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Modeling, Management of Nutrition Processes and Calculation of Energy Status of Machines of the Technological Line of Primary Processing Cotton-Raw Material

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Abstract: In the article methods of modeling of motion and optimal control are considered with the purpose of ensuring uniform movement of the links of the saw gin of the technological line for primary processing of raw cotton with the help of the Lagrange equation of the second kind, a mathematical model of the technological process of jinification of raw cotton is compiled. Optimum control of the functioning of the system according to given conditions is formed. As a result of numerical solutions of the conjugate system, the boundary value problem of the Pontryagin maximum principle and the developed mathematical models, the optimal values of the transient processes are calculated. The equation of the energy state is calculated using the total differential of the Hamiltonian function and the energy state SD is determined. Functional, constructive-technological and geometric parameters that ensure the uniform motion of the engine at given technological resistances are determined.

Keywords: Methods, Mathematical Modeling, Functioning, Algorithm, Technological Line, Primary Processing, Energy State, Optimal Control

1. Introduction

One of the main indicators of the quality of the fiber produced is the content of defects and impurities. The main mass of defects and impurities in the fiber is formed during the sawing of raw cotton. One way to reduce vices and impurities in the fiber is to carry out the process of ginning of raw cotton at the optimum density of the raw roller, which is ensured by the uniform supply of raw cotton [1].

Practice shows that on standard sawed gins there is usually no uniform supply of raw cotton from the feed system to the working chamber. To solve this problem, it is necessary to conduct complex studies using modern methods of optimizing the structural and technological parameters of the process of ginning of raw cotton [10-11].

Currently, for ginning raw cotton of medium-fibrous varieties, the grapes of grade 5DP-130 [2].

2. Construction of the Kinematic Scheme and Dynamic Models

Technological process of the work of the gin: the raw cotton that has undergone the appropriate treatment in the production line of cleaning through feeding rollers 1 is fed to the pin drum 2 with a given capacity, where the loosening and cleaning of it from fine sludge occurs (Figure 1), and the excreted waste is removed by a weed conveyor 3. The raw cotton through the chute 4 enters the working chamber 5, where it comes into contact with the teeth of the saw cylinder 8, forming a rotating raw roller. The teeth of the saw cylinder 8, penetrating into the raw roller, grasp the fiber and drag it into the gap between the bars 7, tearing it from the seeds [3].

Grasped by the teeth, the saw fiber under the action of centrifugal force hits the edge of the grate bars behind the working chamber and the excretion of weedy impurities and takes place. The excreted rubbish and cotton waste fiber falls on the cotton waste fiber conveyor 11, and the purified fiber is removed from the saw teeth and transported to the fiber channel. The degree of pubescence of the excreted seeds is regulated by the seed comb 6.

The kinematic scheme (Figure 2) consists of 4 simple independent links: - the first link: the drive of the spear drum (SD) and feeding rollers (FR): engine M_1 $n = 950$ rpm; 1 - a pulley with a diameter of 140 mm; 2- V-belt transmission; 3 - pulley with a diameter of 260 mm; 4 - shaft of the spear drum II; 5 - pulley with a diameter of 90 mm; 6 - V-belt transmission; 7 - pulley with a diameter of 250 mm; 8 - Variator ИВР-I ТУ 27-10-1227-87; 9-shaft; 10 -free, $z = 30$; I - feeding rollers**.**

- the second link, the drive of the rake conveyor (CC) and the weed screw (SS): engine M_2 $n = 920$ rpm; 11- coupling; 12 - reducer *2Ч-80-i-40*; 13 - coupling; 14 - shaft; 15 - asterisk, $z = 27$; III - chain drive shaft 16; 17 - asterisk, $z = 27$; 18 - an asterisk of a shaft IV, $z = 27$;

- The third link: the drive mechanism of moving the working chamber (MMWCH): drive M_3 $n = 920$ rpm; 19 – pulley with a diameter 100 mm; 20– V-belt drive; 21 - a pulley with a diameter of 200 mm; 22 - reducer *2Ч-80-i-40*; 23 - the system of levers; 24- cam shaft V;

- the fourth link: the drive of the saw cylinder (PC): engine M_4 $n = 730$ rpm; 25-coupling; 26 - saw shaft of the shaft VI.

The aim of the research is to ensure the uniform movement of the links of the saw gin by optimizing the design and technological parameters. To investigate and control the parameters of the links of the saw gin, let us consider the optimal control of the functioning processes by the example of the first link, which includes the drive of the spear drum (SD) and feed rollers (FR). To do this, it is necessary to build a kinematic scheme of saw gin 5DP-130 and dynamic model SD and FR (Figure 3).

