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Influence of the Seed Shaft Parameter of the Linter Machine on the Dynamics and Load of the System

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Abstract. This paper deals with the dynamic study of a machine unit with the mechanism of the seed shaft of a linter machine designed for cleaning cotton fibre from seed residues. Taking into account that the working bodies of the machine operate under variable loads, the authors carry out a comprehensive analysis of the influence of inertial, elastic and dissipative properties of the system on the transient and steady-state modes of its operation. Particular attention is paid to moments of inertia, resistance of the technological environment and the influence of belt transmission parameters. The mathematical model is formulated on the basis of Lagrangian equations of the second kind taking into account the moments of resistance arising in the process of linting. The drive is investigated as a two-mass system, and the model also takes into account the oscillations of the process resistance moment described by a sinusoidal function. For numerical solution of the system of nonlinear differential equations the Runge-Kutta method in Mathcad environment is applied. Calculations at different values of stiffness, viscous friction and resistance amplitude coefficients determining the dynamic behaviour of the system have been carried out. Graphs of change of torque, angular velocity of rotor and seed shaft, as well as dependence of start-up time on the level of technological resistance were obtained. It is established that the increase of the moment of technological resistance leads to the decrease of the torsional oscillation range, but increases the angular velocity of the motor, contributing to the reduction of the steady-state time. The results of the research allow optimising the parameters of the machine unit, increasing the stability of its operation and energy efficiency. The work is of interest to developers and researchers of machines in the cotton processing industry, as well as specialists in the field of applied mechanics.

Key words: linear machine, seed shaft, dynamics of machine unit, transition mode, belt transmission, torque fluctuations, angular velocity, asynchronous electric motor, modelling, Mathcad, technological resistance, torsional vibrations, stability of mechanical system, cotton processing equipment.

Introduction.

Currently, about 100 cotton processing enterprises operate in Uzbekistan. The enterprises are working on modernizing machines and equipment. The main goal of modernizing the factories is to increase machine productivity and produce high-quality products, including lint, that meet the requirements of the global market [1, 2]. The cotton ginning industry produces three types of lint. The first type of lint contains fibres with a masslength of 13/14 mm or more, the second type - from 7-8 to 12-13 mm, and the third type - 6-7 mm or less. In addition, the lint is also characterised by its grade, which is determined according to the grade of the seeds to be processed [3-5]. The process of linting of cotton seeds originated as a preparatory process necessary to maximise the compression of oil from the cotton seeds. The resulting lint had no industrial value. Seed linting was performed on lintering machines developed similar to saw gins in the United States of America [6, 7]. In the creation of machines for cotton ginning industry with high parameters can be realised only on the basis of deep knowledge of physical processes occurring in machines in different loading modes and development of new, more perfect methods of calculation of acting loads, which are the basis for calculation of machine parts and units for strength and endurance. Especially urgent are the issues of development and refinement of methods of calculation of drives and shafts of machines of large capacity or importance for production. This would make it possible to carry out production tests to refine the adopted parameters. One such machine in the cotton processing industry is the linter machine. The lintering process is carried out on linter machines, where the main working organ is the saw cylinder. It is the drive of the saw cylinder of linter machines 18.5 kW that consumes a significant amount of power in the machine.

In the majority of production processes, including lintering process, the load on the motor of machine units is variable. As it is known, the main structural elements of machine units used in technology for driving the working organ are: engine; clutch; gearbox or gearbox (or variator); working organ drive mechanism (belt gears). It has been found that due to varying loads, many machine units operate at varying energy inputs to the engine and varying engine speeds [8].

Usually, the working shafts of machine units in the cotton industry are affected by the parameters (weight, moisture, etc.) of the processed raw material (raw cotton, fibre, seeds) [9]. In [10] it is noted that the maximum load modes in the drive of cotton processing machines are characteristic in the acceleration mode, which is performed either by changing the operating mode of the machine unit at a constant speed of movement, or by changing the speed of the machine unit without changing the operating mode. At the same time, the dynamics of the machine unit at each stage of its movement (acceleration, steady-state movement, gear shifts, stops) have peculiarities in the load modes of both the electric motor and the drive.

