CONTRIBUTION TO THE INVESTIGATIONS ON THE RELATIONS BETWEEN SHUTTLE MOVEMENT AND PARAMETERS OF THE PICKING MECHANISM

By

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The projection of the shuttle in power looms occurring in a split second — when accompanied by adverse conditions of movement (accelerations) due to constructional features or setting of the picking mechanism — results in stresses instantly imposing on the machine parts and the driving motor. Thus, the picking mechanism may be considered as one of the most important part of the loom and a general analysis of the problems connected with its operation is of crucial interest.

In recent years considerable attention has been given to the analysis of shuttle movement and cam-operated picking mechanism. VINCENT [1] published his mathematical theory of shuttle projection in 1939. In his work he takes into account the distortion, but neglects the masses of the picking mechanism, indicating the difficulties arising when masses are to be considered. In 1946 MALISHEV—SMIRNOV—VOROBIEV [2] analyzed the movement of the shuttle, resp. picking mechanism taking into account the distortions and masses of the elements. In 1951 CATLOW and VINCENT [3] built up the laws of shuttle movement for a massless elastic picking mechanism taking into consideration the conditions of place and time of the stroke. Comparing the movements analyzed, they determined the fundamental relationships of the desired shuttle movement.

In spite of the results achieved, the theory of picking mechanism cannot be considered as fully elaborated. Though, conditions favouring the shuttle movement have been suggested, the effect of the practical measures applied by loom-overlookers in setting the required shuttle velocity, remained unrevealed.

In the present investigations the laws of motion of the picking mechanism have been derived, taking into account its masses and the force of checking the shuttle. The effects of the various parameters of the given picking mechanism on the final velocity of the shuttle, resp. on the stresses occurring, have also been discussed.

The present paper is a theoretical summary of the research work carried out by the author in connection with the investigations on picking mechanism.

Control experiments under practical conditions and analysis of the parameters for which the method did not give possibility *(i. e.* the reduction in loom speed during the stroke) are being followed up.

1. Conditions and method of the theoretical investigations on shuttle movement

Some of the dynamic problems of the picking mechanism are connected with the acceleration of the shuttle and the stresses, and distortions occurring are determined by it depending on the other characteristics of the picking mechanism. The following investigations will be based on the characteristics of the picking mechanism experimentally determined, while the rotation of the crank-shaft under the stroke will be assumed to be constant.

The laws of the kinetic movement of the shuttle will be termed — according to Vincent — as laws of *actual movement* and the laws of kinematic (distortionless) movements as laws of *nominal movement.*

1.1 *Differential equation and solution of the shuttle movement*

The differential equation of the picking mechanism was defined by taking its dimensions, masses, elastic elements and the forces acting on the shuttle into consideration.

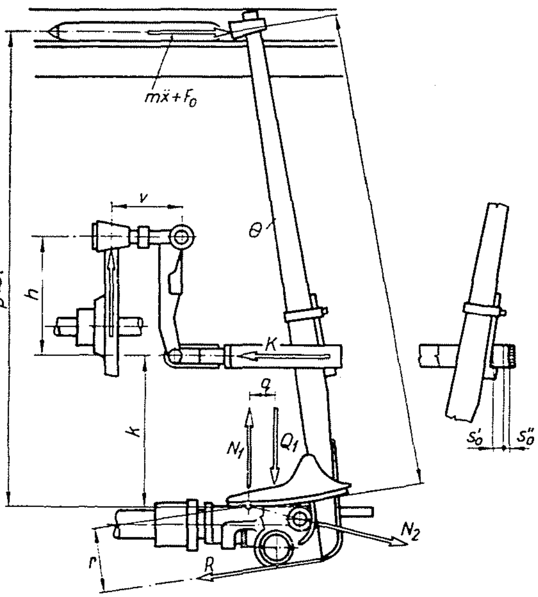

Fig. 1. Scheme of the picking mechanism for dynamical investigation

According to Fig. 1 the partial distortions of the picking mechanism during the stroke are the following:

The distortion of the picking stick (f_1)

$$f_1 = c_1 (m\ddot{x} + F_0) \tag{1}$$

where c_1 — the spring constant of the picking stick,
m — the mass of the shuttle,
$\ddot{x}$ — the acceleration of the shuttle and
F_0 — the checking forces acting on the shuttle.

From the moment-equation plotted for the points of intersection of the forces N_1, N_2, the distortion of the loop of the picking strap (f_2) is

$$f_2 = \frac{l \cdot c_2}{k^2} \left[\left(ml + \frac{\Theta}{l} \right) \ddot{x} + \frac{r^2}{l \cdot c_4} x + F_0 l \right] \tag{2}$$

where c_2 — the spring constant of the loop of the picking strap,
Θ — the total moment of inertia both for picking stick and the shoe,
$\frac{\ddot{x}}{p} \cong \frac{\ddot{x}}{l}$ — the angular acceleration of the picking stick, and
c_4 — the constant of the return spring of the picking stick.