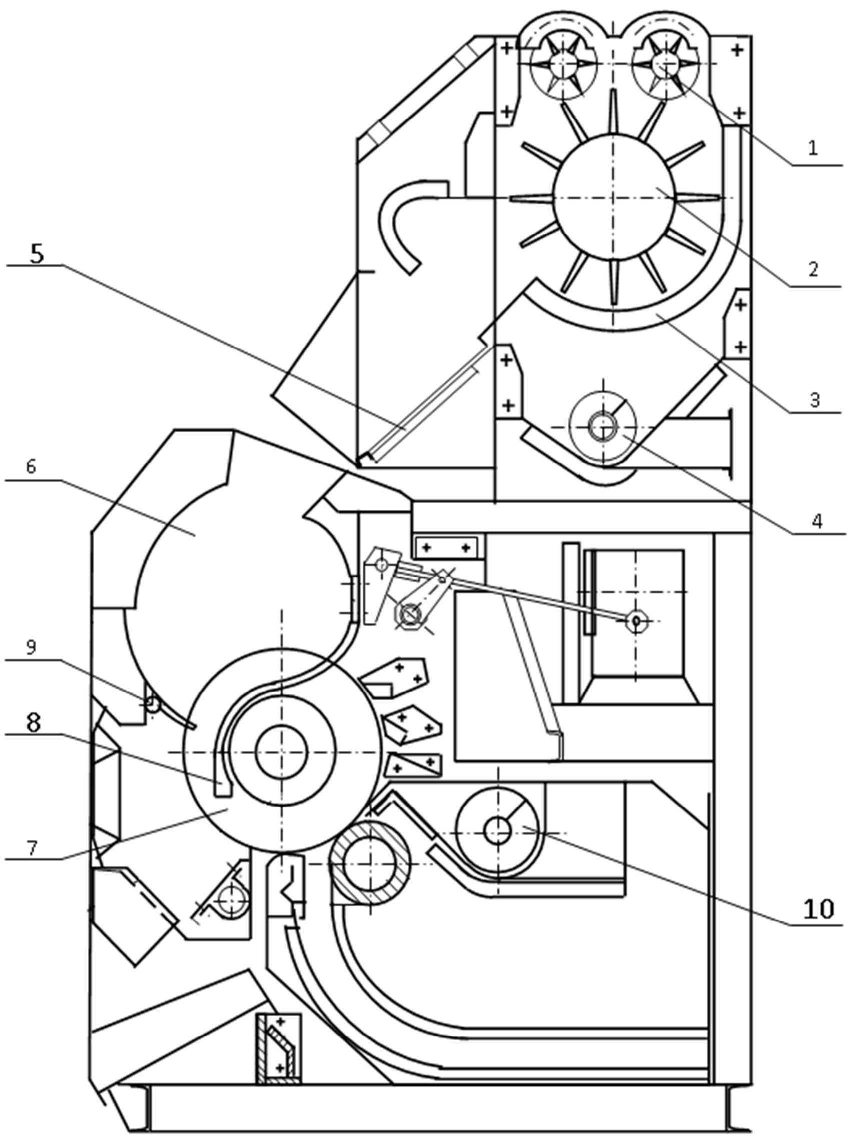

Figure 1. *Cross section of saw gin brand 5DP-130: feeding rollers; 2-pin drum; 3- Perforated mesh; 4-weave conveyor; 5-litter; 6 - working chamber; 7-saw cylinder; 8- console grates; 9-seed comb; 10 -cross conveyor*