In order to overcome such a load without a significant drop in the average speed of operation, it is necessary to use motors with a higher power than would be required if only the external load and the given time of its execution were taken into account, without taking into account the work required for transients in the motor and for the recovery of the kinetic energy of the moving masses of the machine unit lost in the drop in speed after overcoming each recurring peak of the variable load. The greater the frequency and amplitude of load variation and the higher the required average operating speed, the greater the motor power required and the greater the proportion of its work lost to transients. And so, in the process of linting effective work of the seed shaft depends mainly on the dynamic parameters of the machine unit, including the moments of inertia of the masses, elastic, dissipative properties of the belt transmission and the nature of technological loads from raw cotton. To substantiate these parameters it is necessary to investigate the dynamics of transient and steady-state modes of operation of the machine unit of the seed shaft of the seed shaft of the linter machine [11].

During the operation of the linter machine drive, the inertial characteristics of the working bodies of the machine unit change within wide limits. Since the drive includes elements with belt and chain transmissions, as well as variators of unequal angular velocities with non-linear characteristics [12].

1. Main theoretical part

In this case, the nonlinear dynamic model of the drive is represented by the coupling of the moments of inertia of centred masses (*Ji*) and stiffnesses (*C*). The dynamic model of the machine unit with the seed shaft mechanism of the seed shaft of the linter machine is presented in Fig. 1. In this case, the machine unit is a two-mass system, the first mass - the rotor of the electric motor, the second mass - the mass of the seed shaft - the masses of discs and bars of the seed shaft. All discs and slats are counted as one mass.

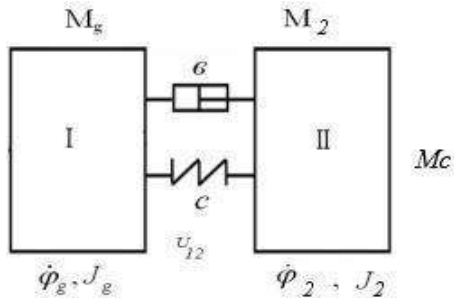


Fig. 1. - Dynamic model of a machine unit with the mechanism of the seed shaft mechanism of the linter machine seed shaft.

The dynamic study of the machine unit with the mechanism of the seed shaft of the linter seed shaft will be considered in the following modes of motion - the transitional mode of the system start; - the established mode of operation of the system. At the same time, the fluctuations of the angular velocity of the seed shaft and the load on the drive are mainly considered.

At researches the asynchronous motor was considered in the form of dynamic mechanical characteristic, offered by I.S.Pinchuk [13,14,16]

$$\dot{M}_g = 2\,M_k\,\omega_c - 2M_k\,p\,\dot{\phi}_g - \omega_c\,S_k\,M_g \tag{1}$$

where M_g, M_k - driving and critical moments of the motor;

ω_c- angular frequency of the network;

ϕ_g- angular displacement of the motor rotor;

S_k- critical slip of the motor.

We will use the Lagrange equation of the second kind [15-17] to formulate the differential equations of motion of this linter machine system:

$$\frac{d}{dt}\left[\frac{\partial T}{\partial \dot{\phi}_i}\right] - \frac{\partial T}{\partial \phi_i} + \frac{\partial \Pi}{\partial \phi_i} + \frac{\partial \Phi}{\partial \dot{\phi}_i} = M_i(\phi_i) \tag{2}$$

where, T - kinetic energy of the system;

Π - potential energy of the system;

Φ - dissipative Rayleigh function;

φ_i - generalised coordinate;
$\dot{\phi}_i$ - generalised velocity;
$M_i(\phi_i)$ - generalised force.

The seed shaft drive consists of an electric motor and a belt transmission, by means of which the movement is transmitted to the working shaft. The following kinematic relations are valid for this drive system:

$$U_{12} = \frac{\dot{\phi}_g}{\dot{\phi}_2} \tag{3}$$

where, $\dot{\phi}_g, \dot{\phi}_2$ - angular velocities of the motor rotor, seed shaft, s^{-1};
U_{12}- transmission ratio of the belt transmission.