The distortion of the picking shaft (f_3) is

$$f_3 = \frac{l \cdot c_3}{k^2} \left[\left(ml + \frac{\Theta}{l} \right) \ddot{x} + \frac{r^2}{l \cdot c_4} x + F_0 l \right] \tag{3}$$

The total distortion of the picking mechanism is given by the amount of the partial distortions:

$$f = f_1 + f_2 + f_3 = \left[mc_1 + \frac{l}{k^2} (c_2 + c_3) \left(ml + \frac{\Theta}{l} \right) \right] \ddot{x} + \frac{r^2}{k^2 \cdot c_4} (c_2 + c_3) x + \\ + F_0 \left[c_1 + \frac{l^2}{k^2} (c_2 + c_3) \right]$$

Or introducing the constants

$$B = mc_1 + \frac{l}{k^2} (c_2 + c_3) \left(ml + \frac{\Theta}{l} \right)$$

$$C = \frac{r^2}{k^2 c_4} (c_2 + c_3)$$

$$D = F_0 \left[c_1 + \frac{l^2}{k^2} (c_2 + c_3) \right]$$

$$f = B\ddot{x} + Cx + D \tag{4}$$

The relationship between the actual (kinetic) (x) and the nominal (kinematic) (s) displacement of the shuttle is

$$x = s - f$$

Substituting and arranging the distortion given by relation (4) the differential equation of the shuttle movement takes the form

$$B\ddot{x} + (C + 1)x = s - D \tag{5}$$

The differential equation has been solved by satisfying the conditions of the compound movement suggested by Catlow and Vincent. Taking the compound movement selected, the shuttle moves in the first stage of the movement with an actual acceleration of

$$a_{x1} = \ddot{x}_1 = A \sin \mu t.$$

For the second stage of the movement the actual acceleration is

$$a_{x2} = \ddot{x}_2 = A - \text{const.}$$

In view of the continuity of the movement the following conditions are to be satisfied:

1. At the transition point the actual movement is continuous.
2. The maximum of the actual acceleration occurs at the transition point.

With the initial conditions $t_0 = 0$, $x_1 = 0$, $v_{x1} = 0$ the solution of the differential equation gives the following relations for the first stage of the actual movement:

$$a_{x1} = \ddot{x}_1 = A \sin \mu t \tag{6}$$

$$v_{x1} = \dot{x}_1 = \frac{A}{\mu}(1 - \cos \mu t) \tag{7}$$

$$x_1 = \frac{A}{\mu^2}(\mu t - \sin \mu t) \tag{8}$$

Substituting equations (6) and (8) into differential equation (5) the nominal displacement of the shuttle will be

$$s_1 = D + \frac{A}{\mu}(C + 1)t - A\left(\frac{C+1}{\mu^2} - B\right)\sin \mu t \tag{9}$$

By differentiating (9), the velocity and the acceleration become

$$v_{s1} = \dot{s}_1 = \frac{A}{\mu}(C+1) - A\,\mu\left(\frac{C+1}{\mu^2} - B\right)\cos\mu t \tag{10}$$

$$a_{s1} = \ddot{s}_1 = A\,(C + 1 - B\,\mu^2)\sin\mu t \tag{11}$$

The maximum of the actual acceleration occurs at the end of the first stage of the movement after time

$$\tau = \frac{\pi}{2\,\mu}$$

The actual acceleration in the second stage of the movement is

$$a_{x2} = \ddot{x}_2 = A \tag{12}$$

with the initial conditions of $t_0 = \dfrac{\pi}{2\,\mu}$; $v_{x2} = v_{x1}$; $x_2 = x_1$

$$v_{x2} = \dot{x}_2 = A\left(t - \frac{\pi}{2\,\mu} + \frac{1}{\mu}\right) \tag{13}$$

$$x_2 = \frac{A}{2}\left(t - \frac{\pi}{2\,\mu}\right)^2 + \frac{A}{\mu}t - \frac{A}{\mu^2} \tag{14}$$

Substituting equations (12) and (14) into differential equation (5) for the second stage of the movement the nominal displacement is obtained in the following form:

$$s_2 = AB + \left[\frac{A}{2}\left(t - \frac{\pi}{2\,\mu}\right)^2 + \frac{A}{\mu}t - \frac{A}{\mu^2}\right](C+1) + D \tag{15}$$

After differentiation

$$v_{s2} = \dot{s}_2 = \left[A\left(t - \frac{\pi}{2\,\mu}\right) + \frac{A}{\mu}\right](C+1) \tag{16}$$

$$a_{s2} = A\,(C+1) \tag{17}$$

In the given case the laws of shuttle movement can be determined on the basis of the required final velocity (V), on the total distance X moved by the picker head, resp., on the actual distance of the first stage of the movement X_1, and on the dimensions and spring constants of the picking mechanism.

Substituting the final shuttle velocity V from (13) the time of the complete movement is

$$T' = \frac{V}{A} - \frac{1}{\mu} + \frac{\pi}{2\mu} \tag{18}$$

To find the maximum acceleration of the shuttle (A) insert time $\tau = \frac{\pi}{2\mu}$ of the first range of the movement into (8) and substitute equation (18) into (14), taking into account $x_1 = X_1$; and $x_2 = X$

$$\mu = \sqrt{\frac{A}{X_1}\left(\frac{\pi}{2} - 1\right)}$$

$$\mu = A\sqrt{\frac{\pi - 3}{2AX - V^2}} \tag{19}$$

whence the value of the maximum acceleration is

$$A = \frac{V^2}{2X - \dfrac{\pi - 3}{\dfrac{\pi}{2} - 1} X_1} \tag{20}$$

1.2 *The laws of shuttle movement for a given picking mechanism*

The laws of movement derived apply for loom speed $n = 200$ rev./min, and for shuttle velocity $V = 17$ m/sec. Other dimensions of the picking mechanism were determined by measurements, resp. in the course of designing:

$c_1 = 3.54 \cdot 10^{-2}$ cmkg^{-1}, $c_2 + c_3 = 0.2851 \cdot 10^{-2}$ cmkg^{-1},
$c_4 = 0.62$ cmkg^{-1}, $\Theta = 1.8542$ kgcmsec^2, $X = 22$ cm,
$X_1 = 8.6$ cm, $l = 74$ cm, $k = 23$ cm, $r = 8{,}3$ cm,
$m = 0.428 \cdot 10^{-3}$ kgsec^{2}cm^{-1}, $F_0 = 5$ kg.

