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Modelling of a Tachogram of Machine Sewing Process

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Abstract
The configuration of a tachogram of the machine sewing process is described using a polygonal curve. It is stated that the efficiency of a tachogram with its configuration established is determined using the following: values of machine parameters, the responsetime of an operator to visual signals and delays in the circuits of textile control, the drive set in action by the operator, the efficiency of reactions established in a tachogram, the number of machine working cycles, as well as the share of particular reactions of the tachogram in a general number of machine working cycles. It is also stated that the minimum number of machine working cycles for which a technological task can be carried out is characteristic for the particular configuration and parameters of the tachogram. The experimental results obtained were used for the programme control of a sewing machine drive in a machine - operator system.

Key words: *sewing process tachogram, polygonal curve, sewing machine drive, operator response time.*

Introduction

The field of sewing machine drives has made significant progress in recent years. The energy-saving non-clutch drives [1] more commonly used today enable to program a series of operations [2], such as needle positioning, the number of machine working cycles divided into sequences, fixing realisation, thread cutting as well as many other possibilities available thanks to the use of the logic support system, including machine learning functions in the field of textiles processing [2] and control of the parameters of the sewing process [3]. The use of the ’machine learning’ function enables to search for machine parameters necessary to carry out a technological task previously designed. For example, to form a shortening/condensing seam, the settings of the autonomous feed dog should be determined taking into account switching the values of the settings with the use a logical system on a sewing path. Introducing the ‘learning’ functions to sewing machines is done due to the sensitivity of mechanisms forming the seam, for example, the transport mechanism is sensitive to changes in rotational speed [4, 5, 11]. In fact, the ’machine learning’ functions currently used solve only a part of the problem. The diverse character of the rotational speed of a machine in the process of ‘learning’ and in the process of task realisation may cause a deviation in the real parameters of the stitch from those established in the process of clothing design [5]. Therefore, it seems as if programme speed control may be the next step in the field of the driving mechanisms of sewing machines, with the so-called ‘open-technological cycle’ working in the machine - operator system [6], which requires a well-trained operator who acts according to the drive control of the machine [8].

Hence the problem of modelling a tachogram should be emphasised, paying special attention to its efficiency and its relation to the contents of technological tasks. The process of ‘learning’ should include the adjustment of a tachogram to the technological task and to the adaptability of the operator. It was demonstrated [6] that a tachogram should take the form of a polygonal curve, which is used to define the assumptions of the structure of the model tachogram presented in this paper.

The aim of this work is to identify and evaluate the efficiency of the configurations of a tachogram created in the form of a polygonal curve. The experimental results obtained can be used to elaborate a database of tachograms for the programme drive control of a sewing machine in a machine-operator system.

The description and identification of a tachogram presented in this article is the author’s original work.

Structure of a tachogram – indicators evaluating the efficiency of drive control

The choice of a technique used for the drive control of a sewing machine may be significant for the efficiency of the sewing process.

It was assumed that the image of a tachogram of any configuration is a polygonal curve n(t) fulfilling the following conditions: $n(0) = 0 \wedge n(t_e) = 0$, where: t – time, n – rotational speed of the sewing machine, and t_e – time of realisation of a technological task. The curve can be described using an order set with three types of reactions: take-off run, stationary run, and braking run. An example of a tachogram is presented in ***Figure 1***, where (1) is an increasing function, (0) – a stationary function and (-1) – a decreasing function. The parameters of pedipulation reactions are as follows: α_i, s^{-2} – acceleration, β_i, s^{-2} – deceleration, n_i, s^{-1} – rotational speed during the established reaction, and t_1, t_2, …, t_9 – times of pedipulation reactions.

The modeling of a tachogram requires taking into consideration assumptions referring to the times of pedipulation reactions t_i and the slope of transient reactions α_i and β_i (***Figure 1***). It is assumed that the slopes of transient reactions cannot exceed the values set for the machine. The time of any reaction $t \geq \tau$ cannot be shorter than the total sum of the time of delays in the operator response to visual signals (τ_1) and time of delays in the circuit of textile control (τ_2) [7, 9]. Moreover, the control of the drive by the operator requires taking into consideration the delay time in the drive control circuit (τ_3) [7].

Figure 1 presents an area describing the number of machine working cycles in a technological cycle, which are extended in time due to the presence of reactions established at differentiated levels $n_i < n_{max.}$, characteristic for a particular operator.

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It was assumed that the basic indicator for evaluation of the efficiency of a technological task properly carried out will be the average rotational speed of the machine:

$$n_{av} = N \cdot t_e^{-1} \text{ in s}^{-1}, \qquad (1)$$

where:
N – number of machine working cycles, which is the number of stitch links in a seam,
t_e – task realisation time, s.

The number of machine working cycles in a technological cycle N is determined by the area under a tachogram curve. Thus, for each configuration of a tachogram we have:

$$N = \sum^{i(1)} \alpha_i \cdot t_i \left(\frac{t_i}{2} + \sum_{k=i+1}^{k=r} t_k\right) + \qquad (2)$$
$$- \sum^{j(-1)} \beta_j \cdot t_j \left(\frac{t_j}{2} + \sum_{p=j+1}^{p=r} t_p\right)$$

The expansion of ***Equation 2*** leads to the total sum of rectangular trapezoid areas formed by the increasing function, which is reduced by the total sum of rectangular trapezoid areas formed by the decreasing functions. The base line for the trapezoids is the B axis (***Figure 1***), described by equation:

$$t = t_e = \sum_{i=1}^{i=r} t_i. \qquad (3)$$

Assuming that the slope of transient reactions does not depend on their position (α = const., β = const.), the time of realisation of a technological task for each tachogram can be described as:

$$t_e = (\alpha^{-1} + \beta^{-1})(\sum n_{max/lok} + \qquad (4)$$
$$- \sum n_{min/lok}) + \sum^{u(0)} t_u,$$

where:

$n_{max/lok}$, $n_{min/lok}$ – local extremum of the machine rotational speed,
t_u – time of established reaction,
u(0) – symbol of established reactions.

