STUDIES ON SPEED-UP AND INEQUAL RUNNING OF LOOMS

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The study of the operation of weaving looms from the dynamical point of view can be considered as one of the most complicated tasks. Due to the fluctuating reversible energy of the swinging masses, the momentary decrease in the revolution per minute accompanying the great energy consumption of the pick, and other losses of energy, the inequality degree of the operation of the loom may be subject to variations on a broad scale. The changes in the energy of the slay can be followed by means of analytical or graphoanalytical methods, but the energy requirements of picking and its effect exerted upon the operation of the loom, can only be determined by measurements.

1. Measurement of inequal running of looms

Most of the instruments applied for measuring the inequal running of looms are of the impulsive type. KRYMOV applies 36 wire-contacts placed on a synthetic disc at identical distances, whereas RAEVSKI adopts a so-called cog-wheel generator to determine fluctuations of the rpm [1].

The measuring instrument of the Hungarian Textile Research Institute, consists of a commutator of 29 segments attached to the crankshaft by means of a cardan shaft [2].

The Department for Textile Technology of the Polytechnic University, Budapest, applied the following method for determining the fluctuations of rpm.

A disc of 380 mm diameter had been wedged on the crankshaft of the loom, periphery of which had been broken at every 4° by grooves of 4,5 mm and the same filled with insulating material. Thus the disc with the 90 insulated sections on its periphery becomes similar to a commutator. During the measuring — as illustrated by Fig. 1 — the circuit reaching the insulating sections through a point-contact, will be interrupted.

Simultaneously with the impulses obtained through the commutator, the 500 Hz time-signals, the phase-current of the driving motor, and also the moment of beat-up — which could be determined by means of a contact closing down in the frontal deadpoint position of the slay — were registered on a film by an oscillograph.

Characteristic oscillograms of the measurements are shown on Fig. 2, where $\Delta\lambda$ is the cyclic length of the 500 Hz time-signals, Δl_i the pulse-length of the commutator, I the phase-current of the driving motor and b the line, marking the beat-up of the reed.

The measurements were evaluated by projecting the film. By this method the commutator segments of an average length of 13,26 mm were considered

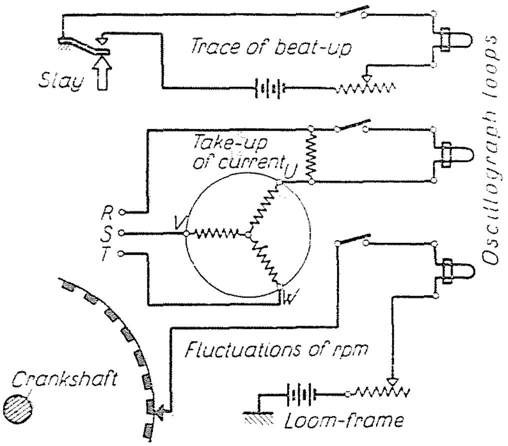


Fig. 1. Principle of the measuring instrument

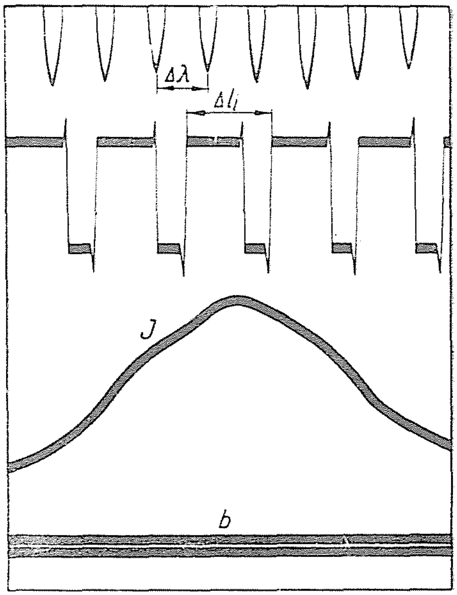


Fig. 2. Characteristic oscillogram of the measurements

in an enlargement of 12,4. The enlarged Δl_i pulse-lengths were read to a precision of $\pm 0{,}25$ mm.