For generalised coordinates we take angular displacements of rotating masses of the machine unit, $\dot{\phi}_g, \dot{\phi}_2$. The kinetic energy of the considered system has the form:

$$\mathrm{T} = \frac{J_g\dot{\phi}_g^2}{2} + \frac{J_2\dot{\phi}_2^2}{2} \tag{4}$$

The potential energy of the system is a homogeneous quadratic form of the generalised coordinates and is written in the following form:

$$\Pi = \frac{1}{2}\left[c \cdot \left(\phi_g - U_{12} \cdot \phi_2\right)^2\right] \tag{5}$$

The dissipative Rayleigh function for this system is expressed as:

$$\Phi = \frac{1}{2}\left[b \cdot \left(\dot{\phi}_g - U_{12} \cdot \dot{\phi}_2\right)^2\right] \tag{6}$$

Next, we define the terms of the Lagrangian equations:
(a) derivatives of the kinetic energy of the machine unit

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\phi}_g}\right) = J_g\ddot{\phi}_g; \frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\phi}_2}\right) = J_2\ddot{\phi}_2 \tag{7}$$

b) partial derivatives on displacements from potential energy

$$\frac{\partial \Pi}{\partial \phi_2} = \mathrm{c} \cdot (\phi_2 - U_{12}\phi_2); \tag{8}$$

c) partial derivatives on velocities from the dissipative function

$$\frac{\partial \Phi}{\partial \dot{\phi}_g} = \text{в} \cdot \left(\dot{\phi}_g - U_{12} \cdot \dot{\phi}_2\right);\ \frac{\partial \Phi}{\partial \dot{\phi}_2} = -\text{в}\, U_{12} \cdot \left(\dot{\phi}_g - U_{12} \cdot \dot{\phi}_2\right) \tag{9}$$

e) generalised forces (moments):

$$M(\phi_g) = M_g; \quad M(\phi_2) = M_C - \mathrm{M}_{pri}; \tag{10}$$

where M_C - is the moment of resistance from the cotton on the seed shaft, *Nm*; M_{pri} -is the moment of resistance from the rest of the drive, *Nm.*

Putting in (2) certain terms of Lagrangian equations, we obtain the differential equations of motion of the machine unit of the seed shaft of the seed shaft of the linter machine:

$$\begin{gathered} \dot{M}_g = 2M_k\omega_c - 2M_k p\dot{\phi}_g - \omega_c S_k M_g; \\ J_g\ddot{\phi}_g = M_g - c\left(\phi_g - U_{12}\phi_2\right) - \text{в} \cdot \left(\dot{\phi}_g - U_{12}\dot{\phi}_2\right) - \mathrm{M}_{pri} \\ J_2\ddot{\phi}_2 = U_{12}c\left(\phi_g - U_{12}\phi_2\right) + U_{12}b\left(\dot{\phi}_g - U_{12}\dot{\phi}_2\right) - M_C - \mathrm{M}_{pri} \end{gathered} \tag{11}$$

2. Main practical part

The resulting system of nonlinear differential equations (11) is difficult to solve analytically, so the solution of system (11) is performed on a PC. The Runge-Kutta method was chosen as the numerical method, in which the function is calculated sequentially by incrementing the argument under given initial conditions. The mathematical program "MathCad" was used. To do this, the following transformations need to be performed:

$$_{g}(t) = {}_{1}(t);\ _{g}(t) = {}_{1}(t)$$

$$_{g}(t) = {}_{2}(t);\ _{g}(t) = {}_{2}(t) = {}_{3}(t);\ \ddot{}_{g}(t) = {}_{3}(t);$$

$$_{2}(t) = {}_{4}(t);\ _{2}(t) = {}_{4}(t) = {}_{5}(t);\ \ddot{}_{2}(t) = {}_{5}(t) = {}_{6}(t);$$

After transformations using the mathematical software "MathCad" and taking into account the accepted designations, the mathematical model of the machine unit with the seed shaft mechanism of the linter machine will be presented as follows:

$$y := (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0)^T$$

$$D(t,y) := \begin{bmatrix} 2\cdot M_k\cdot\left(W_c - P\cdot y_3\right) - W_c\cdot S_k\cdot y_1 \\ y_3 \\ \left[\dfrac{y_1 - c\cdot\left(y_2 - U_{12}\cdot y_4\right) - b\cdot\left(y_3 - U_{12}\cdot y_5\right) - M_{pri}}{J_d}\right] \\ y_5 \\ \dfrac{y_1 - \dfrac{c\cdot\left(y_2 - U_{12}\cdot y_4\right)}{U_{12}} + \dfrac{b\cdot\left(y_3 - U_{12}\cdot y_5\right)}{U_{12}} - M_c - M_{pri}}{J_2} \\ \alpha \end{bmatrix}$$

To obtain the solution, it is necessary to set the initial conditions and initial parameters of the system.

$$t_0 = 0;\ = {}_2 = 0;\ _g = {}_2 = 0;\ M_g = M_r = M_{or}$$

Drive of the executive body of the mechanism of the accelerator mechanism of the raw material roller of the saw gin is carried out by the asynchronous electric motor with squirrel-cage rotor of mark 4A90L4U3 [18] are given on Table 1.