Thus the average machine rotational speed expressed by dependence (1) can be written as ***Equation 5***.

The minimal number of machine working cycles $\mathbf{N_{min}}$ is characteristic for the configuration of a tachogram, as well as for its parameters (α, β, τ, n_{max}). Therefore, the average rotational speed of the machine for $\mathbf{N \geq N_{min}}$ is described by

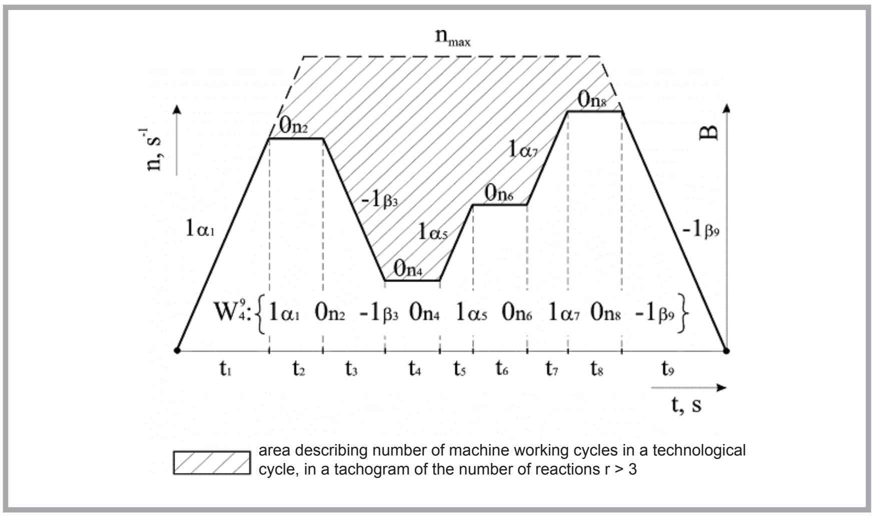


Figure 1. *Tachogram of the machine sewing process in the form of a polygonal curve – an example.*

$$n_{av} = \frac{\sum^{i(1)} \alpha \cdot t_i \left(\frac{t_i}{2} + \sum_{k=i+1}^{k=r} t_k\right) - \sum^{j(-1)} \beta \cdot t_j \left(\frac{t_j}{2} + \sum_{p=j+1}^{p=r} t_p\right)}{(\alpha^{-1} + \beta^{-1})(\sum n_{max/lok} - \sum n_{min/lok}) + \sum^{u(0)} t_u}, \qquad (5)$$

$$n_{av}(N) = \frac{\overbrace{\sum^{i(1)} \alpha \cdot t_i \left(\frac{t_i}{2} + \sum_{k=i+1}^{k=r} t_k\right) - \sum^{j(-1)} \beta \cdot t_j \left(\frac{t_j}{2} + \sum_{p=j+1}^{p=r} t_p\right)}^{N_{min}} + \sum^{u(0)} \Delta N_u}{\underbrace{[(\alpha^{-1} + \beta^{-1})(\sum n_{max/lok} - \sum n_{min/lok}) + \sum^{u(0)} \tau_u]}_{t_{min}} + \sum^{u(0)} \frac{\Delta N_u}{n_u}}, \qquad (6)$$

$$\eta_e(N) = \frac{[(\alpha_{max}^{-1} + \beta_{max}^{-1}) n_{max} + \tau_u + \Delta N_{min} \cdot n_{max}^{-1}] + \Delta N_u \cdot n_{max}^{-1}}{[(\alpha^{-1} + \beta^{-1})(\sum n_{max/lok} - \sum n_{min/lok}) + \sum^{u(0)} \tau_u] + \sum^{u(0)} \frac{\Delta N_u}{n_u}}, \qquad (8)$$

Equations: 5, 6, and 8.

Equation 6 where: t_i, t_j, t_k, $t_p \geq \tau$ are the minimal reaction times for the tachogram configuration, τ_u – minimum time of established reaction, n_u – level of rotational speed during the established reaction, ΔN_u – increment of the number of machine working cycles in the established reaction exceeding N_{min}, t_{min} - time corresponding with the number of machine working cycles N_{min}.

The possibility of the application of the average – the maximum for a machine – rotational speed in the realisation of a technological task can be determined using a factor called the technological efficiency of the machine – the operator system or operating efficiency of the machine in an open technological cycle,

$$\eta_e = \frac{n_{av/e}}{n_{av/max}} = \frac{t_{e/min}}{t_e} \qquad (7)$$

where $n_{av/max}$ and $t_{e/min}$ are, respectively, the average rotational speed in a technological cycle, when a machine is fully used (three segmental tachogram: α_{max}, β_{max}, n_{max}) and its time of task realisation, $n_{av/e}$ & t_e, are, respectively, the average operating rotational speed of the machine and its time of task realisation.

Using dependence (4), the technological efficiency of the machine-operator system for a number of machine working cycles N ≥ N_{min} can be described in ***Equation 8***.