Errors in measuring the momentary rpm. values originating from the faults in commutator divisions and from those of contacts and of reading were determined from 240 signals obtained at 200/min constant rpm. According to the calculations made, the fault of the momentary rpm. is characterized by a coefficient of variation of $\pm 1{,}25\%$.

The momentary rpm. values (n_i) were determined from the momentary pulse-length Δl_i and from the average cyclic length $\Delta\lambda$ of the 500 Hz time-signal (Fig. 2).

Duration of the pulse-length Δl_i is :

$$\Delta t_i = \frac{\Delta l_i}{500 \Delta \lambda}$$

and the pulse-length Δl_i — as there are 90 sectors on the periphery — corresponds to the

$$\omega_i = \frac{\Delta \varphi_i}{\Delta t_i} = 500 \, \frac{2 \pi \Delta \lambda}{90 \Delta l_i}$$

momentary angular speed and to the

$$n_i = 60 \frac{\omega_i}{2 \pi} \cong 333{,}33 \, \frac{\Delta \lambda}{\Delta l_i}$$

momentary rpm.

Estimating our measurements concerning the speed-up, the momentary rpm. values n_i were considered in view of the position of the crankshaft and of the mean-time t_i beloging to the pulse given.

The mean-time, belonging to the pulse given is :

$$t_i = \frac{l_0 + \Sigma \Delta l_{i-1} + \frac{\Delta l_i}{2}}{500 \Delta \lambda}$$

where l_0 is the signal-length extending to the first pulse.

With the above described method comparative tests were made on a loom Type R-105 with direct V-belt drive and with the very same V-belt drive operating a clutch. In order to make these comparative test reliable, revolution of the loom was precisely adjusted by means of a V-belt pulley, diameter of which could be controlled. Other constructional settings of the loom remained unchanged.

2. Estimation of the speed-up of the loom

Satisfactory driving conditions of the loom are, first of all, determined by speed-up conditions and by the safe starting of the machine.

Researches evaluate speed-up conditions by two methods. MALISHEV [3] considers the momentary rpm. values — belonging to the momentary crank position — as a characteristic feature of the speed-up of the loom. Completion of the speed-up which takes place when the momentary rpm. attains the tachometric average revolution of the loom — is given by him also in the displacement angle of the crankshaft.

ALPÁR [2] illustrates the speed-up curve in the function of time and considers the time-value elapsing up to the completion of the speed-up, defined by MALISHEV, a characteristic feature of speed-up conditions.

The significant difference between these two points of views are elucidated by the results of the measurements described. Fig. 3 illustrates a speed-up curve in the function of the crankposition obtained for V-belt drive and for clutch drive with identical n_{av}=183,5/min tachometric average revolution and at identical $\varphi_0 = 208°$ starting position of the crankshaft. Fig. 4 shows the same speed-up conditions in the function of time.