Table 1. Parameters of the asynchronous electric motor

Parameter	Value
rated motor power	N=11 kW
nominal number of rotor revolutions of the motor rotor per minute	n=960 min^{-1}
critical (maximum) torque on the engine rotor shaft	M_k=M_n-2=218,8 Nm
nominal moment on a shaft of a rotor of the motor	M_n=9550-(N/n)=9550-(11/960)=109,4 Nm
mains frequency	*f_c=50 Hz*
number of pole pairs	*P=2*

Calculation of necessary parameters and motor coefficients was made as follows [18] (Table 2).

To determine the influence of dynamic parameters of the machine unit with the seed shaft and to find the relationship between other parameters of the system and modes of its motion, we give the following variations:

- coefficient of stiffness dissipation of elastic element from technological resistance of the system c=100÷1000 Nms/rad;
- coefficient of dissipation or viscous friction b=0,5÷5 Nms/rad. This range of variation, established by the results of experiments for the elastic element;
- moment of resistance from technological load (seed shaft) on the seed shaft M_C at angular speed n=300;350;400;450;500 min^{-1}, which corresponds to M_C = 260; 245,9; 218,5; 197,5; 178,9 Nm

Table 2. Calculation of necessary parameters and motor coefficients was made

Circular frequency of the network	$\omega_S=2\pi f_S=314$ rad/sec.
Nominal angular speed of the motor rotor	$\omega_n=\pi n/30=3{,}14\text{-}960/30=100{,}5$ rad/s.
Angular velocity of ideal idling of the electric motor rotor	$\omega_O=2\pi f_S/P=2\text{-}3{,}14\text{-}50/2=157$ rad/s.
Moment of inertia of the electric motor rotor	$J_e= GD^2/4g=0{,}24/4\text{-}9{,}81=0{,}061$ Nms^2
Nominal slip value	$S_n= (\omega_O\text{-}\ \omega_n) / \omega(o) =(157\text{-}100{,}5)/157=0{,}36$
Critical value of slip	$S_k = \lambda \cdot S_H \left(1 + \sqrt{1 - \frac{1}{\lambda^2}}\right) = 1{,}34$

Consideration of technological loads on the working body is explained by the fact that this parameter will not mediate on the load of the drive. From the known method [10] approximate function of mathematical expectation of the moment of technological resistance force from the material has the form $M1=M_C+M(0)\ (Sin\alpha t)$ where, $M0$- amplitude of fluctuations of the moment of resistance.

The range of variation of the values of the stiffness and dissipation coefficients is established by the calculation data for V-belt gears of types A and B [18-22].

The technological resistance acting on the seed roll seed shaft during linting varies widely depending on the seed shaft rotation speed as well as on the seed roll density (Table 3) [23].

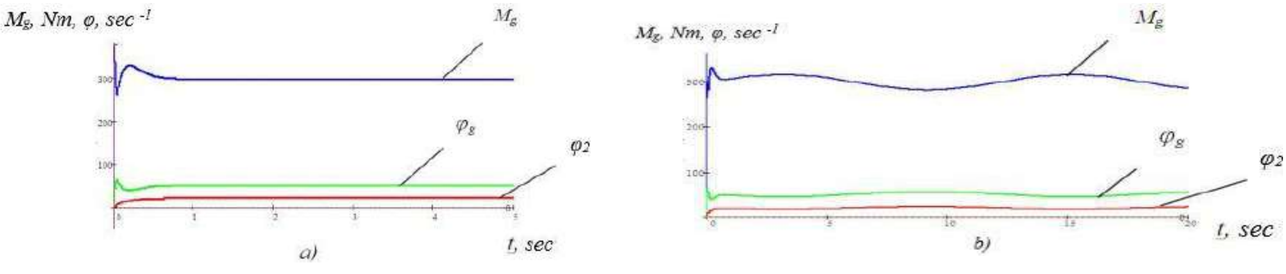
Table 3. The technological resistance

n (seed shaft) ., (min^{-1})	300	350	400	450	500
MC (N m)	260	245.9	218.5	197.5	178.9
m, (kg)	51	46	42	39	36

3. Analysis of results

As a result of realisation of the mathematical model of the machine unit, graphical dependences (laws of motion of the system) are obtained, which are shown in Fig. 2.