The increment of the machine working cycles in ***Equation 8***

$$\Delta N_{min} = N^{r}_{min} - N^{3}_{min} \qquad (8a)$$

defines the difference between the minimum number of machine working cycles for a tachogram of r pedipulation reactions and a three-segmental tachogram as the most effective (α_{max}, β_{max}, n_{max}, r = 3).

Configurations of tachograms for a number of operator responses – graph of tachogram configurations

The number of available variants of the drive control of a sewing machine, fulfilling the conditions:

1. $n(t_0) = 0 \wedge n(t_e) = 0$, where: n – machine rotational speed, t_0& t_e – the initial and final moment of drive control,
2. a tachogram of each configuration, described by a polygonal curve formed by at least two out of three reaction types: increase (1), decrease (-1) and established reaction (0) is determined by the recurrent equation:

$$W_{r+1} = 2^{r-2} - W_r \qquad (9)$$

with the initial condition $W_2 = 1$, where r is the number of operator responses.

$$W_4^9 : \{1_{\alpha_{max}} 0_{n_2} - 1_{\beta_{max}} 0_{n_4} 1_{\alpha_{max}} 0_{n_6} 1_{\alpha_{max}} 0_{n_8} - 1_{\beta_{max}}\} \qquad (11)$$

Equation 11.

It is possible to create a graph of tachogram configurations fulfilling the conditions mentioned above. ***Figure 2*** presents such a graph for the number of reactions $2 \leq r \leq 7$.

The particular paths of the graph are the tachogram configurations with a decreasing function at the end. Any decreasing function on the graph's path can be used to distinguish a tachogram configuration of the number of reactions $r \geq 2$. A rise in the number of reactions in the graph increases the number of tachogram configurations, according to dependence (9).

Figure 3 presents such configurations, numbered in a way characteristic for the graph.

Figure 3 presents two types of tachograms: type I – having at least one sequence: increase (1) – decrease (-1) or the opposite, and type II – without these sequences. The analysis of the role of pedipulation reactions in the realisation of tasks, described by a tachogram, explains the diversity of these roles. It can be assumed that the transient reactions (take-off run, braking run) are used in order to change the level of segmental complexity of the task, which enables to change the level of the established reaction (n parameter). As a result, tachograms with the sequences mentioned above can be regarded as failed attempts at drive control.

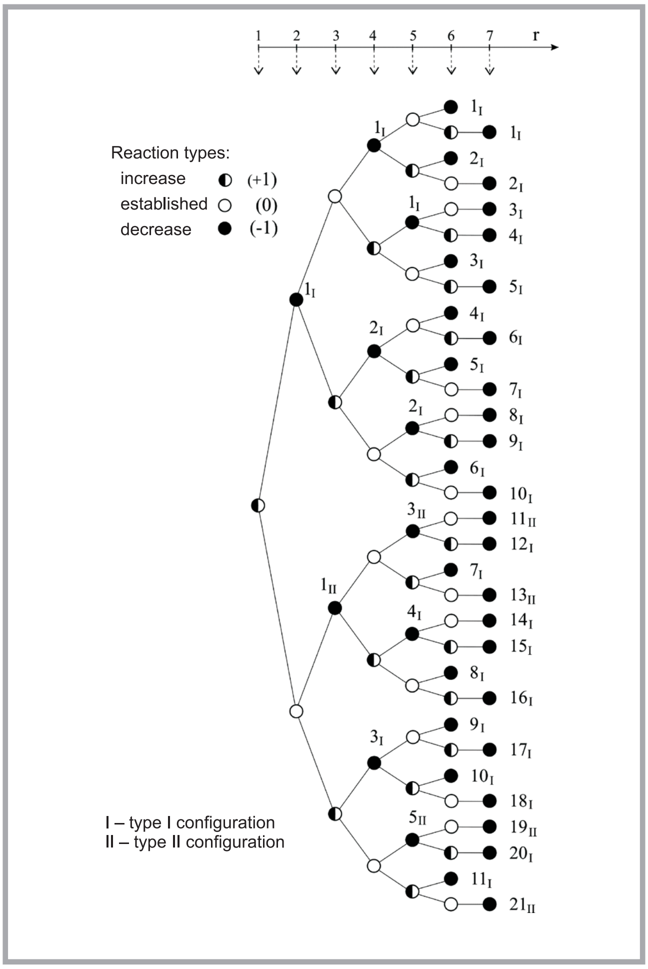


Figure 2. *Graph of tachogram configurations of type I and II for the number of operator response $2 \leq r \leq 7$.*