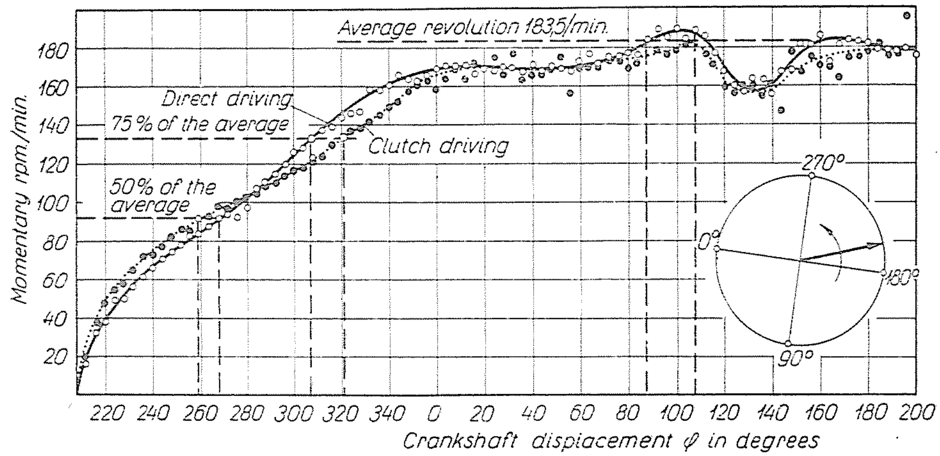


Fig. 3. Speed-up relation of direct and clutch driving in function of the crankshaft displacement with a start of $\varphi_0 = 208°$

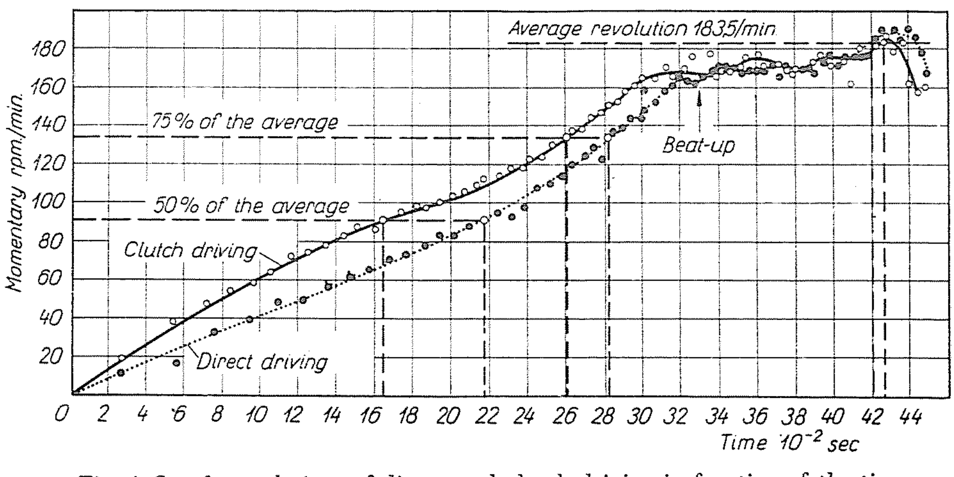


Fig. 4. Speed-up relations of direct and clutch driving in function of the time

From Fig. 4 improved speed-up conditions of the clutch-driving may be concluded: this, however, cannot be considered acceptable, as the inadequately chosen parameter of the speed-up (the time) is misleading. This seems to be proved by the following:

Though the tachimetric average rpm. is reached by a direct drive somewhat earlier (in 0,42 sec. instead of 0,426 sec.), 50% of the average revolution with clutch driving is attained in 0,164 sec. instead of 0,218, and 75% of the same in 0,26 sec. instead of 0,282 sec. Different speed-up conditions can, however, be seen from Fig. 3. Speed-up conditions with a clutch are — up to a crank position of about $\varphi = 282°$ better and momentary rpm. values higher. After $\varphi = 282°$ circumstances will change and a reverse case is presented; 75% of the average revolution appears already at about 307°, whereas with clutch driving the same takes place but at a crankshaft position of about 321°. Thus, the two methods are leading not only to different, but to contradictory results as well.

In view of the fact that the performances of the loom (picking, opening the shed, etc.) are not determined by the time elapsing from starting the machine but by the position of the crankshaft, speed-up conditions given in the function of the crankshaft position have to be considered as characteristic features.

3. Speed-up conditions with direct drive and clutch drive

In case of direct driving it is the moment of the motor and with a clutch drive it is the kinetic energy of the loose pulley which promotes the starting of the loom. Alpár [2] in evaluating the tests he carried out, points out the decisive advantage of clutch driving. According to his statements the speed-up curve of clutch driving goes up steeply and passes above the almost linear speed-up curve of the direct drive. Due to the abrupt rise of the momentary revolution curve, Alpár considers loom start with clutch drive to be safe from any position of the slay.