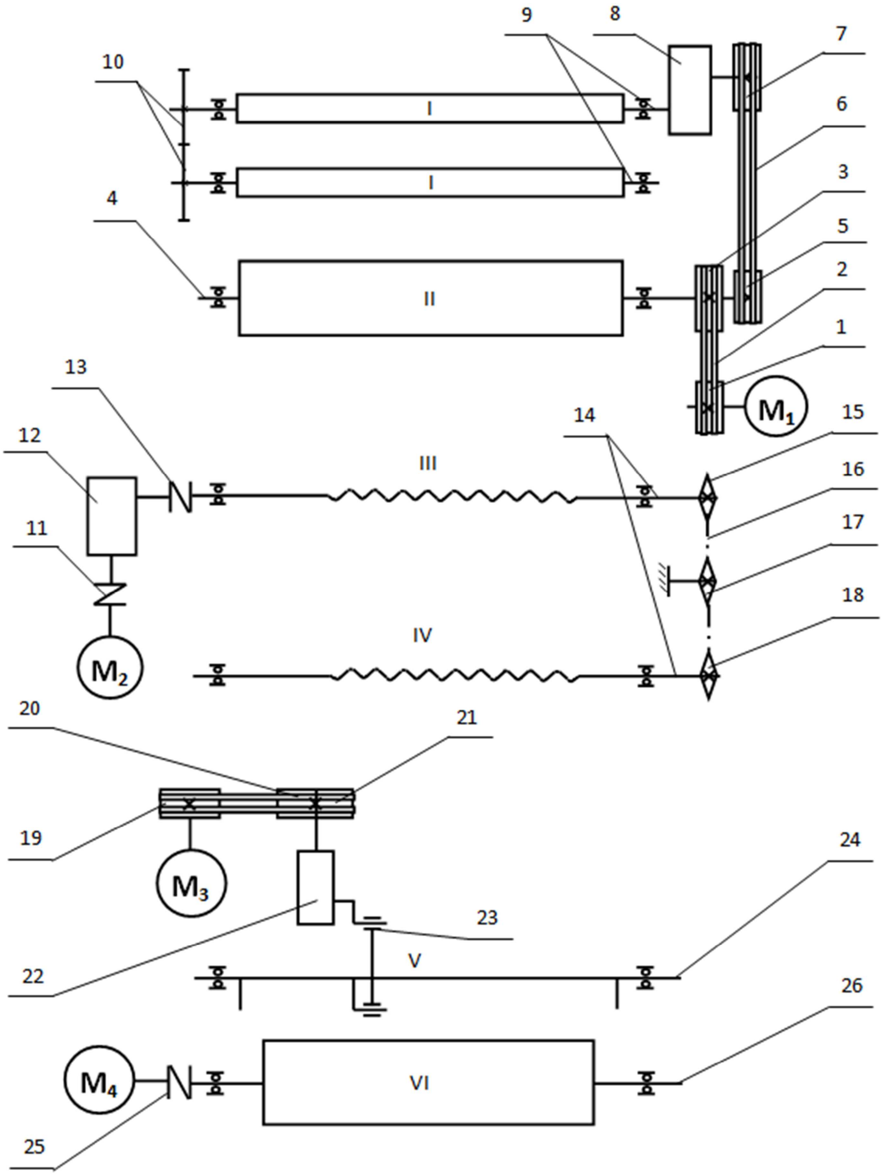

Figure 2. *Kinematic scheme of saw gin brand 5DP-130.*

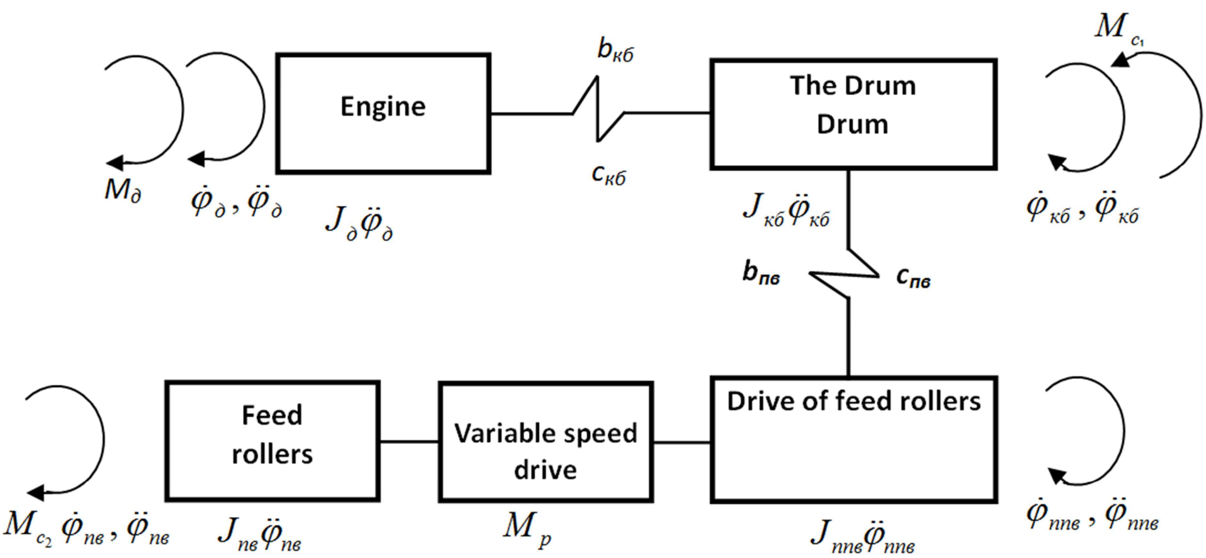

Figure 3. *Dynamic model of SD and FR.*

3. Mathematical Modeling

Using the Lagrange equation of the second kind, a mathematical model SD and FR [1, 2, 6, 7]:

$$\left.\begin{aligned}
&j_{\text{д}}\ddot{\phi}_{\text{д}} = M_{\text{д}} - b_{\text{кб}}(\dot{\phi}_{\text{д}} - i_1\dot{\phi}_{\text{кб}}) - c_{\text{кв}}(\phi_{\text{д}} - i_1\phi_{\text{кб}})\\
&j_{\text{кб}}\ddot{\phi}_{\text{кб}} = i_1 b_{\text{кб}}(\dot{\phi}_{\text{д}} - i_1\dot{\phi}_{\text{кб}}) + i_1 c_{\text{кб}}(\phi_{\text{д}} - i_1\phi_{\text{кб}}) - M_{c_1} - j_{\text{ппв}}\ddot{\phi}_{\text{ппв}}\\
&j_{\text{ппв}}\ddot{\phi}_{\text{ппв}} = i_2 b_{\text{ппв}}(\dot{\phi}_{\text{кб}} - i_2\dot{\phi}_{\text{ппв}}) - i_2 c_{\text{ппв}}(\phi_{\text{кб}} - i_2\phi_{\text{ппв}}) - j_{\text{пв}}\ddot{\phi}_{\text{пв}}\\
&j_{\text{пв}}\ddot{\phi}_{\text{пв}} = M_{\text{в}} - M_{c_2}
\end{aligned}\right\}, \qquad (1)$$

Where $j_{\text{д}}$, j_{SD}, j_{nFR}, j_{FR} - Moment of inertia of the engine SD, Drive FR (DFR) and SD, $H{\cdot}м{\cdot}c^2$; $\phi_{\text{д}}, \phi_{\text{кб}}, \phi_{\text{пв}}$ - Angular movements of the rotating masses of the engine, SD and FR, *rad*; $\dot{\phi}_{\text{д}}, \dot{\phi}_{\text{кб}}, \dot{\phi}_{\text{пв}}$ - Angular velocities of the rotating masses of the engine, SD and FR, c^{-1}; $\ddot{\phi}_{\text{д}}, \ddot{\phi}_{\text{кб}}, \ddot{\phi}_{\text{пв}}$ - Angular acceleration of the rotating masses of the engine, SD and FR, c^{-2}; b_{SD}, b_{FR}- coefficient of viscous drag SD and FR, $N{\cdot}m{\cdot}s/rad$; c_{SD}, c_{FR} - Belt stiffness factor SD и FR, $N{\cdot}m/rad$; i - gear ratio; $M_{\text{д}}$, M_{c_1}, $M_{\text{в}}$, M_{c_2} – driving moments of the engine, variation and moments of resistance in SD and FR, Н·м.

4. Solution of Optimal Control Problem

Proceeding from the above, one can choose the optimal control problem SD и FR [8, 9].

At the initial moment of time, the SD and the FR are in the state

$$\phi_i(0) = \phi_0(0), \qquad \dot{\phi}_1(0) = \dot{\phi}_0(0). \qquad (2)$$

It is required to choose such a control *u(t)*, which will transfer the SD и FR to a predetermined final state

$$\phi_i(t) = \phi_0(t), \qquad \dot{\phi}_1(t) = \dot{\phi}_0(t), \qquad (i = \overline{1,n}) \qquad (3)$$
$$0 \le t \le T.$$

This requires that the time of the transient is the smallest. Then the goal of control is reduced to minimizing the functional

$$J(\phi_0, u(t), \phi(t)) = \int_{t_0}^{T} f^0(\phi(t), u(t), t)dt). \qquad (4)$$

Under the conditions (2), (3) and according to the law

$$\dot{\phi}(t) = f(\phi(t), u(t), t). \qquad (5)$$

$$u \in U, \quad t_0 \le t \le T, \qquad (6)$$

where *f(...)* - a continuously differentiable function with its derivatives; *u(t)* -piecewise continuous function on a segment [t_0, T].