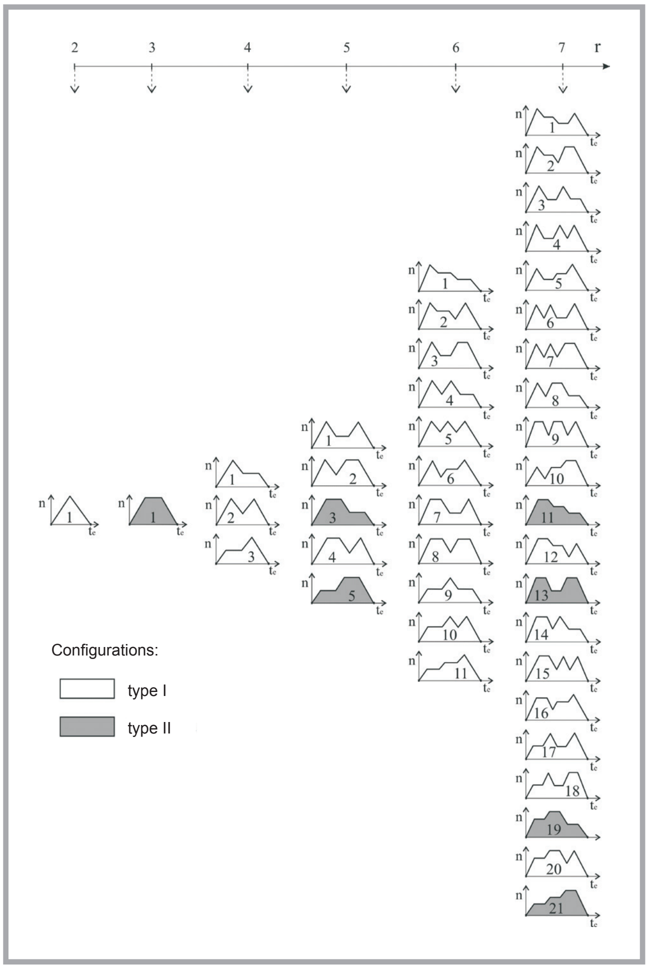


Figure 3. *Tachogram configurations of type I and II for a number of operator responses $2 \leq r \leq 7$.*

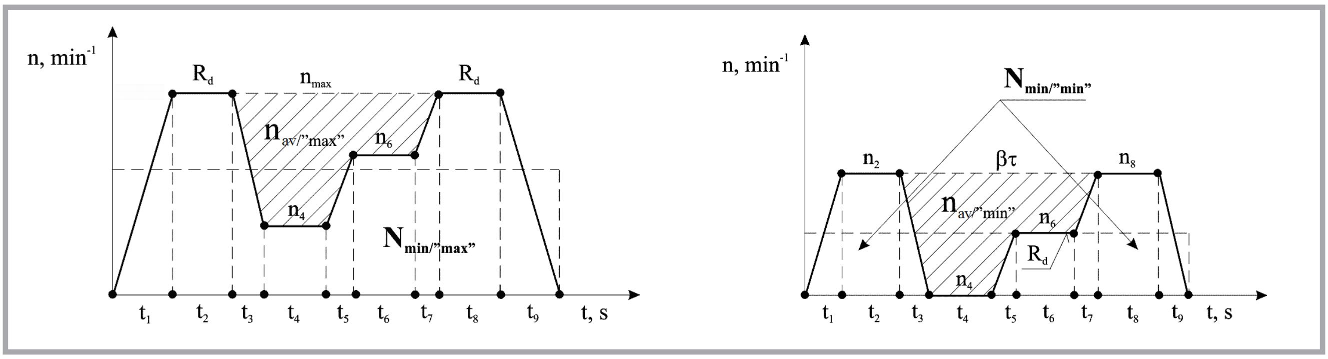


Figure 4. *Boundary tachograms of* W_4^9*: {1 0 -1 0 1 0 1 0 -1} configuration.* $N_{min/„max”}$, $N_{min/„min”}$ *– minimum number of machine working cycles for the 'max' and 'min' states.* R_d *– adjustment reaction with regards to N.*

The number of variants of drive control of type II i.e. those without the sequences mentioned, can be determined using the following dependence:

$$W_{r+1} = 2W_r, \qquad (10)$$

where: r = 2k+1; k = 1, 2, 3,... with the initial condition $W_3 = 1$.

For an even number of reactions it is impossible to form this kind of configuration.

An assumption differentiating the role of the reaction in a tachogram significantly decreases the number of configurations.

A Tachogram of each configuration can be presented using a sequence of symbols which determine the type of operator response, taking into account its position in the graph. For example, a type II tachogram, with the number of reactions r = 9, taking the 4th position in the graph, has the ***Equation 11***.

The indexes of particular reactions are the parameters of these reactions. Considering the role of transient reactions in the process of drive control, conducted according to a type II tachogram, the following condition should be fulfilled: $\alpha = \alpha_{max}$ and $\beta = \beta_{max}$, which results from lowering the extension in time of the transient reactions.

Limits of the efficiency of the tachogram configuration

In order to identify a tachogram whose configuration and parameters are determined, it is necessary to define the limits of its efficiency. If the measure of efficiency is the average rotational speed of the machine, then $n_{av/„max”}$ (N) and $n_{av/„min”}$ (N) should be determined. This task was carried out using a tachogram with nine reactions, as an example. Assuming that the values of parameters α and β are constant, irrespective of the position of transient reactions, it is possible to determine the times of particular reactions in the tachogram presented in ***Figure 4***, for the maximum (“max”) and minimum (“min”) states.

The times of particular reactions in a tachogram enable to determine the time of task realisation (t_e), the number of machine working cycles (N), and the average rotational speed of a machine (n_{sr}), which for the boundary states takes the ***Equations 12*** and ***13*** (see page 52) where: $\Delta N_{„max”}$, $\Delta N_{„min”}$ – increment of the number of machine working cycles on the basis of the most efficient reaction established n_{max} and the least efficient reaction $n_{min} = \alpha \cdot \tau$.

The assumptions previously made concerning the reaction time in a tachogram $t_i \geq \tau$ bring some limitations, which for the boundary states of an exemplary tachogram take the following form:

for „max” state $\alpha \leq \frac{n_{max}}{2\tau}$ and $\beta \leq \frac{n_{max}}{\tau}$,
for „min” state $\beta = 2\alpha$.

