\right)^2+B_{34}\left(\frac{d\alpha_3}{d\varphi_1}\right)^2+B_5\left(\frac{d\alpha_5}{d\varphi_1}\right)^2+B_{67}\left(\frac{d\alpha_6}{d\varphi_1}\right)^2+B_{89}\left(\frac{d\alpha_8}{d\varphi_1}\right)^2\right]+\\&-\left(\frac{d\varphi_1}{dt}\right)^2\left[B_{12}\frac{d^2\alpha_1}{d\varphi_1^2}\frac{d\alpha_1}{d\varphi_1}+m_{ig}\frac{d^2u_{ig}}{d\varphi_1^2}\frac{du_{ig}}{d\varphi_1}+B_{34}\frac{d^2\alpha_3}{d\varphi_1^2}\frac{d\alpha_3}{d\varphi_1}+B_5\frac{d^2\alpha_5}{d\varphi_1^2}\frac{d\alpha_5}{d\varphi_1}+B_{67}\frac{d^2\alpha_6}{d\varphi_1^2}\frac{d\alpha_6}{d\varphi_1}+\right.\\&\left.+B_{89}\frac{d^2\alpha_8}{d\varphi_1^2}\frac{d\alpha_8}{d\varphi_1}\right]+F_pR_w+\left(N_{ig}+N_p\right)\frac{du_{ig}}{d\varphi_1}+N_3\cdot e_3\frac{d\alpha_3}{d\varphi_1}+N_5\cdot e_5\frac{d\alpha_5}{d\varphi_1}+M_{N_T}\frac{d\alpha_8}{d\varphi_1}=0.\end{aligned}\qquad(12)$$

Equations 12.

In order to perform the calculations for the computer simulation of the sewing machine dynamic, Equation (12) was taken into consideration, as well as at the same time Equation (13) of the moments balance of the driving system and the differential Equation (14) of the driving motor moment [4].

$$B_m\frac{d^2\varphi_m}{dt^2}+F_p\cdot R_m-M_m=0,\qquad(13)$$

$$\frac{dM_m}{dt}=\frac{1}{T}\left[C_m\left(\omega_m-\frac{d\varphi_m}{dt}\right)-M_m\right].\qquad(14)$$

The solution of the system of differential Equations (12, 13 and 14), which means the solution that represents the subsequent study-state conditions, was obtained by numerical integration using the Runge Kutta method [5].

Data for calculation and an example of the results obtained

The computer simulation was carried out on the basis of the geometrical parameters of the mechanisms and the results of a kinematic analysis of the selected sewing machine, which are listed in [1]. On the basis of the design of the selected machine elements, addi-

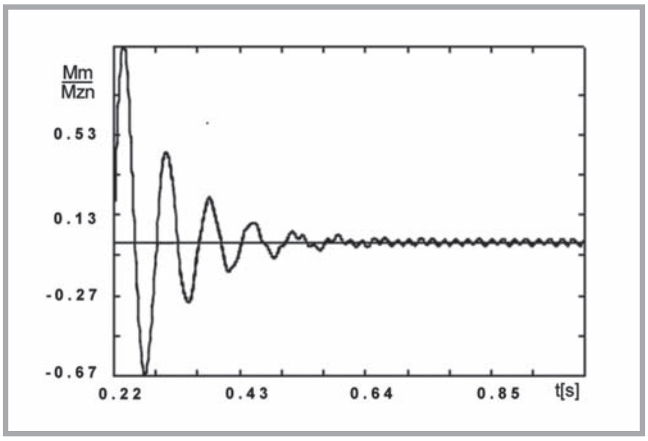

Figure 3. *Torque-time characteristic during the starting phase under full technological load.*

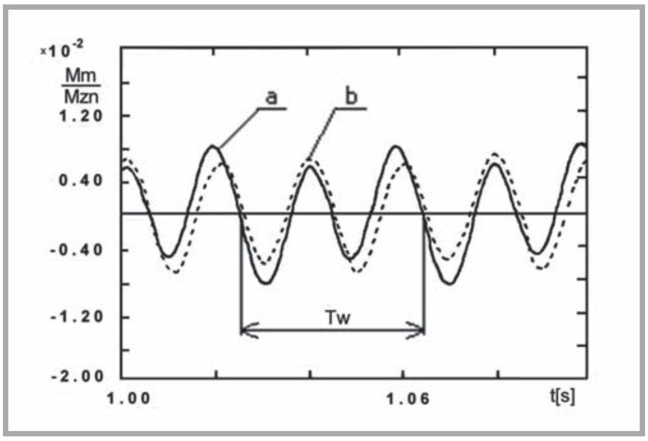

Figure 4. *Influence of the dynamic of the needle unit mechanism (a) and the grippers' mechanism (b) on the torque-time characteristic of the motor without a load caused by the process of stitch formation.*