Under the conditions of the motion study, the quality criteria can be estimates of the speed of the mechanisms for the speed at given conditions for the operation of the SD and FR. Therefore, in the process of controlling the design and the FR, it is necessary to take into account the loading process, which must be specified by certain values of the quality index *J*.

In order to investigate the necessary conditions for optimal control of the SD and FR under consideration, we use the Pontryagin maximum principle [4, 5].

To formulate the maximum principle, we introduce the Hamilton-Pontryagin function for SD and FR

$$H = (\phi, u, t, \psi_i, \psi_0) = -f^0(\phi, u, t) + \langle \psi, u \rangle \qquad (7)$$

And the conjugate system

$$\left.\begin{aligned}
&\frac{d\psi_1}{dt} = -\frac{\partial H_{\text{кб}}}{\partial y_1} = -j_{\text{кб}}^{-1}c\psi_2, \qquad \frac{d\psi_2}{dt} = -\frac{\partial H_{\text{кб}}}{\partial y_2} = -\psi_1 + j_{\text{кб}}^{-1}b\psi_2\\
&\frac{d\psi_1}{dt} = -\frac{\partial H_{\text{ппв}}}{\partial y_1} = -j_{\text{ппв}}^{-1}c\psi_2, \qquad \frac{d\psi_2}{dt} = -\frac{\partial H_{\text{ппв}}}{\partial y_2} = -\psi_1 + j_{\text{ппв}}^{-1}b\psi_2
\end{aligned}\right\} \qquad (8)$$

With restriction on management $|u| \le 1$.

To solve the problem under consideration, the necessary condition must be satisfied

$$H(\phi_i(t), u(t), t, \psi_i, \psi_0) = \max_{u \in U} H(\phi_i(t), u, t, \psi_i(t), \psi_0). \qquad (9)$$

Turning to the definition of optimal control on the basis of (7), we form the function

$$\left.\begin{aligned}
&\phi_{\text{д}} = y_1,\ \dot{\phi}_{\text{д}} = y_2,\ \dot{y}_2 = u_{\text{д}} - j_{\text{д}}^{-1}\left[b_{\text{кб}}(y_2 - i_1 y_4) + c_{\text{кб}}(y_1 - i_1 y_3)\right]\\
&\phi_{\text{кб}} = y_3,\ \dot{\phi}_{\text{кб}} = y_4,\ \dot{y}_4 = j_{\text{кб}}^{-1}\left[i_1 b_{\text{кб}}(y_2 - i_1 y_4) + i_1 c_{\text{кб}}(y_1 - i_1 y_3)\right] - u_{c_1} - u_{\text{ппв}}\\
&\phi_{\text{ппв}} = y_5,\ \dot{\phi}_{\text{ппв}} = y_6,\ \dot{y}_6 = j_{\text{ппв}}^{-1}\left[i_2 b_{\text{ппв}}(y_4 - i_2 y_6) + i_2 c_{\text{ппв}}(y_3 - i_2 y_5)\right] - u_{\text{пв}}\\
&\phi_{\text{пв}} = y_7,\ \dot{\phi}_{\text{пв}} = y_8,\ \dot{y}_8 = u_{\text{в}} - u_{c_2}
\end{aligned}\right\} \qquad (10)$$

And obtain a mathematical model characterizing management $u_{\text{д}} = \frac{1}{j_{\text{д}}}M_{\text{д}}$ Movement of SD and FR, where $u_{c_i} = \frac{1}{j_i}M_{c_i} = \frac{1}{j_i}\left(M_i + M_0 \sin\omega t\right) = u_i + u_0 \sin\omega t$ (M_0- Amplitude of vibration of the moment of resistance in relation to its average value M_i).

Since, if $f^0 \equiv 1$, то $J(\phi_0, u(t), \phi(t)) = T - t_0$ - in this case the problem (2) - (6) is called the speed problem.