According to him the abrupt rise of the speed-up curve is a result of the considerable kinetic energy of the rotor part of the clutch. Malishev arrives to a similar conclusion in his work quoted.

In the measurements carried out by us improved speed-up conditions — in favour of clutch driving — as stated by the authors referred to, have not been found.

From Fig. 5 showing a speed-up curve obtained with a crankshaft position of $\varphi_0=140°$ and at $n=193$/min tachometric average revolution, conditions identical to those of Fig. 3 can be seen. In both cases clutch driving are characterized by higher momentary rpm. values in the initial stages, at about $\varphi \cong 74°$, however, momentary rpm. values of the two drivings become identical, and subsequently (up to the zone of beat-up) the speed-up curve of the clutch driving pass below the curve of the direct driving.

According to Figs. 3 and 5 there is no significant difference between the curves of the two drivings. This can be explained by the fact that the kinetic energy of the clutch gets only partly and but in the first stage of the speed-up effective. With clutch driving at the moment of switching on considerable slip takes place, annihilating a part of the kinetic energy of the clutch (transforming it into heat). Nor can the residual kinetic energy of the clutch be considered of an additive character, for when starting the motor, it exerts — in accordance with the rest of the kinetic energy — less work.

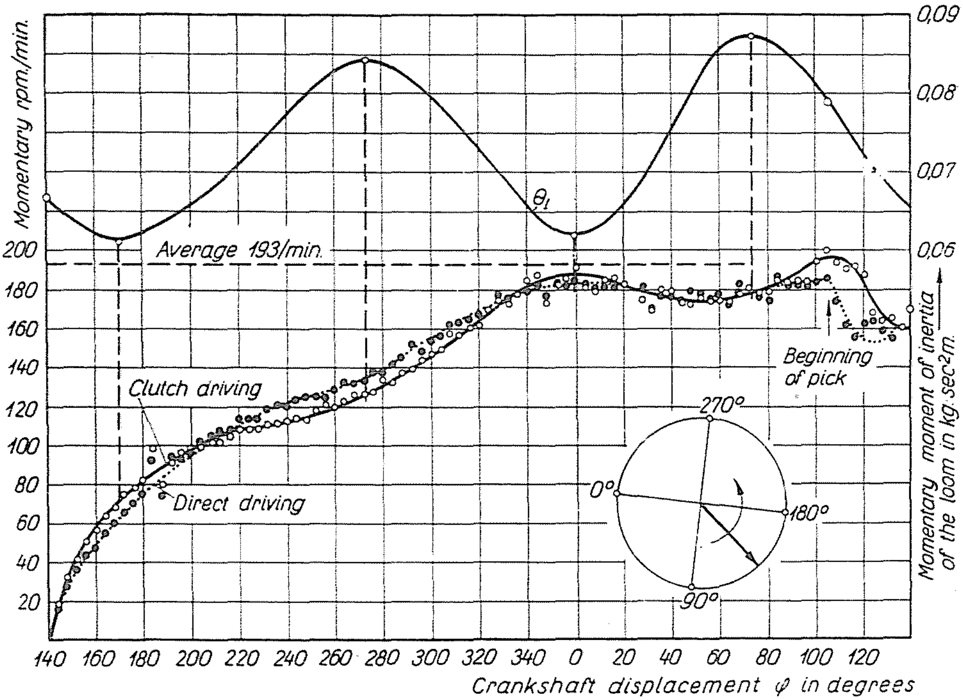


Fig. 5. Speed-up curves of direct and clutch driving with a start of $\varphi_0 = 140°$