With the above data from equation (20) $A = 690$ msec^{-2}, $\mu = 67.95$ sec^{-1}, $\tau = 2.3116 \cdot 10^{-2}$ sec, and $T = 3.3 \cdot 10^{-2}$ sec.

The defined laws of the nominal and actual movements are shown in Fig. 2.

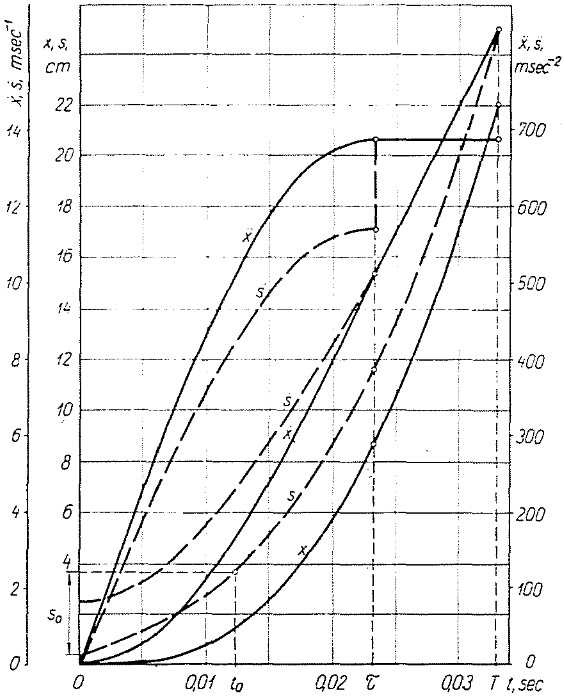

Fig. 2. Laws of motion of the picking mechanism for nominal (s, $\dot{s}$, $\ddot{s}$) and actual (x, $\dot{x}$, $\ddot{x}$) movements

2. Effect of variations in the parameters of the picking mechanism on laws of the shuttle movement

In the following the effect of changing the kinematic and dynamic parameters of the picking mechanism will be considered. As a result of experimental setting or substituting broken machine parts by new ones of different elasticity and masses, the operation of the picking mechanism may deviate from the designed data. Thus, the analysis of the changes in the main parameters governing the operation of the picking mechanism is of interest, and may lead to a better understanding of it.

For the purpose of the present investigations a cam designed for the derived compound movement has been assumed and the effects of variations in loom speed, in the play and in the position of the loop of the picking strap (resp. in the spring constant), in the checking and in the weight of the shuttle were considered.

Changing the loom speed requires the transformation of the function obtained for the law of motion. If the picking mechanism designed for the given

n_1 rev./min. of the loom operates with n_2 rev./min., the function $s = f(t)$ takes the form

$$s = f(qt),$$

where $q = \frac{n_2}{n_1}$.

When changing the play of the loop of the picking strap, the basic play of the same, taken into account for designing a cam (necessary in view of the swinging movement of the slay), will be assumed to be of magnitude 0. If the play is increased, so the picking head will start its movement by t_0 times later and the operation range of the cam will also be reduced by s_0. Thus, a change in the play again requires the transformation of the function and the laws of movement will be obtained by the substitutions of

$$t' = t + t_0 \text{ and}$$
$$s' = s + s_0$$

(The notations t' and s' are used for simplicity's sake in the same meaning as s resp. t were previously used.)

Variations in other parameters of the picking mechanism (Θ, c, l, k, a. s. o.) influence but the constants B, C, D, from differential equation (5). It has to be considered, however, that with the changing of the position of the loop of the picking strap, the spring constant c_1 of the picking stick changes, too.

Using the notations of Fig. 1 the spring constant will vary with the changes in the position of the loop of the picking strap, approximately according to the relation

$$c_1 = \frac{(l-k)^2 \cdot l}{3\,JE} \tag{20a}$$

When fitting in new machine parts, the dimensions and spring constants have again to be correspondingly determined.

2.1 *Consideration of the changes of parameters in the expressions for the shuttle movement*

In order to define the laws of the nominal movement of the shuttle, the following substitutions had to be made

$$\begin{aligned} s' &= s + s_0 \\ t' &= q\,(t + t_0) \end{aligned} \tag{21}$$

On substituting these values, the laws of the nominal movement will take the following forms:

for the first stage of movement

$$s_1 = D - s_0 + \frac{A}{\mu}(C+1)\,q\,(t+t_0) - A\left(\frac{C+1}{\mu^2} - B\right)\sin\mu\,q\,(t+t_0) \tag{22}$$

$$v_{s1} = \frac{A}{\mu}(C+1)\,q - A\,\mu\,q\left(\frac{C+1}{\mu^2} - B\right)\cos\mu\,q\,(t+t_0) \tag{23}$$

$$a_{s1} = A\,(C+1-B\,\mu^2)\,q^2\sin\mu\,q\,(t+t_0) \tag{24}$$

for the second stage of movement

$$s_2 = AB - s_0 + \left\{\frac{A}{2}\left[q\,(t+t_0) - \frac{\pi}{2\mu}\right]^2 + \frac{A}{\mu}\,q\,(t+t_0) - \frac{A}{\mu^2}\right\}(C+1) + D \tag{25}$$

$$v_{s2} = \left\{Aq\left[q\,(t+t_0) - \frac{\pi}{2\,\mu}\right] + \frac{A}{\mu}\,q\right\}(C+1) \tag{26}$$

$$a_{s2} = Aq^2\,(C+1) \tag{27}$$

In determining the laws of actual movement, variations in other parameters of the picking mechanism have also been taken into account in the form of the new constants B', C', D'.