From Fig. 2. it can be seen that taking into account the amplitude of oscillation of the resistance moment from the seeds, the torque and angular velocity of the electric motor shaft, as well as the seed shaft changes. To determine the rational dynamic parameters carried out possible variations that are summarised in Table 4, which shows the effect of changing $M0$- the amplitude of the oscillation of the drag torque, stiffness coefficient and dissipation of the elastic transmission on the value of motor torque Mg and its angular velocity φg, as well as on the angular velocity of the seed shaft and $\varphi(g)$.



a) graphs of change of Mg and φg, $\varphi(thief)$, without taking into account the amplitude of oscillations of the seed resistance moment; b) graphs of change of Mg and φg, φthief, at $M1=M_C+M0Sin\alpha$; $M_C=100$; $M0=10$; $\alpha=\pi/6$

Fig. 2. - Graphs of change of driving torque of induction motor and angular velocities of drive shafts

Table 4. The rational dunamic parameters

$M_0 = 5$					$M_0 = 15$			
C	50	100	150	500	50	100	150	500
Mg	220	220	220	220	237	237	237	237
	202	202	202	202	185	185	185	185
φg	84	84	84	84	90	90	90	90
	78	78	78	78	72	72	72	72
φ2	35	35	35	35	37	37	37	37
	32	32	32	32	30	30	30	30
$M_0 = 10$					$M_0 = 20$			
g	228	228	228	228	245	245	245	245
	194	194	194	194	177	177	177	177
φg	87	87	87	87	93	93	93	93
	75	75	75	75	69	69	69	69
φ2	36	36	36	36	39	39	39	39
	31	31	31	31	28	28	28	28

The analysis of the obtained data characterising the operation of the machine unit in different technological modes and at different system parameters leads to functional dependences of the range of oscillations of angular velocity $\Delta\varphi_g$, torque ΔM_g on the electric motor shaft. Which are presented in Fig.3. they show that at increase of technological resistance M_c from 103,4 Nm to 115 Nm the range of motor torque ΔM_g oscillations decreases from 96,04 Nm to 76,24 N-m accordingly. A similar increase in M_s affects the angular velocity spread of the engine shaft of the machine unit $\Delta\varphi_g$ positively, that is, the spread $\Delta\varphi_g$ also increases from 6.8 rad/s.to 13.4 rad/s.

From the tabulated data, it can be seen that the values of M_g, φ_g and φ_2 at increasing the amplitude of oscillation of the resistance torque M_0 from 5 to 20 decrease respectively M(g) from 202 Nm to 177 Nm, φ(g)from 78 rad/s to 69 rad/s and φ_{thief} from 32 rad/s to 28 rad/s.

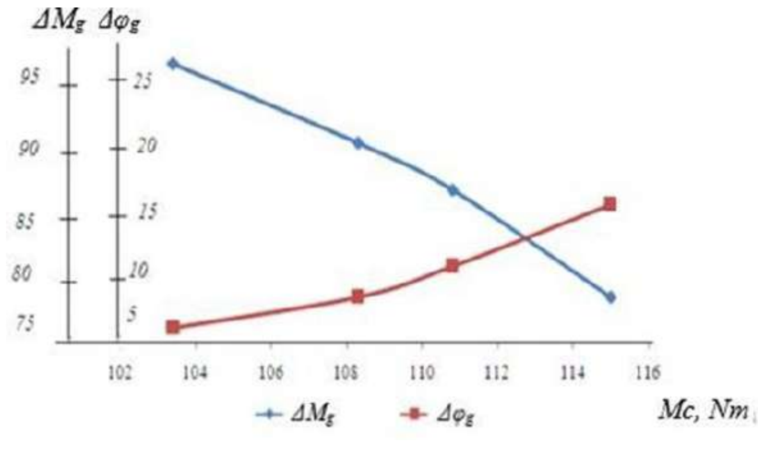


Fig. 3. - Effects of process resistance *Mc* on the variation of torque (*Mg*) and angular velocity *φ(g)* of the motor of the machine unit with linter machine seed shaft mechanisms