Assuming that at the moment of switching on, the torque of the motor and the pull of the belt cease to work, the loss of energy arising by turning on the clutch, can be determined. If under such conditions contact is produced between the coupling unit with a moment of inertia of Θ_I rotating with an angular speed of ω_I and the loom with a moment of inertia of Θ_{II} the energy of the clutch before turning on will be :

$$E_I = \frac{1}{2} \Theta_I \omega_I^2$$

The total energy of the loom and of the clutch at a common angular speed of ω_{II} after having turned on will be :

$$E_{II} = \frac{1}{2}(\Theta_I + \Theta_{II})\,\omega_{II}^2$$

The common angular speed ω_{II} after turning on is (as there is no change in the angular momentum as a consequence of switching on)

$$\omega_{II} = \frac{\Theta_I}{\Theta_I + \Theta_{II}}\,\omega_I$$

Thus

$$E_{II} = \frac{\Theta_I}{\Theta_I + \Theta_{II}}\,E_I$$

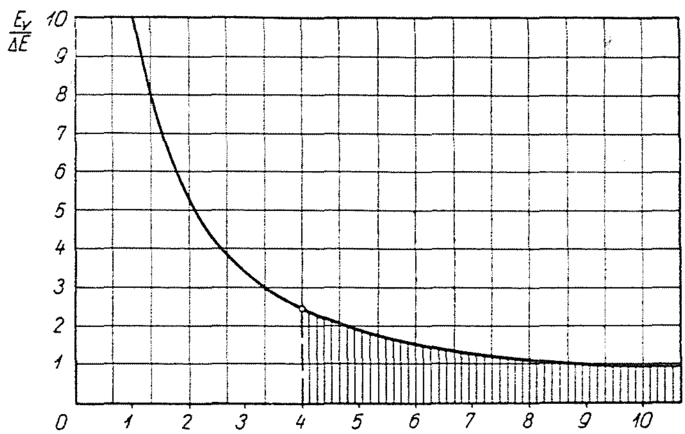
The loss of energy is :

$$E_v = E_I - E_{II} = \frac{\omega_{II}}{\omega_I + \omega_{II}}\,E_I$$

For instance, if $\Theta_I = 0{,}0291$ kgsec²m and the total moment of inertia of the loom reduced to the crankshaft at a crankshaft position of $\varphi_0 = 140°$ ($\Theta_t = 0{,}066$ kgsec²m) together with the moment of inertia of the fast pulley of the clutch (0,01214 kgsec²m) is $\Theta_{II} = 0{,}07814$ kgsec²m, so the loss of energy at the moment of switching on will be

$$E_v = 0{,}729\,E_I$$

In other words, at the moment of switching on 72,9% of the clutch own energy disappears, *i. e.* is transformed into friction heat.



Moment of intertia of the rotating clutch pulley 8, 10⁻² kgsec²m.

Fig. 6. Relation of ratios of loss of energy and useful energies depending on the moment of inertia of the loose clutch pulley

On the loom given, the loss of energy produced by turning on, can easily be decreased by increasing the moment of inertia of the loose pulley of the clutch. This is shown by Fig. 6 illustrating the relation of ratios of the loss of energy (E_v) and the useful energies($\Delta E = E_I - E_v$)depending on the moment of inertia of the loose-pulley, on a loom Type R-105 in the most unfavourable starting position $\varphi_0 \cong 70°$. From the figure it can be seen, that the proportion of the loss of energy and that of the energies to be used for speeding up will be 1 : 1 only in the case of a loose pulley with a moment of inertia of $\Theta_I \cong 0{,}09$ kgsec²m. This, however, can not be realized, as taking the inertia radius $\vartheta = 0{,}125$ (form factor) of the clutch tested, it would give a flywheel weighing

$$G = \frac{\Theta_I}{\vartheta^2} = 56{,}5 \text{ kg}.$$

In the case described, considering the 60% loss of energy at switching on as a peak-value, the lowest limit of the moment of inertia of the loose pulley, can be taken as $\Theta_I = 0{,}04$ kgsec²m.