Thus the new form of differential equation (5) for the picking mechanism is

$$B'\ddot{x} + (C'+1)\,x = s - D' \tag{28}$$

In order to define the laws of actual movement for the first stage of movement substitute (22) into (28) and the following differential equation is obtained

$$B'\,\ddot{x} + (C'+1)\,x = D - D' - s_0 + \frac{A}{\mu}(C+1)\,q\,(t+t_0) -$$

$$- A\left(\frac{C+1}{\mu^2} - B\right)\sin\mu\,q\,(t+t_0)\ . \tag{29}$$

Assuming that the solution of the homogeneous equation is of the form

$$X_1 = e^{\lambda t}$$

the characteristic equation for the solution of the differential equation will be

$$B'\lambda^2 + (C'+1) = 0$$

whence

$$\lambda = \pm i \sqrt{\frac{C' + 1}{B'}} .$$

Having made the substitution

$$\psi = \sqrt{\frac{C' + 1}{B'}}$$

the general solution of the homogeneous equation takes the form

$$X_1 = K_1 \cos \psi t + K_2 \sin \psi t \tag{30}$$

The particular solution of the inhomogeneous equation with the known experimental assumption may be satisfied in the form

$$x_{p1} = k_1 + k_2 (t + t_0) + k_3 \cos \mu q (t + t_0) + k_4 \sin \mu q (t + t_0) \tag{31}$$

By double differentiation

$$\ddot{x}_p = - k_3 \mu^2 q^2 \cos \mu q (t + t_0) - k_4 \mu^2 q^2 \sin \mu q (t + t_0) \tag{32}$$

Substituting (31) and (32) in the inhomogeneous equation (29) and identifying the coefficients (assuming that $\frac{C + 1}{\mu^2} - B \neq 0$, *i. e.* the cam profile is not straight) obtain

$$k_1 = \frac{D - D' - s_0}{C' + 1} = E$$

$$k_2 = \frac{A}{\mu} \frac{C + 1}{C' + 1} q = \frac{A}{\mu} Fq$$

$$k_3 = 0$$

$$k_4 = - \frac{A}{\mu^2} \frac{C + 1 - \mu^2 B}{C' + 1 - \mu^2 q^2 B'} = - G \tag{33}$$

The solution of differential equation (29) gives the laws of actual movement for the first stage of movement by substituting the (30) homogeneous and the (31) particular solutions, resp. the (33) coefficients

$$x_1 = K_1 \cos \psi t + K_2 \sin \psi t + E + \frac{A}{\mu} qF (t + t_0) - G \sin \mu (t + {}'_0) \tag{34}$$

by differentiating

$$v_{x1} = -K_1 \psi \sin \psi t + K_2 \psi \cos \psi t + \frac{A}{\mu} qF - G \mu q \cos \mu q (t + t_0) \quad (35)$$

$$a_{x1} = -K_1 \psi^2 \cos \psi t - K_2 \psi^2 \sin \psi t + G \mu^2 q^2 \sin \mu q (t + t_0) \quad (36)$$

The constants of equations (34), (35), and (36) may be obtained with the initial conditions $t = 0$; $x_1 = 0$; and $x_1 = v_{x1} = 0$

$$\left. \begin{aligned} K_1 &= G \sin \mu q t_0 - \frac{A}{\mu} qFt_0 - E \\ K_2 &= \frac{1}{\psi} \left(G \mu q \cos \mu q t_0 - \frac{A}{\mu} qF \right) \end{aligned} \right\} \quad (37)$$

In order to determine the laws of actual movement for the second stage of movement substitute the term of the nominal movement from (25) into differential equation (28)

$$\begin{aligned} B' \ddot{x} + (C' + 1) x = D - D' - s_0 + AB + \\ + (C + 1) \left[\frac{A}{2} q^2 (t + t_0)^2 + \quad + \frac{A}{\mu} q \left(1 - \frac{\pi}{2} \right) (t + t_0) + \frac{A}{\mu^2} \left(\frac{\pi^2}{8} - 1 \right) \right] \end{aligned} \quad (38)$$

Similarly to the solution of equation (29), the general solution of the homogeneous equation is

$$x_2 = K_3 \cos \psi t + K_4 \sin \psi t \quad (39)$$

The particular solution may be found in the form

$$x_{p2} = k_5 (t + t_0)^2 + k_6 (t + t_0) + k_7 \quad (40)$$

By differentiating and substituting the expressions x_{p2}, resp. $\ddot{x}_{p2}$ in the inhomogeneous equation and identifying the coefficients, the following constants are obtained:

$$\begin{aligned} k_5 &= F \frac{A}{2} q^2 = H \\ k_6 &= F \frac{A}{\mu} q \left(1 - \frac{\pi}{2} \right) = I \\ k_7 &= E + \frac{AB}{C' + 1} + F \frac{A}{\mu^2} \left(\frac{\pi^2}{8} - 1 \right) - F \frac{Aq^2 B'}{C' + 1} = M \end{aligned} \quad (41)$$

The laws of actual movement for the second stage of movement may be obtained by substituting the (39) homogeneous and the (40) inhomogeneous solutions, resp. the coefficients from (41).