The object under consideration is a stationary system and the problem (4) what f and U do not depend explicitly on time, i.e.

$$f(t, y, u) = f(y, u), \qquad U(t) = U \qquad (11)$$

If the stationary problem (4), (11) has optimal control *u(t)* and the optimal trajectory $\phi_0(t)$. Then there exists a nonzero vector of conjugate variables $(\psi_1(t),\ \psi_2(t))$, $\psi(t) \in R^n$ satisfying the conditions (9); the maximum condition (7)

$$\psi_0(t) = const \le 0 \qquad (12)$$

Since the ad joint system (8) is homogeneous with respect to ψ_i , We can arbitrarily choose a constant in Eq. (12) so that

$$\psi_0(t) = -1 \qquad 0 \le t \le T. \tag{13}$$

From the conditions $\max\limits_{|u|\prec 1} H$ should be $u = sign\psi_2$ at $\psi_2 \neq 0$. Then the boundary value problem of the maximum principle is written in the form:

$$\left.\begin{array}{l} \phi_{\partial} = y_1,\ \dot{\phi}_{\partial} = y_2,\ \dot{y}_2 = sign\psi_2 - j_{\partial}^{-1}\left[b_{\text{кб}}(y_2 - i_1 y_4) + c_{\text{кб}}(y_1 - i_1 y_3)\right] \\ \phi_{\text{кб}} = y_3,\ \dot{\phi}_{\text{кб}} = y_4,\ \dot{y}_4 = j_{\text{кб}}^{-1}\left[i_1 b_{\text{кб}}(y_2 - i_1 y_4) + i_1 c_{\text{кб}}(y_1 - i_1 y_3)\right] - sign\psi_2 - sign\psi_2 \\ \phi_{\text{пнв}} = y_5,\ \dot{\phi}_{\text{пнв}} = y_6,\ \dot{y}_6 = j_{\text{пнв}}^{-1}\left[i_2 b_{\text{пнв}}(y_4 - i_2 y_6) + i_2 c_{\text{пнв}}(y_3 - i_2 y_5)\right] - sign\psi_2 \\ \phi_{\text{нв}} = y_7, \dot{\phi}_{\text{нв}} = y_8, \dot{y}_8 = sign\psi_2 + sign\psi_2 \end{array}\right\} \tag{14}$$

The boundary-value problem of the maximum principle in these cases will consist of the system (12), the boundary conditions (2) and (3) following from (9), and condition (13).

We compose the Hamilton-Pontryagin function, which has the form

$$\left.\begin{array}{l} H_{\partial} = \psi_0 + \psi_1 y_2 + \psi_2 \dot{y}_2 \\ H_{\text{кб}} = \psi_0 + \psi_1 y_4 + \psi_2 \dot{y}_4 \\ H_{\text{пнв}} = \psi_0 + \psi_1 y_6 + \psi_2 \dot{y}_6 \end{array}\right\}. \tag{15}$$

Hence it is clear that the condition (9) $u = sign\psi_2$, $\psi_2 \neq 0$. The boundary value problem (10), (14) in this case consists of [4]

$$H_i = -f^0 u + \psi_2(t) u_{\partial}. \tag{16}$$

In this case

$$u_k = sign\psi_2(t) = \begin{cases} 1, & \psi_2(t) > 1 \\ -1, & \psi_2(t) < 1 \end{cases}, \ k = 2,4,\dots,2n; \tag{17}$$

i.e. management $u_k(t)$ can only have one switching point.

To determine the auxiliary functions (8) by a numerical method, the conjugate system with variation of design parameters b_i, c_i, j_i.

5. Discussion of Experimental Results

The systems (1), (8), (12), (14) are solved using numerical Runge-Kutt methods. Control $u_k(t)$, which gives the maximum of the function (9), is defined in the region (17).

As a result, the graphical dependences of the velocities and accelerations of SD and FR, the maximum values *H*-functions, as shown in Figure 4 and 5, table 1.

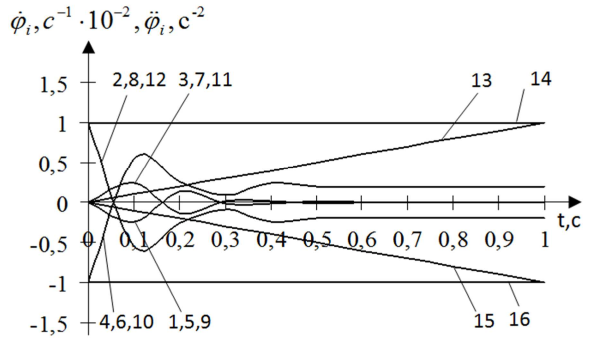

Figure 4. *Graphs of the change in the function of angular velocities (1, 3, 5, 7, 9, 11, 13, 15) and angular accelerations (2, 4, 6, 8, 10, 12, 14, 16) of the engine (1, 2, 3, 4), SD (5, 6, 7, 8), DFR (9, 10, 11, 12), FR (13, 14, 15, 16) in the transient process. 1, 2, 5, 6, 9, 10, 13, 14 for u (t) = + 1; 3, 4, 7, 8, 11, 12, 15, 16 for u (t) = -1.*