Conditions on looms of other massdistribution are, of course, different.

In the above considerations the energy consumption during the operation of the loom (friction, beat-up) has not been taken into account and the work of the motor has been also neglected.

The power consumption of the motor is proportional to the torque exerted. From the oscillogram (Fig. 7) illustrating the uptake of current by the clutch driving at the start, can be stated, that the torque exerted by the motor at starting, is considerably lower (intensity of current 2A) than that with direct driving (intensity of current 5,5A), where the uptake of current suddenly increases at the moment of starting (Fig. 8). This can be considered as an effect of the residual kinetic energy of the clutch, which appears, first of all, in the partial discharge of the motor.

For completeness sake, attention has to be paid to the relation existing between the speed-up curve and the reduced moments of inertia.

The total moment of inertia reduced to the crankshaft of the loom, is:

$$\Theta_t = f(\varphi) = \frac{2\,E_t}{\omega^2}$$

where $E_t = E_r + E_s$ is the total energy of the rotating and swinging masses of the loom and ω is the angular speed of the crankshaft.

Fig. 5 illustrates the total moment of inertia reduced to the crankshaft (Θ_t) of the loom tested in function of the crankshaft position, without the moment of inertia of the clutch and that of the V-belt pulley, respectively.

Comparing the momentary moment of inertia of the speed-up curve and that of the loom, shows that in the decreasing stages of the reduced moments of inertia (75°—170°, 270—0°) the slope of the speed-up curve is steep. With increasing momentary moments of inertia the speed-up curve becomes flatter, as the major part of the surplus moment is to serve the maintenance of the

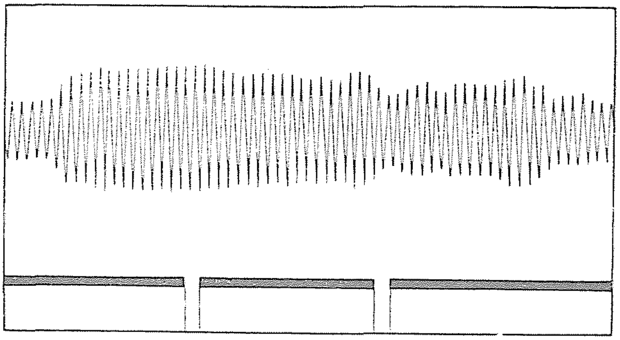


Fig. 7. Power consumption of the motor with clutch drive

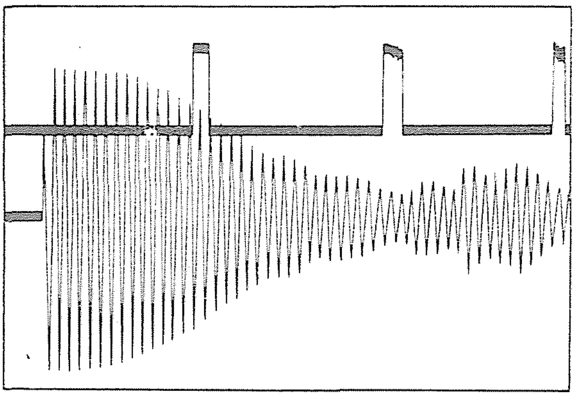


Fig. 8. Power consumption of the motor with direct drive

speed of the „increasing" masses. The difference between the speed-up curve of direct driving and clutch driving can also be explained by these relationships. In case of clutch-driving, the rotating masses of the loom are greater. When switching on, the joint effect of the motor and the clutch produces a somewhat higher torque than does the direct driving. (This is shown by the speed-up curve being more ascendant.) Subsequently the load of the motor gradually increases and as the total mass of the loom (its moment of inertia) due to the clutch is greater than that with direct driving the speed-up curve becomes flat and passes below the curve of the direct driving.