$$x_2 = H(t+t_0)^2 + I(t+t_0) + M + K_3 \cos \psi t + K_4 \sin \psi t \tag{42}$$

by differentiation

$$v_{x2} = 2H(t+t_0) + I - K_3 \psi \sin \psi t + K_4 \psi \cos \psi t \tag{43}$$

$$a_{x2} = 2H - K_3 \psi^2 \cos \psi t - K_4 \psi^2 \sin \psi t \tag{44}$$

The constants in (42), (43) and (44) may be determined with the following initial conditions: $t = \tau - t_0$; $x_2 = x_1$; $\dot{x}_2 = \dot{x}_1$. Introducing the notation

$$\varrho = \psi(\tau - t_0)$$

and taking into account the further initial conditions

$$\begin{aligned} K_3 &= N \cos \varrho - \frac{P}{\psi} \sin \varrho \\ K_4 &= N \sin \varrho + \frac{P}{\psi} \cos \varrho \end{aligned} \tag{45}$$

where

$$N = H\tau^2 + I \frac{\pi}{2-\pi} \tau - M + K_1 \cos \varrho + K_2 \sin \varrho + E - G \sin q \frac{\pi}{2}$$

$$P = -2H\tau + I \frac{\pi}{2-\pi} + K_2 \psi \cos \varrho - K_1 \psi \sin \varrho - G\mu q \cos q \frac{\pi}{2} \tag{46}$$

The time of the total motion is

$$T = \frac{T' - t_0}{q} \tag{47}$$

2.2 *Development of laws of the shuttle movement depending on some of the parameters*

The most frequently varied parameters of the picking mechanism are the play s_0' and the position k of the loop of the picking strap (Fig. 1).

The play related to the pickerhead may be obtained, taking into consideration the play s_0' from relation

$$s_0 = s_0' \frac{l}{k} \tag{47a}$$

The value t_0 corresponding to the value s_0, defined by this method, may be obtained from the nominal distance curve (Fig. 2). The analysis was carried out on the basis of equations (34)—(36) and (42)—(44) by substituting the corre-

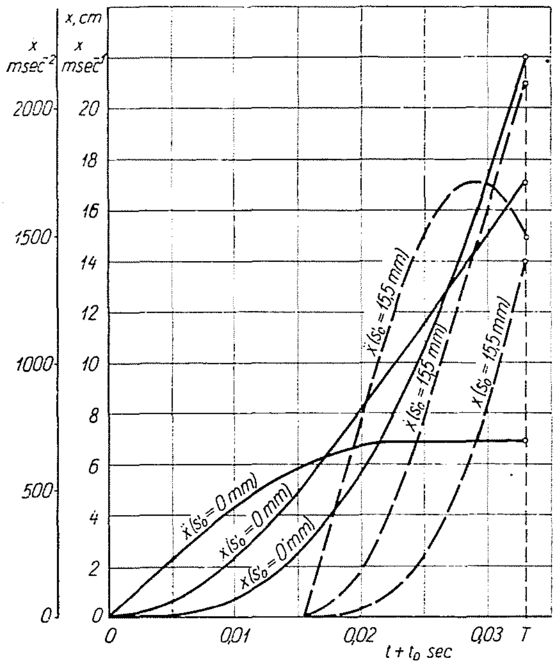

Fig. 3. Laws for actual movement of a picking mechanism operating with a play of $s_0 = 15.5$ mm compared to the laws of the original movement ($s_0 = 0$)

sponding $s_0 - t_0$ values. The laws of movement obtained on the basis of the foregoing data — by taking into account a play of $s_0' = 15.5$ mm — compared to the original laws of movement ($s_0' = 0$), is shown in Fig. 3.

A characteristic feature resulting from an increased play is the reduced time of the pick, resp. the reduced distance travelled by the shuttle. In spite of that, with a play of 15.5 mm, the final velocity of the shuttle will be higher by $\Delta V = 3.88$ msec^{-1} (22.8%). With the play selected, the acceleration of the shuttle reaches its maximum before completion of the pick. In the present case the value of maximum acceleration compared to that of a picking mechanism, operating under designed conditions, is by 1.021,17 msec^{-2} (148%)

higher. Consequently, when increasing the play, distortions in the conditions of acceleration and increased strain on the picking mechanism are to be expected. When changing the position of the loop of the picking strap, the kinematic gear-ratio and, according to relation (20*a*), the spring constant c_1 of the picking stick will have to be changed too. In usual practice, when increasing the final velocity of the shuttle, the position of the loop of the picking strap used to be lowered. The final velocity could, however, only in certain positions of the

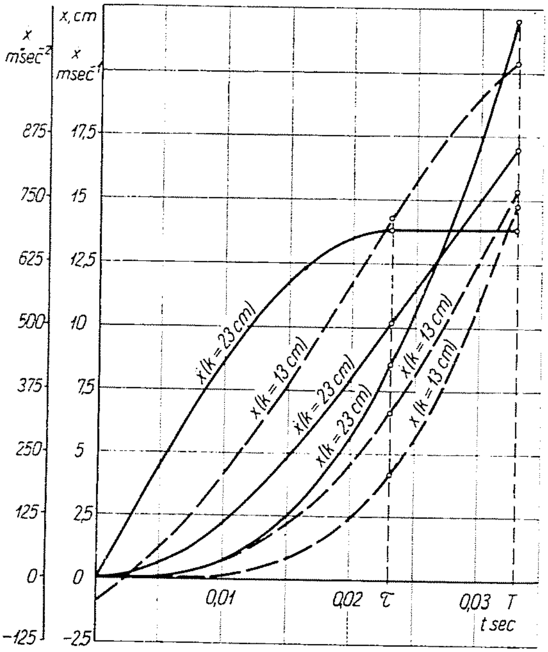

Fig. 4. Laws for actual movement of a picking mechanism operating with $k = 13$ position of the loop of the picking strap compared to the laws of the original movement ($k = 23$ cm)

loop of the picking strap ($k = 19$—23 cm) be increased. If the position of the loop of the picking strap is lowered further, then owing to the change in the spring constant, the final velocity decreases. This is shown in Fig. 4, where the laws of movement obtained in a position of the loop of the picking strap $k = 13$ cm, and the original laws of movement ($k = 23$ cm) are given. It is also to be seen, that due to the change in the spring constant of the picking stick, the acceleration diagram is distorted; on reaching the final velocity, the acceleration is by 329.39 msec^{-2} higher than the original acceleration, the increasement being 47.7%. In spite of the rising acceleration, the final velocity of the shuttle remains lower; it is 90.17% (15.33 msec^{-2}) of the original final velocity. By the higher value of the spring constant of the picking stick, the distance made by the shuttle will also be influenced; it will be reduced to 14.77 cm, which is 67.14% of the original distance.