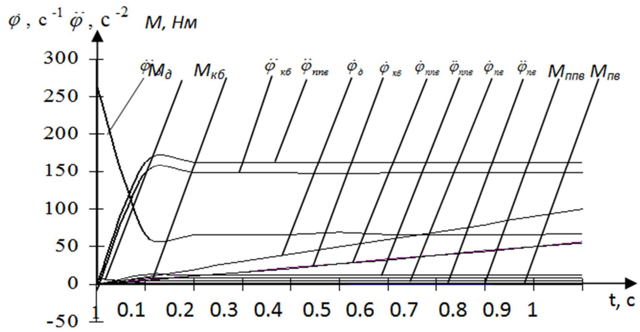

Figure 5. *Character of change of parameters of functioning SD and FR.*

Table 1. *The values of the parameters of the functioning of the engines SD, DFR and FR.*

T. c	$\dot{\phi}_{\partial}$, rad/s	$\ddot{\phi}_{\partial}$, rad/s^2	M_{∂}, Nm	$\dot{\phi}_{\text{кб}}$, rad/s	$\ddot{\phi}_{\text{кб}}$, Рад/с^2	M_{SD}, Nm	$\dot{\phi}_{\text{нв}}$, rad/s	$\ddot{\phi}_{\text{нв}}$, rad/s^2	M_{nFR}, Nm	$\dot{\phi}_p$, rad/s	$\ddot{\phi}_p$, rad/s^2	M_p, Nm
1	2	3	4	5	6	7	8	9	10	11	12	13
0	0	263.95	7.9185	0	-8.13	-0.732	0	0	0	0	-0.009	-0.012
0.1	10.15	65.931	1.97	5.68	147.84	13.3	5.11	163.46	7.846	0.126	4.07	5.09
0.2	20.07	65.96	1.97	11.24	147.83	13.3	10.66	163.48	7.846	0.26	4.07	5.09
0.3	29.99	66.23	1.98	16.79	147.67	13.29	16.22	163.54	7.85	0.4	4.079	5.098
0.4	39.91	66.01	1.98	22.35	147.83	13.3	21.77	163.61	7.85	0.54	4.08	5.1
0.5	49.83	68.62	2.05	27.9	146.28	13.16	27.33	163.63	7.85	0.678	4.08	5.1
0.6	59.75	66.25	1.98	33.46	147.7	13.3	32.88	163.42	7.84	0.817	4.076	5.095
0.7	69.67	66.13	1.98	39.02	147.67	13.29	38.44	163.47	7.84	0.95	4.07	5.09
0.8	79.59	66.01	1.98	44.57	147.83	13.3	43.99	163.45	7.84	1.09	4.07	5.09

T. c	$\dot{\phi}_д$, rad/s	$\ddot{\phi}_д$, rad/s²	$M_д$, Nm	$\dot{\phi}_{кб}$, rad/s	$\ddot{\phi}_{кб}$, Рад/с²	M_{SD}, Nm	$\dot{\phi}_{пв}$, rad/s	$\ddot{\phi}_{пв}$, rad/s²	M_{nFR}, Nm	$\dot{\phi}_p$, rad/s	$\ddot{\phi}_p$, rad/s²	M_p, Nm
1	2	3	4	5	6	7	8	9	10	11	12	13
0.9	89.54	66.18	1.98	50.11	147.83	13.3	49.55	163.4	7.84	1.23	4.07	5.09
1	99.43	67.39	2.021	55.68	147.74	13.3	55.11	163.24	7.83	1.37	4.07	5.09

6. Determining of Energy State

The task of maintaining the energy balance of the SD was solved with the following condition [8]:

$$|P_z - P_p| \le \varepsilon, \tag{18}$$

where P_z – target drive power SD; P_p – rated drive power SD; $\forall\varepsilon$ $(0<\varepsilon<1)$- small value.