Consequently, the effects of drag torque $M_1 = M_c + M_0 \sin\alpha$ will affect the dynamic loads of the machine. We can also consider the effects of the oscillation frequency of the drag torque α. As the oscillation frequency increases, changes in M_g, and φ(2) are observed which are shown in Fig. 4.

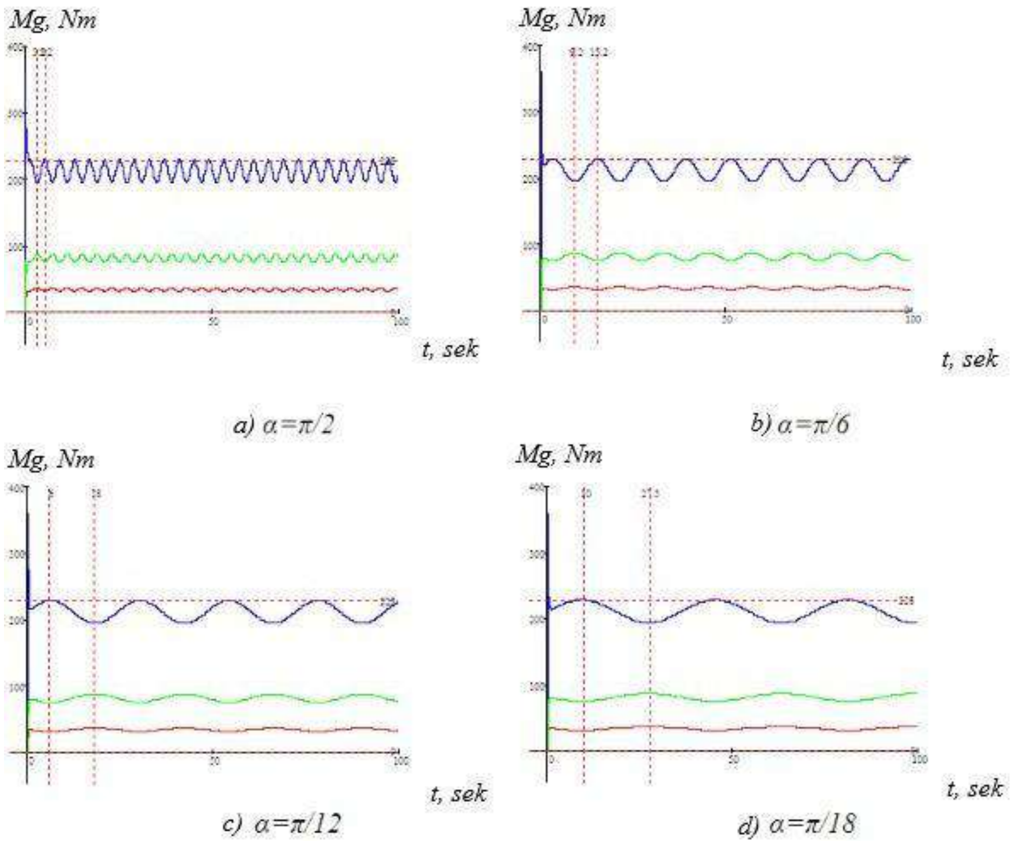


Fig. 4. - Variation of M_d and φ of the seed shaft as a function of oscillation frequency α: M_c=100; M_0=10; C=50; b=2

By solving the mathematical model of the machine unit, taking into account the seed shaft of the seed shaft, it is possible to determine the main stage of the machine unit operation, i.e. the "start-up" period.

It is known that any machine unit operates in the following stages: "Start"-entry into the established mode; "Mode"-established mode; "Stop"-from the established mode to a complete stop, which are shown in Fig. 5 [23-26].