3. Analysis of the final velocity of the shuttle depending on the setting parameters

In order to attain the required shuttle velocity, the parameters of the picking mechanism used to be adjusted experimentally by the overlookers. In the present section the characteristic effects caused by the variations of the parameters on the final velocity of the shuttle, will be analyzed neglecting the development of the laws of movement during picking. For the sake of completeness, in addition to the final velocity, the distance moved by the shuttle during the maximum velocity (the path of the pick) and the accelerations will also be determined.

The path of the pick may be obtained by substituting the time of the total movement (47) from equation (42)

$$X = H(T+t_0)^2 + I(T+t_0) + M + K_3 \cos \psi T + K_4 \sin \psi T \qquad (48)$$

Similarly, the maximum velocity V and the corresponding acceleration A_0 may be obtained from equations (43) and (44).

$$\begin{aligned} V &= 2H(T+t_0) + I - K_3 \psi \sin \psi T + K_4 \psi \cos \psi T \\ A_0 &= 2H - K_3 \psi^2 \cos \psi T - K_4 \psi^2 \sin \psi T \end{aligned} \qquad (49)$$

3.1 *Effect of variation in loom speed*

As shown above, variations in loom speed can be expressed by the transformation of function $s = f(t)$, $s = f(qt)$, where $q = \dfrac{n_2}{n_1}$. By variation in the loom speed the laws of movement do not formally change.

Investigations have been carried out in the speed range $n_2 = 160-240$ rev./min. under the above conditions. The results are shown in Fig. 5.

It can be seen, that with the given cam profile and with increasing loom speed, the final velocity of the shuttle increases to a higher degree than is desirable, and the required velocity could only be attained when the loom runs with the designed rev./min. The required velocity (V_r) was determined on the basis of the free shed opening, using the method developped by the author [1]. The required shuttle velocity increases linearly depending on the loom speed and can be determined from equation

$$V_r = \frac{100}{100 - p\%} \; \frac{s6n}{\varphi_v}$$

where $p\%$ is the retardation of the shuttle in the shed opening (approximately 10%), s the length of the shuttle and that of the shuttle race, φ_v the time of the free shed opening measured in the angular displacement of the crank shaft.

At speeds lower than the designed ones, the shuttle velocity is lower than that required. The deviation of the actual velocity from the required one is, however, not considerable; at loom speeds of 160 rev./min. it is -5.2%, while when reaching its maximum at 225 rev./min. the deviation is only 1.8%.

The acceleration of the shuttle rises rapidly with increasing loom speed. Increasing the loom speed from 200 to 240 rev./min., the rise in the shuttle

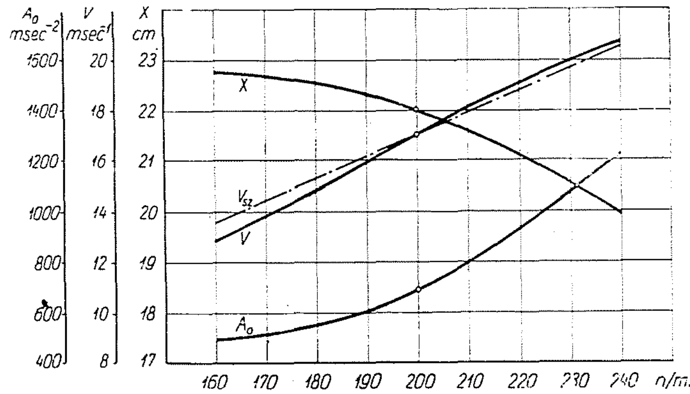

Fig. 5. Effect of the changes in loom speed on the characteristics of the movement occurring on completion of the pick

velocity will be 17.85%, while that of the acceleration amounts to 77%; simultaneously the distance travelled by the shuttle diminishes. Thus, at speeds higher than the designed value, the stresses imposed on the picking mechanism show an abnormal rise. At speeds lower than the designed ones, and with practically appropriate shuttle velocity there is a slight decrease in the acceleration of the shuttle.

3.2 *Increase in the play of the loop of the picking strap*

The investigations on the play of the loop of the picking strap are based on the corresponding values of $s_0 - t_0$ defined in Fig. 2. Substituting the values determined for the play in the range $s_0' = 0 - 60$ mm, the relations X, V, A, obtained from equations (47*a*), (48) and (49), are shown in Fig. 6.

When analyzing the curves, it can be seen, that the distance travelled by the shuttle diminishes proportionally with the play of the loop of the picking strap. *E. g.* with a play of $S_0 = 60$ mm, the exploitation of the original distance made by the shuttle is 1.1%. The change in the velocity shows a maximum; it rises approximately up to a play of 12.5 mm, then it decreases. Thus, the definition, that the "force" of the stroke decreases with increasing play is ambiguous and apply only for cases when the play is extremely high (Fig. 6).