Each tachogram of a number of reactions r > 3 enforces such limitations.

Figure 5 presents changes in $n_{av/„max”}$ and $n_{av/„min”}$ described by ***Equations 12*** and ***13*** (see page 52) for the values of parameters n_{max}, α, β & τ selected.

As can be seen in ***Figure 5***, $n_{av/„max”}$ increases asymptotically to n_{max}. The minimum number of machine working cycles increases along with the rise in speed n_{max}. However, when it comes to the average $n_{av/„min”}$, it is different - it decreases asymptotically from $n_{av/„min”} = 27.5\ s^{-1}$ to $n_{av/”min”} = \alpha \cdot \tau$ ($\alpha \cdot \tau = 25\ s^{-1}$). Thus, in the range of the

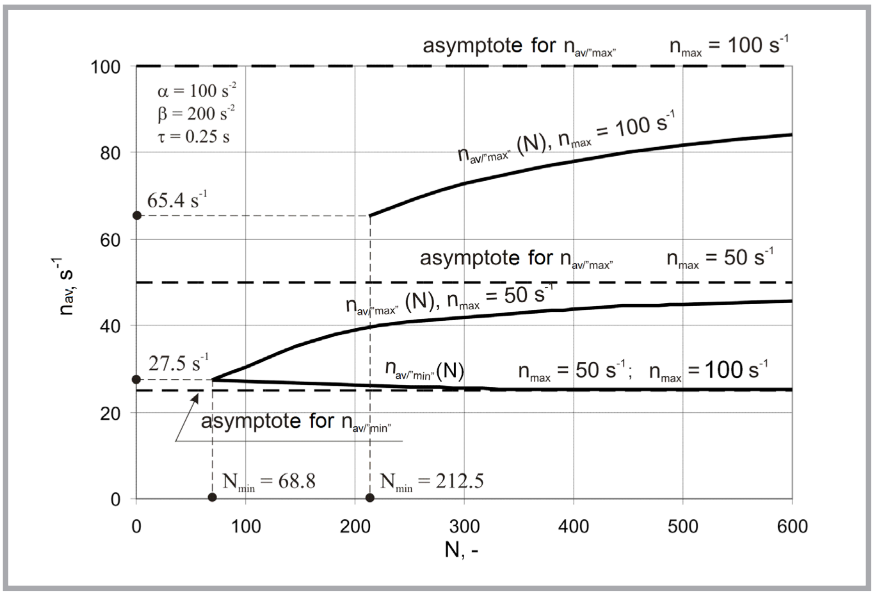


Figure 5. *Limits of the average rotational speed of a machine (*$n_{av/„max”}$*,* $n_{av/„min”}$*), depending on the number of working cycles of a machine (N) for the tachogram presented in Figure 4.*

$$n_{\text{av/„max"}}(N)=\frac{0.5n_{\text{max}}^{2}(\alpha^{-1}+\beta^{-1})+7\tau\cdot n_{\text{max}}-3\tau^{2}\beta+\Delta N_{\text{„max"}}}{n_{\text{max}}(\alpha^{-1}+\beta^{-1})+7\tau+\Delta N_{\text{„max"}}\cdot n_{\text{max}}^{-1}},\qquad(12)$$

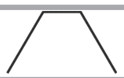
$$n_{\text{av/„min"}}(N)=\frac{5.5\beta\tau^{2}+\Delta N_{\text{„min"}}}{10\tau+\Delta N_{\text{„min"}}\cdot\alpha^{-1}\cdot\tau^{-1}},\qquad(13)$$

$$n_{\text{av}}=\frac{N}{t_{e}}=\frac{\frac{1}{2}n_{u}^{2}(\alpha^{-1}+\beta^{-1})+t_{u}\cdot n_{u}}{n_{u}(\alpha^{-1}+\beta^{-1})+t_{u}}\qquad(13)$$

$$n_{\text{av/"max"}}(N)=\frac{\overbrace{\frac{1}{2}n_{\text{max}}^{2}(\alpha^{-1}+\beta^{-1})+\tau\cdot n_{\text{max}}}^{N_{\text{min}}}+\Delta N_{\text{"max"}}}{\underbrace{n_{\text{max}}(\alpha^{-1}+\beta^{-1})+\tau}_{t_{\text{min}}}+\Delta N_{\text{"max"}}\cdot n_{\text{max}}^{-1}},\qquad(15)$$

Equation 12, 13, 13, and 15.

***Table 1.** Comparison of the efficiency of tachogram configurations for the maximum state; the parameters assumed are as follows: $\alpha = 100\ s^{-2}$, $\beta = 200\ s^{-2}$, $n_{max} = 100\ s^{-1}$, $\tau = 0.25\ s$.*