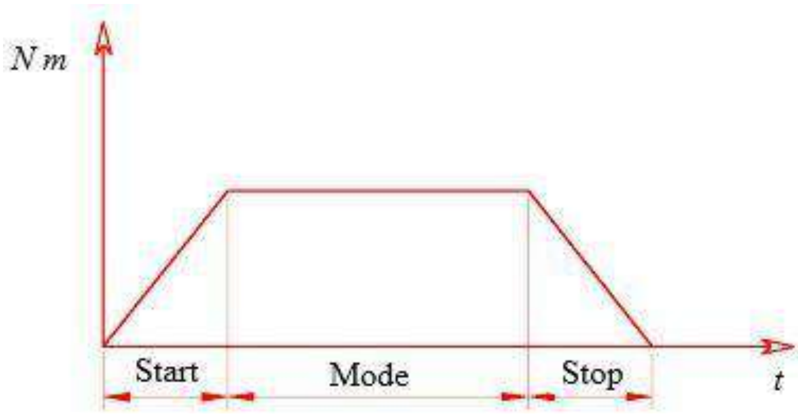


Fig. 5. - Operating modes of the machine unit

It is clear that the painless passage of the "start-up" mode directly affects the operation of the machine unit Therefore, we were interested in the question of the "start-up" time. The analysis of the data obtained when solving the problem of dynamics of the machine unit of the linter machine with a seed shaft of the seed shaft shows that when the force of technological resistance from the matershaft shaftial M_1 increases from 103 to 115 *Nm* the time of "start" t_{start}

are different. This can be seen in fig. 6. are curves where it can be clearly seen that the difference between the process resistances M1 affects the "start up" time. At values of technological resistance *M1* from 103 *Nm* to 115 *Nm*, the start-up time for the motor shaft is from 1.7 *sec*. to 1.5 *sec*. respectively for the seed from 1.5 *sec*. to 1.3 *sec*. This is due to the fact that the mass of the seed shaft dampens the peak stage of the start-up mode and thus the transition to the set mode takes place.

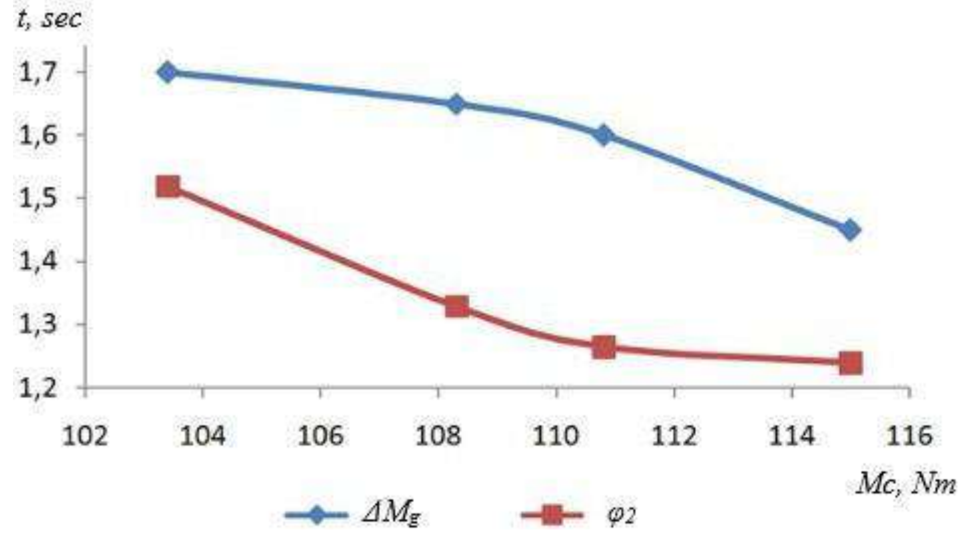


Fig. 6. - Changes in the start-up time of the seed shaft machine depending on the technological resistance

Conclusion

It is revealed that with the increase of the moment of technological resistance affects the range of torque fluctuations (decreases) and the range of angular velocity (increases).

This indicates that the moment of technological resistance affects the process of "start-up" of the system. The difference between peak and nominal values is reduced, and the decrease in the start-up time confirms this.

If we take into account that the moment of technological resistance overestimate from the angular speed of the seed shaft of the seed shaft of the linter machine, we can conclude that the growth of the angular speed of the seed shaft leads to a faster start-up process, which is important in the operation of the machine unit.

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