With higher play the stresses imposed on the picking mechanism considerably increase. Neglecting the interim maximum of the acceleration of the shuttle (Fig. 3) and taking into account the acceleration when attaining the final velocity, it may be seen from Fig. 6, that with a play of $s_0' = 35$ mm, the

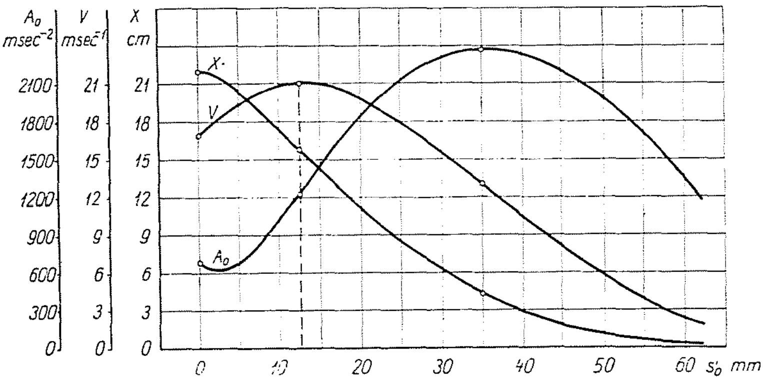

Fig. 6. Effect of changes in the play of the loop of the picking strap on the characteristics of the movement occurring on completion of the pick

acceleration of the shuttle rises to 340% of its original value. Accelerations of such magnitude lead to abnormal stresses on and rapid wear of the picking mechanism.

3.3 *Effect of change in the weight of the shuttle*

Under practical circumstances, the weight of the shuttle changes in two cases: when using new shuttles different in dimension and weight, and when the weight of the pirn decreases with the unwinding of the yarn.

The change in the weight, resp. in the mass m of the shuttle influences the value B (term $3a$) used in the relations. Fig. 7 shows the result obtained by changing the weight of the shuttle in the practical range $Q = 380-520$ g.

As indicated in Fig. 7, by increasing the weight of the shuttle its final velocity rises, while at the same time the distance travelled decreases. The rise in the final velocity of the shuttle is, however, of no importance. On increasing the weight of the shuttle by 140 g, the length of the pick decreases by 2 cm (4.5%), while the drop in the final velocity will be 8.5% (1.44 m/sec).

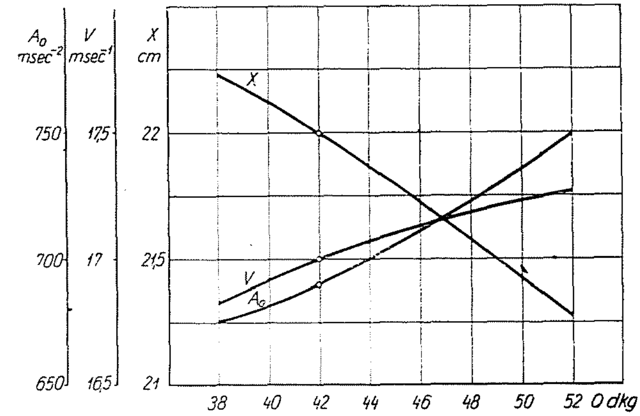

Fig. 7. Effect of changes in the weight of the shuttle on the characteristics of the movement on completion of the pick

The conditions of acceleration cannot be estimated on the basis of the accelerations occurring when reaching the final velocity, as the distortions in the laws of motion are accompanied by an interim maximum of the acceleration.

3.4 *Effect of checking the shuttle*

Variations in checking the shuttle effect the value of the constant D (term $3a$) used in the equations.

Studying the magnitude of shuttle checking in the range of $F_0=0$—10 kg, Fig. 8 indicates, that when increasing the checking force, the final velocity of the shuttle slightly rises. Increasing the checking force from 0 to 10 kg, the final velocity rises but by 0.83 msec^{-1} (5%), while the length of the pick decreases by 0.25 cm. There is no contradiction in that, however, when considering the acceleration diagrams from Fig. 9 with checking forces of 5 and

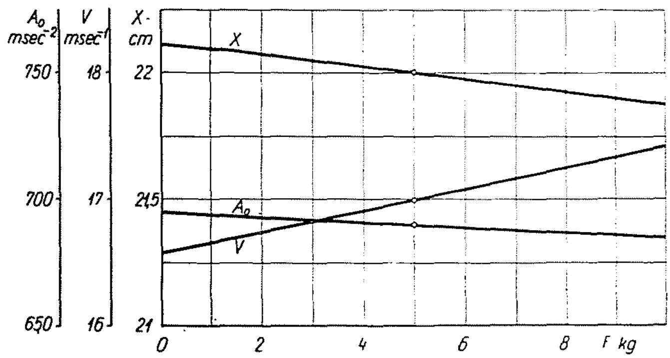

Fig. 8. Effect of changes in the checking of the shuttle on the characteristics of the movement on completion of the pick

10 kgs. With higher checking forces, the acceleration diagram shows distortions; before reaching the final shuttle velocity there is a transitory maximum in the acceleration, higher than the acceleration occurring at completion of the pick.

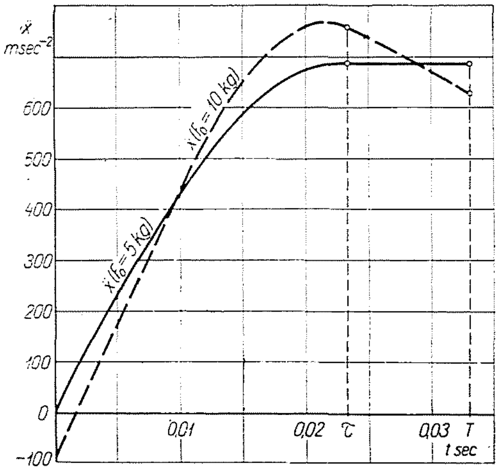

Fig. 9. Actual acceleration of the picking mechanism with checking the shuttle by $F_0 = 10$ kg, compared to the original movement of $F_0 = 5$ kg

3.5 *Effect of changes in the position of the loop of the picking strap*

As has been shown above, the developments of the values of velocity and acceleration resulting from changing the position of the loop of the picking