From the speed-up curves discussed hereabove and from the uptake of current at the start, the conclusion can be drawn that stationary operation of the loom will be attained but during the second revolution of the crankshaft. The speed-up can, therefore, by no means be considered as completed at the stage when the momentary rpm. reaches the tachometric average revolution. Thus neither the speed-up time defined above, nor the displacement of the crankshaft can be considered as characteristic for speed-up conditions as they do not prove the advantage of a clutch, *i. e.* the possibility of assuring safe loom start.

Different picture is obtained, however, when comparing the energies, to be disposed of for the first pick after starting the loom.

Using a clutch, with a starting pick of $\varphi = 105°$, the reduced moment of inertia is 0,12026 kgsec^{2}m, whereas in the case of direct driving it amounts to 0,0986 kgsec^{2}m. On the basis of the speed-up curves illustrated in Figs. 3 and 5 the total energy of the loom at the moment of the pick is shown in Table I.

Table I

Drive	rpm. at the moment of pick	rpm. average	Energy of the moment of pick mkg
direct	189	183,5	19,26
clutch	183		22,60
direct	185	193,0	18,50
clutch	196		25,22

According to the above results at the beginning of a pick, a loom provided with clutch driving (with both average rpm.) has higher kinetic energy. In case of $n_{av} = 183{,}5$/min., a surplus energy of $\Delta E = 3{,}34$ mkg, and in case of $n_{av} =$ $= 193$/min a surplus energy of $\Delta E = 6{,}72$ mkg can be observed. The surplus energies promote safe shuttle traversing at the first pick. Contrary to the speed-up curves, the surplus energies shown, leave no doubt about the advantage of clutch-driving.

4. Inequal operation of the loom with direct driving and with clutch driving

Practically, the rpm. of the loom is determined by the average revolution of the crankshaft per minute. With regard to time, this rpm. value can be considered as an average, as the crankshaft is forced to inequal running by the swinging and rotating masses of the loom. The inequal operation of the crankshaft is characterized by the so-called inequality degree, usually expressed in per cents :