Configuration of tachogram $W_k{}^r$		Number of machine working cycles N		
		N_{min}	240	400
$W_1{}^3$		$N_{min} = 100.0$ $n_{av/„max"} = 57.1\ s^{-1}$	$n_{av/„max"} = 76.0\ s^{-1}$	$n_{av/„max"} = 84.2\ s^{-1}$
$W_1{}^9$		$N_{min} = 137.0$ $n_{av/„max"} = 55.0\ s^{-1}$	$n_{av/„max"} = 68.1\ s^{-1}$	$n_{av/„max"} = 78.1\ s^{-1}$
$W_2{}^9$		$N_{min} = 143.8$ $n_{av/„max"} = 57.5\ s^{-1}$	$n_{av/„max"} = 69.4\ s^{-1}$	$n_{av/„max"} = 79.0\ s^{-1}$
$W_3{}^9$		$N_{min} = 200.0$ $n_{av/„max"} = 61.5\ s^{-1}$	$n_{av/„max"} = 65.8\ s^{-1}$	$n_{av/„max"} = 76.2\ s^{-1}$
$W_4{}^9$		$N_{min} = 131.3$ $n_{av/„max"} = 52.5\ s^{-1}$	$n_{av/„max"} = 66.9\ s^{-1}$	$n_{av/„max"} = 77.1\ s^{-1}$
$W_5{}^9$		$N_{min} = 212.5$ $n_{av/„max"} = 65.4\ s^{-1}$	$n_{av/„max"} = 68.1\ s^{-1}$	$n_{av/„max"} = 78.0\ s^{-1}$
$W_6{}^9$		$N_{min} = 189.1$ $n_{av/„max"} = 65.8\ s^{-1}$	$n_{av/„max"} = 70.9\ s^{-1}$	$n_{av/„max"} = 80.3\ s^{-1}$
$W_7{}^9$		$N_{min} = 231.3$ $n_{av/„max"} = 71.2\ s^{-1}$	$n_{av/„max"} = 71.9\ s^{-1}$	$n_{av/„max"} = 81.0\ s^{-1}$

numbers of machine working cycles investigated, its value is constant (irrespective of n_{max}). Therefore, N_{min} does not depend on n_{max}. An increase in the maximum speed of the machine n_{max} increases the range of potential changes in the average rotational speed of the machine, as a result of the $n_{av/„max"}$ increase. Thus, the length of the stitch path in a seam changes this range. In general, it should be stated that functions $n_{av/„max"}(N)$ and $n_{av/„min"}(N)$ are monotonic with the asymptote at point $n = n_d$, where n_d is a parameter of the adjustment reaction (R_d in ***Figure 4***), which increases the technological cycle of the machine (N). The $n_{av/„max"}$ function is a parameter of the most efficient reaction established (n_{max}), while $n_{av/„min"}$ is a parameter of the least efficient reaction greater than zero (for example, in ***Figure 4*** $n_d = n_6 = \alpha \cdot \tau$). Thus when $n_{av}(N_{min}) < n_d$, then the function is increasing monotonically, but when $n_{av}(N_{min}) > n_d$, then the function is decreasing monotonically. In the same way, the operating efficiency of a machine $\eta_{e/„max"}$ (N) and $\eta_{e/„min"}$ (N) can be assumed to be a measure of efficiency.

In a tachogram with the number of reactions r = 3, the decrease in the number of machine working cycles is due to the run-up reaction (α) to the speed established (n_u) and to the braking run reaction (β). As a result, the average rotational speed in a technological cycle of the machine can be described by ***Equation 14*** where:

n_u – rotational speed in the established reaction in s^{-1},
t_u – time of the established reaction in s.

For the maximum state, ***Equation 14*** takes the ***Equation 15*** where:

$$\alpha \le n_{max} \cdot \tau^{-1},\ \beta \le n_{max} \cdot \tau^{-1}.$$

For each tachogram with a number of reactions r > 3, losses in the number of machine working cycles are increased by those caused by additional transient reactions of type (1) and (-1) and by the diversified efficiency of established reactions ($n_u < n_{max}$).

The results of measurements of the average rotational speed $n_{av/„max"}$ (***Table 1***) for the tachogram configurations selected, as well as the values of machine parameters (α, β, n_{max}) and time of operator response (τ) indicate that tachogram $W_1{}^3$ is the most efficient.

The decrease in $n_{av/„max"}$ for particular configurations of a tachogram in relation to tachogram $W_1{}^3$ is within the range of 5.4% - 13.4%, for the number of machine working cycles N = 240 (sewing length L=60 cm at stitch step s = 2.5 mm). An increase in the N value decreases the differences (for N = 400 $n_{av/„max"} \in$ < 3.8% ÷ 9.5% >. The diversification is more significant in the case of the minimum number of machine working cycles exceeding 100% (for tachogram $W_1{}^3$, N_{min} = 100, while for tachogram $W_7{}^9$, N_{min} = 231.3). The limits of the efficiency of tachogram configurations were evaluated. However, it should be stated that the choice of the adjustment reaction with regard to the number of machine working cycles, N, required and the segmental complexity of a technological task can significantly change the efficiency of a tachogram. For a tachogram with an established configuration, the efficiency of the drive control measured at the average rotational speed of the machine is determined by the values of machine parameters (α, β, n_{max}) and the value of the reaction time of the operator τ. An increase in the values of machine parameters increases the average rotational speed, while an increase in the reaction time τ - decreases the average rotational speed, accompanied by changes in the minimum number of working cycle of the machine.

Figure 6 presents exemplary changes in the rotational speed $n_{av/„max”}$ for tachogram $W_4{}^9$, in relation to the number of machine working cycles, N, for different values of the time of delay of the operator response τ.