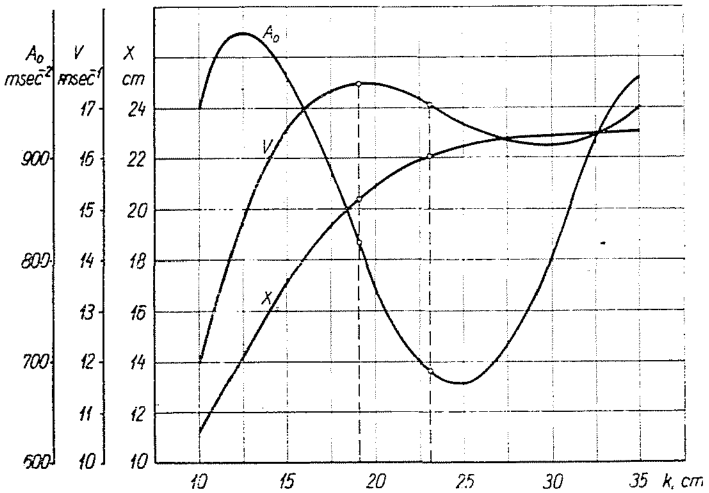

Fig. 10. Effect of changing the position of the loop of the picking strap on the characteristics of the movement on completion of the pick strap — due to the simultaneous change in the spring constant of the picking stick — are of ambiguous nature.

From Fig. 10 it is to be seen, that when lowering the designed position of the loop of the picking strap ($k = 23$ cm) a slight rise in the final velocity may take place (in the range $k = 19-23$ cm); if the position of the loop of the picking strap is $k < 19$ cm, the final velocity decreases rapidly, while when $k > 23$ cm, after a transitory fall (4.6%), it slightly increases. On completion of the pick — as a result of the distortion of the acceleration curve in Fig. 4 — the final velocity shows fluctuations in a broad range.

Conclusions

In the above paper the laws of movement for an under-pick picking mechanism have been derived, taking its masses into account. At the same time the laws of actual and nominal movement of the shuttle were determined. Distortions occurring with the latter movement were considered.

For further investigations a cam designed for a compound movement of primary sinus and secondary constant acceleration were assumed, and the relations showing the effect of the changed kinematic and dynamic parameters of the picking mechanism with the given cam had been determined. It has been proved that variations both in loom speed and in the play of the loop of the picking strap may be analyzed by transformation of the functions of the derived relations, while the other parameters effect the values of the constants. The position of the loop of the picking strap influences the spring constant of the picking stick, hence, in addition to the kinematic changes of dimensions, it has also to be considered.

From the relations expressing the laws of motion of the shuttle — by taking into account the final conditions of the movement — the maximum velocity, the acceleration, resp. the distance travelled by the shuttle were derived.

Studying the development of the final shuttle velocity in relation to the parameters of loom-setting, the following may be stated:

Optimum stresses proved to be characteristic only for picking mechanisms operating under designed conditions, as the lowest maximum acceleration occurs in such cases. Contrary to practice, followed up to now, variations of the final velocity may be best achieved by changing the length of the picking lever (Fig. 1) as in such case merely a kinematic change of dimension occurs, by which the change of dynamical conditions takes place without considerable distortions.

Most setting methods in use have a distorting effect on the laws of motion of the picking mechanism, and abnormally increase the accelerations proportional to the stresses on the picking mechanism.

When increasing the play of the loop of the picking strap, the final velocity of the shuttle first rises, then — if the play is extremely high — decreases considerably. Simultaneously, the displacement of the shuttle also decreases while the accelerations necessarily increase. Changing the position of the loop of the picking strap results in changes in the spring constant of the picking strap, owing to which — in certain ranges — the final velocity of the shuttle — though to a negligible degree — also changes. In the given case, with positions of the loop of the picking strap in the range of $k = 19-35$ cm, the shuttle velocity is by 2.4% higher, resp. 4.6% lower than the designed value. Under these conditions, on completion of the pick, accelerations also fluctuate in broad range (Fig. 10). With $k = 19$ cm position of the loop of the picking strap, the steep decrease in the final velocity is accompanied by a high increase in the acceleration.

In addition to the dimensional changes of the picking mechanism, effects of loom speed, weight and checking of the shuttle have also been analyzed.

As to the final velocity, the operation of the picking mechanism is in the range of 160—240 rev./min. satisfactory, and deviations from the required shuttle velocity are but of the magnitude of —5.2%, resp. +1.8%.

At loom speeds higher than the designed ones, in spite of the satisfactory final velocity, the rise in the accelerations is not in proportion and an increase of 17.85% in the shuttle velocity may be achieved but by an acceleration of 77%.

Changes in the weight of the shuttle in the practical range of 380—520 g do not decisively influence the final velocity of the shuttle. If the weight of the shuttle is 520 g instead of 320 g, the final velocity will be increased by 8.5%.

The effect of checking the shuttle is smaller than that of the shuttle weight. By increasing the checking force from 0 to 10 kg, the final velocity rises by 5%.

Summary

Picking mechanisms, taking their masses into account, were analyzed in view of a compound sinusoidal movement. Effects of loom speed, dimensions of the picking mechanism and weight and checking of the shuttle were considered.

From the results obtained conclusion may be drawn as to the effect of the changes in the parameters on the final velocity of the shuttle and on the development of the stresses imposed on the picking mechanism.

References

1. VINCENT, J. J.: Journal of the Textile Institute **30**, 103 (1939).
2. MALISHEV, A. P.—SMIRNOV, A. O.—VOROBIEV, P. A.: Основы проектирования ткацких станков. Moscow, 1946.
3. CATLOW, M. G.—VINCENT, J. J.: Journal of the Textile Institute **42**, 413 (1951).

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