$$\delta\,\% = \frac{n_{max} - n_{min}}{n_{av}}\,100$$

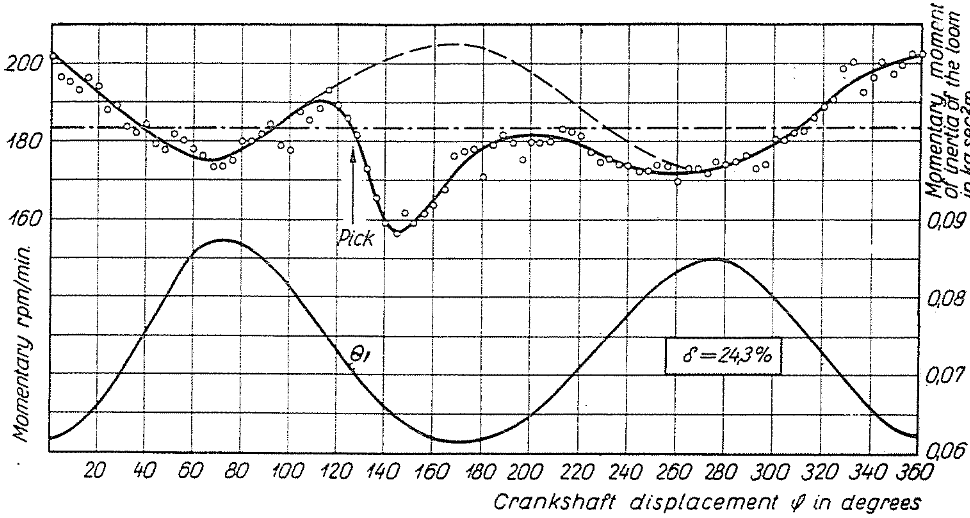


Fig. 9. Inequal running with direct drive

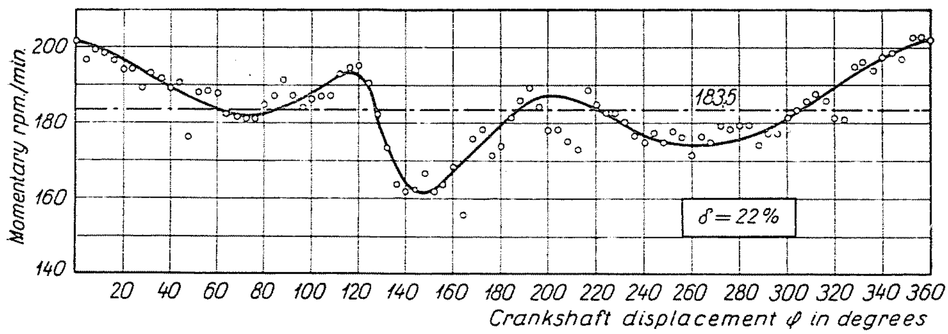


Fig. 10. Inequal running with clutch drive

where n_{max}, n_{min} — are the extreme values of the momentary revolution of the crankshaft and

n_{av} — is the tachometric average speed.

On a loom, set in accordance with our procedure, measurements were made both with direct driving and clutch driving with $n_{av} =$ 183,5/min. and 193/min., respectively. Development of the momentary revolution within one single revolution with $n_{av} = 183{,}5$/min. and with direct driving is shown in Fig. 9, while the same with clutch driving is illustrated in Fig. 10.

Characteristics of the measurements are shown in Table II.

Table II

Drive	n_{av}	n_{max}	n_{min}	δ %
direct	183,5	202,0	157,5	24,3
clutch		201,5	161,0	22,0
direct	193,0	218,0	164,0	28,0
clutch		213,5	168,5	23,3

From the above table it can be concluded that the inequality degree of loom operation is improved by using the clutch tested :

$$\text{at } n_{av} = 183{,}5/\text{min. average revolution by } \Delta\delta = 2{,}3\%,$$

$$\text{at } n_{av} = 193{,}0/\text{min. average revolution by } \Delta\delta = 4{,}7\%.$$

Fig. 9 gives the moment of inertia of the swinging masses of the loom reduced to the crankshaft, though without the driving elements. (The latter values can be considered constant in function of the crankshaft displacement, thus they can be directly added to the momentary values.)

The relationship between the reduced moments of inertia and the momentary rpm. curve of the loom, considered already in connection with speed-up conditions, is quite obvious. The effect of pick is to be observed in the deviation from the probable basic curve, represented by a dotted line. The pick appears in form of a momentary and considerable decrease of the rpm. and its effect increases the inequality degree. According to the curve, it is apparent, that early picking (80—100°) increases, late picking reduces the inequality degree.

Summary

With the described impulsive type test method of speed-up and inequal running of looms, momentary rpm. values characterized by a coefficient of variation of $\pm 1{,}25\%$ can be determined. Comparative tests made with direct driving and with clutch driving show that the speed-up of looms have to be evaluated on the basis of momentary rpm. values related to the position of the crankshaft and on the basis of the total energy produced at the moment of the pick.

It seems to be characteristic for clutch driving that — depending on the mass of the clutch and that of the loom and due to the slip taking place at switching on — a considerable part of the kinetic energy of the loose pulley will be transformed into heat. The proportion between the loss of energy arising at switching on and the energy remaining for the speed-up, depends on the masses of the clutch and the loom, respectively. Close relationship can be established between the curves of speed-up and inequal running on one part and between the momen-

tary moment of inertia of the loom reduced to the crankshaft on the other part. In the ranges of the increasing reduced moments of inertia, the load of the motor also increases which results in the flattening of the speed-up curves.

The described procedure seems to be suitable for carrying out wide-scale experiments on the basis of the results discussed.

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