The functions increase monotonically with asymptote $n = n_{max}$. An increase in the response time of the operator decreases the average speed $n_{av/„max”}$, while the changes in the minimum number of machine working cycles are characteristic. If $\tau \rightarrow 0$, then the fall in the number of machine working cycles, described by the second and third segment (dependence 12), decreases to zero, which means that there is a tendency of each tachogram to achieve the most efficient value $W_1{}^3$: {1 0 -1}. (curve No. 1 in ***Figure 6***). Thus, for the boundary state "max" we have:

$$\lim_{\tau\rightarrow 0} n_{av/"max"} = \frac{\frac{1}{2} n_{max}^2 (\alpha^{-1} + \beta^{-1}) + \Delta N_{"max"}}{n_{max}(\alpha^{-1} + \beta^{-1}) + \Delta N_{"max"} \cdot n_{max}^{-1}} \qquad (16)$$

irrespective of the configuration of the tachogram. Taking $\Delta N_{„max”} = 0$, we obtain $n_{av/”max”} = 1/2\ n_{max}$, which is the value of the average rotational speed of the machine, corresponding to N_{min} (the initial point in ***Figure 6*** is for τ = 0). Curve No. 1 in ***Figure 6*** is the basis for determining the technological efficiency of a machine.

$$\eta_m = \frac{n_{av/m}(N)}{n_{max}} = \frac{N}{N + N_{str}}, \qquad (17)$$

where:

$n_{av/m}$ – average rotational speed with the machine fully used, depending on parameters α, β, n_{max} and the number of working cycles N,

N_{str} – number of working cycles of the machine, extended in time as a result of the take-off run and breaking run, depending on parameters α, β and n_{max}.

Dependence (17) describes the highest level of application of the maximum rotational speed of a machine.

The relation between a machine and operator using the rotational speed of a machine is presented in ***Figure 7***.

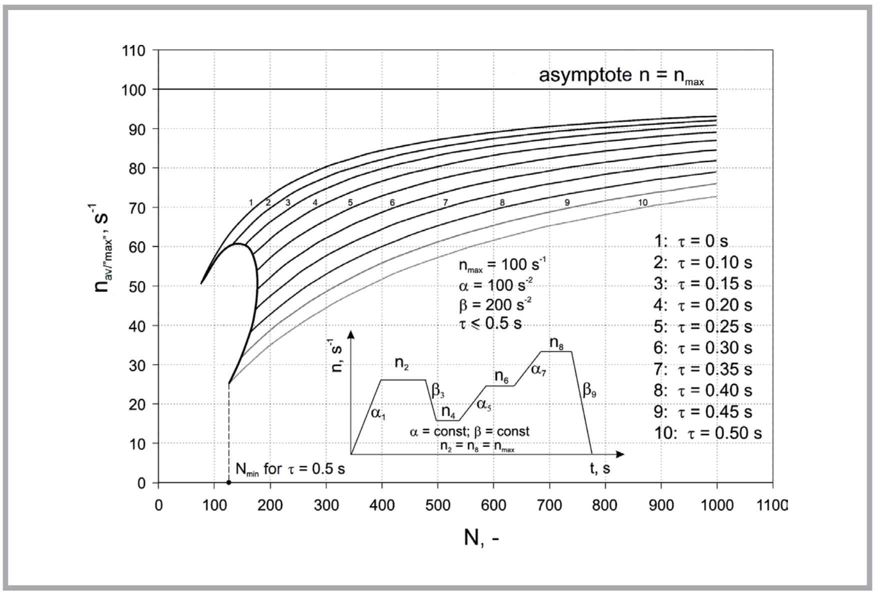


Figure 6. *Changes in the average boundary rotational speed of the machine $n_{av/„max”}$ during a technological cycle, depending on the number of machine working cycles, N, and the time of delay of the operator response τ (tachogram $W_4{}^9$).*

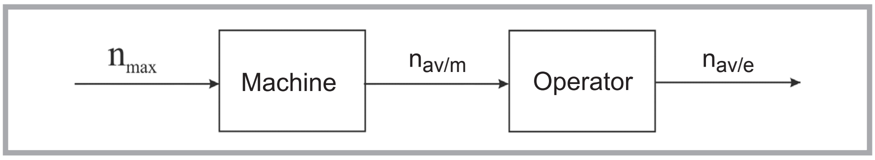


Figure 7. *Scheme of the sewing machine – operator system; $n_{av/m}$ – average rotational speed of a machine fully used, $n_{av/e}$ – real average rotational speed of a machine in a technological cycle on a working stand (exploitative speed).*

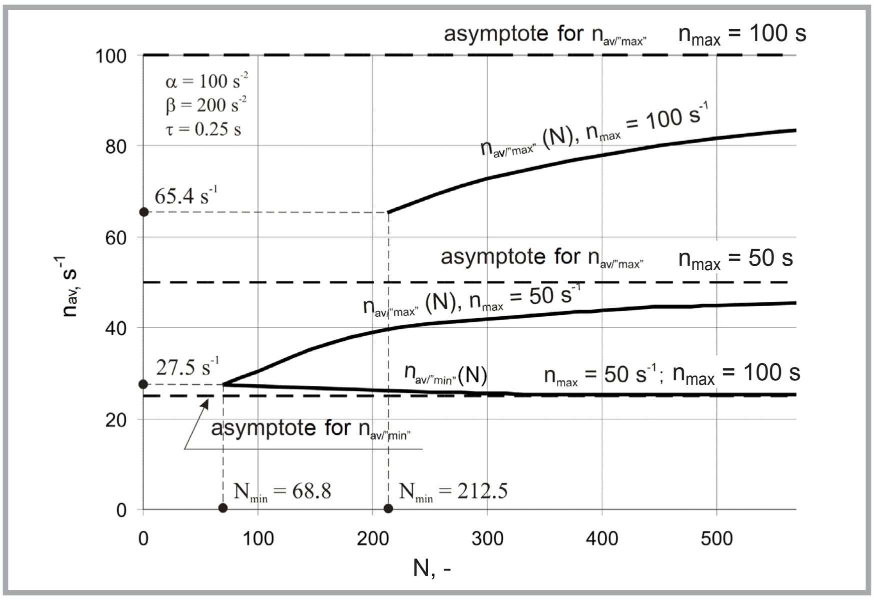


Figure 8. *Average rotational speed $n_{av/„max”}$, depending on the number of working cycles of the machine N and the efficiency of the adjustment reaction R_d; $W_3{}^9$: {1_{75} 0_{75} -1_{150} 0_{75} 1_{75} 0_{75} -1_{150} 0_{75} -1_{150}}* $\alpha = 75\ s^{-2}$, $\beta = 150\ s^{-2}$, $n_{max} = 75\ s^{-1}$.