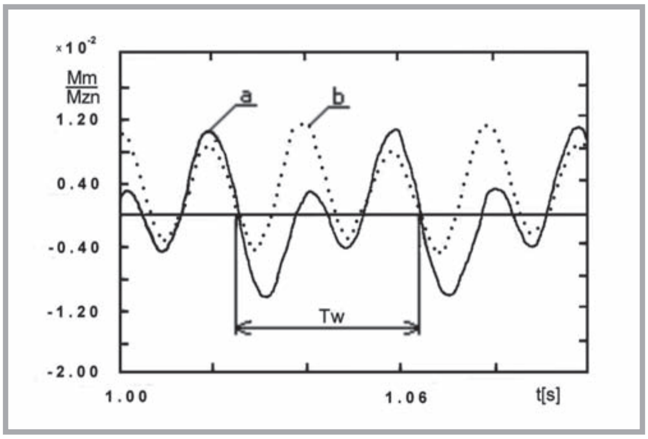

Figure 5. *Torque-time characteristic of the moment changes under technological loads separately for the needle unit mechanism (a) and the grippers' mechanism (b).*

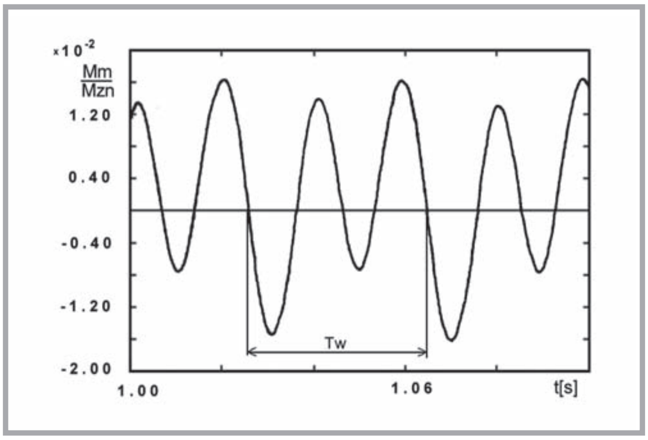

Figure 6. *Torque-time characteristic illustrating the influence of the technological load caused by the sewing process and the mechanisms' dynamic on the motor torque in steady-state motion conditions for a time t > 1 s.*

tional parameters necessary for the calculation of the machine dynamics were determined. These were the following parameters:

- the moments of inertia reduced to the rotary axis: of the shaft $B_A = 540\times10^{-6}$ kgm^2, of the rotor $B_m = 300\times10^{-6}$ kgm^2 and of the rockers' units $B_{12} = 100\times10^{-6}$ kgm^2, $B_{34} = 85\times10^{-6}$ kgm^2, $B_5 = 25\times10^{-6}$ kgm^2, $B_{67} = 75\times10^{-6}$ kgm^2 and $B_{89} = 65\times10^{-6}$ kgm^2;
- the mass of the needle unit elements $m_{ig} = 0.045$ kg;
- the radii of the belt wheels $R_w = 0.030$ m, $R_m = 0.017$ m;
- the belt rigidity $S_b = (1\div3)\times10^3$ N/m;
- the dumping coefficient $D_p = (1\div2)\times10^2$ Ns/m;
- the radii of forces' actions $e_3 = 0.064$ m and $e_5 = 0.063$ m.

Additionally, a drive with the following parameters was accepted: time constant T = 0.8 s, rigidity of the motor characteristic $C_m = 0.25$ N/ms/rad and angular speed of the rotor $\omega_m = 280$ rad/s.

In order to perform the computer calculations, examples of the quantity time dependencies and values of technological loads presented in [2] and [3] were used. The following quantities and their values were accepted: the load of the needle unit caused by threads N_{ig} – from 0 to 270 cN, the piercing force of a needle N_p – from –40 cN to +115 cN, the loads caused by threads on the grippers N_3 – from 0 to 200 cN and N_5 from 0 to 200 cN, as well as by the force N_T – from 0 to 2 N modelled by the author.

Examples of the results of the computer simulation are presented in the form of torque-time characteristics in ***Figures 3*, *4*, *5*** and ***6*** (see page 55).

Conclusions

1. The calculations and computer simulations carried out indicated that, for the assumed parameters, the starting period of the sewing machine under a technological load is equal to about 0.3 s (***Figure 3***).

2. Considering the steady-state motion phase, which means past about 0.8 s after the starting phase, during a singular period (T_w) of the main shaft rotation of the sewing machine that is under a technological load (***Figure 5***) or without this load (***Figure 4***), two oscillations of the motor shaft moment occur. The character of these oscillations is caused by the inertia and the masses of the mechanisms' elements, which are in reverse motion.

3. The masses of the needle unit and the grippers, which are in reverse motion, considered separately have a similar influence on the shape of the torque–time characteristic with a minimal shift according to the interaction in the stitch formation.

4. The forces of inertia of the mechanism elements of the transport unit acting during the technological process in reality have no influence on the character and value of changes in the motor shaft moment in comparison with the remaining machine mechanisms.

5. On the basis of calculation results obtained that are not presented in this paper, it can be stated that there is a significant influence of the belt dumping coefficient on the amplitude of moment changes. The influence of changes in the belt rigidity on the torque–time characteristic is minimal considering that all the other parameters and conditions remain the same as presented in this paper.

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