The level of application of the maximum speed of a machine in a process of technological task realisation as the total efficiency can be described by

$$\frac{n_{av/e}}{n_{max}} = \frac{n_{av/m}}{n_{max}} \cdot \frac{n_{av/e}}{n_{av/m}} \quad \Rightarrow \eta_o = \eta_m \cdot \eta_e. \ (18)$$

The choice of the configuration and parameters of a tachogram, as well as its adjustment, with regards to the number of working cycles of a machine required is of great significance from the point of view of the efficiency of the machine –

operator system. Such an adjustment can be performed using the established reactions, with the efficiency calculated from a quotient of the increment of the number of machine working cycles to the time in which the gain was obtained:

$$K_{ef} = \frac{\Delta N}{\Delta t} \qquad (19)$$

where:
ΔN – increment of machine working cycles,
Δt – increment of the time.

Thus, for the established reaction, the indicator takes a constant value. When determining the limits of the efficiency of a tachogram, the most efficient (parameter n_{max}) and least efficient ($n_{min} > 0$) reactions are chosen. For the selection of a tachogram for a particular technological task and for the adaptability of an operator, one can use any reaction established or a particular group of this kind of reaction, with the required share in regard to the number of machine working cycles at the segment of a seam of different executive complexity.

Figure 8 presents an example of changes in tachogram efficiency (tachogram $W_3{}^9$) caused by the choice of adjustment reactions R_d, which extend the technological cycle N. Assuming R_d with factor K_{ef} = max (curve No. 1), function $n_{av/„max”}(N)$ takes the form of an increasing one. While assuming R_d with factor K_{ef} = min (curve No. 2), the function takes the form of a decreasing one. And finally the third possibility: when selecting a group of adjustment reactions with the shares established (curve No. 3), in the first two cases the asymptote is determined by the adjustment reaction parameter (n_R), and in the third case it is the arithmetic average weighted as a sum of products: the adjustment reaction parameter (n_R) and the share of this reaction in an extension of the technological cycle (u_R). Thus the asymptote is determined by:

$$n_{av/R} = \sum^{R} n_R \cdot u_R, \text{ for } \sum u_R = 1 \qquad (20)$$

Whether function $n_{av/„max”}(N)$ is of an increasing or decreasing character, or it takes a constant value, it depends on the position of the value of this function at point $N = N_{min}$ with regard to the asymptote.

Because of the length of the sewing path, N_{min} should be the smallest possible. An effective way of decreasing N_{min} for the configuration of a tachogram is to decrease the maximum rotational speed n_{max}. Machines with a support of the logical type make this possible. However, one should keep in mind that it decreases the efficiency. The decrease in efficiency increases the reaction type of operator τ (compare the curves for τ = 0.25 s and = 0.45 s in ***Figure 8***). However, it is accompanied by an increase in the minimum number of working cycles of the machine N_{min}.

Conclusions

1. A tachogram can be a source of information about the course of the machine sewing process and its efficiency. The investigations proved that each course of the rotational speed of a sewing machine can be introduced by way of a polygonal curve. The modelling of a tachogram enabled to distinguish, with the use of a graph, all possible configurations for the number of operator responses established.
2. Type II configurations were distinguished among the tachograms and recognised as the most rational in the realisation processes occuring in the machine – operator system. The sequences mentioned can be treated as failed attempts at changing the levels of the segmental complexity of a technological task.
3. The indicators of efficiency proposed enable to evaluate the limits of the efficiency of a tachogram with the configuration and parameters established.
4. The structure of the tachogram used was applied to form a system for the program control of a sewing machine servo drive, with an open technological cycle. A program drive control can be used to practise the manipulative activity of an operator and his control of a drive or in order to program a tachogram using the learning function. The reason for programming the course of the rotational speed, with the use of ‘learning’, is the sensitivity of the feed dog to changes in rotational speed.
5. In a tachogram of optional configuration, one can distinguish the extension in time of the number of machine working cycles caused by transient reactions (increase, decrease) and the differentiated efficiency of the established reactions (for tachograms with a number of reactions r > 3). The efficiency of a tachogram of the configuration established is determined by values of machine parameters (acceleration and delay in transient reactions, maximum speed), as well as by the response time of the operator, the efficiency of established reactions, the number of machine working cycles and the share of particular reactions in the total number of machine working cycles.
6. The minimum number of machine working cycles allowing a technological task to be conducted is characteristic of a tachogram of established configuration and parameters. The adjustment to the task of the number of machine working cycles can be proceeded by extending the time of established reactions or decreasing the efficiency thereof.
7. The selection of a tachogram configuration for a technological task should be carried out by analysing the task with respect to its segmental complexity on the sewing path, while the choice of tachogram parameters requires the training of the operator.

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