Let us formulate the equation of the energy state SD using the total differential of the Hamiltonian function [8, 9]:

$$\frac{dH}{dt} = \sum_{i=1}^{n}\left(-\frac{\partial H}{\partial \varphi_i} + Q_i\right)\dot{\varphi}_i = \sum_{i=1}^{n} Q_i\dot{\varphi}_i \tag{19}$$

Let SD- be a stationary object with constant parameters, a given power, and has a common coordinate of the connection ϕ_c . Then, substituting (19) in (18), we obtain the energy balance equation:

$$\varepsilon = P_z - P_p = \sum_{i=1}^{n}\left[\left(-\frac{\partial H}{\partial \phi_i} + Q_z\right) - \left(-\frac{\partial H}{\partial \phi_i} + Q_p\right)\right]\dot{\phi}_i = \sum_{i=1}^{n}\left(Q_z - Q_p\right)\dot{\phi}_i, \tag{20}$$

where $Q_i = M_i\dot{\phi}_i = j_i\ddot{\phi}_i\dot{\phi}_i$

Substituting the angular velocity values $\dot{\varphi}_i$, moments of driving forces and resistances $Q_i = M_i$ in (20), Determine the energy state of the technological process of primary processing of raw cotton, which satisfies the formulated conditions (18). The values (table 2) and graphical dependences of the energy state by the engine SD, DFR and FR in the technological process of primary processing of raw cotton are obtained (Figure 6).

The results of the research showed that the energy state and stability of the operation of the engines SD, DFR and FR depend on the mass and parameters of the elastic transmission of the drive mechanisms, the values of which are determined by the numerical solution of the boundary value problem of the Pontryagin maximum principle.

Table 2. *Results of the power state of the vehicle.*

T,s	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
$P_д$,кWt	0	0.02	0.04	0.06	0.08	0.1	0.118	0.138	0.157	0.177	0.2
P_{SD},кWt	0	0.0755	0.15	0.223	0.3	0.367	0.445	0.52	0.6	0.666	0.74
P_{nFR},кWt	0	0.04	0.08	0.127	0.17	0.2	0.257	0.3	0.345	0.388	0.43
P_{FR},кWt	0	0.0006	0.0013	0.002	0.0027	0.0034	0.004	0.0048	0.0055	0.0062	0.007

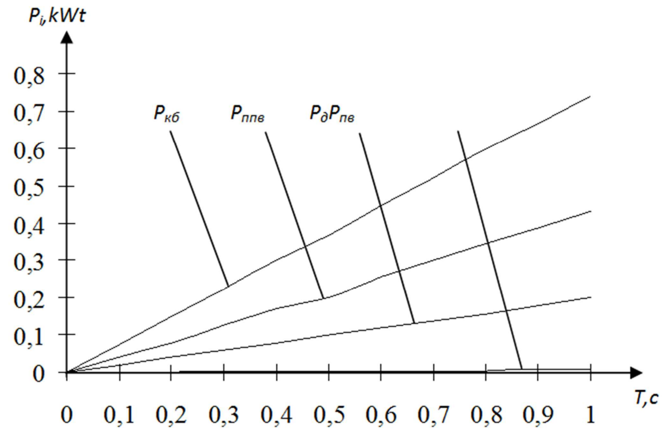

Figure 6. *The schedule of changes in the capacities of the engines SD, DFR and FR in the technological process of primary processing of raw cotton.*

Based on the results of numerical studies, we compile a comparative table of the optimum parameters of the engines SD, DFR, and FR, given in table 3.

Table 3. *Comparison of the results of the study.*

№	Name of parameters	Unit of measurement	Initial value	Esti-mated value	Set value
1	2	4	3	5	6
1.	Electric motor power	kWt	2.2	0.2	0.2÷1.1
2.	Rated speed	rpm	950	950	980
3.	Rated angular velocity of the shaft	rad/s	99.43	99.43	99.43
4.	Rated torque on the motor shaft	Nm	22.126	2.015	2÷11

№	Name of parameters	Unit of measurement	Initial value	Esti-mated value	Set value
1	2	4	3	5	6
5.	Moment of inertia of the motor	Nms^2	0.03	0.03	0.03
6.	Drive Pulley SD	mm	D_1 =140	140	140
7.	Slave Pulley SD	mm	D_l=250	250	250
8.	Gear Ratio	$i_1 = \frac{\omega_д}{\omega_{кб}}$	1.786	1.786	1.786
9.	Drive Pulley DFR	mm	90	90	90
10.	Slave Pulley DFR	mm	250	250	250
	Gear Ratio	$i_2 = \frac{\omega_{кб}}{\omega_{ппв}}$	1	1	1
11.	Gear Ratio	$i_3 = \frac{\omega_{ппв}}{\omega_{пв}}$	0.025	0.025	0.025
12.	Angular velocity SD	rad/s	55.68	55.68	55.68
13	Moment of resistance SD	Nm	0.732	0.732	0.732
14.	Belt drive SD A-1250, GOST 1284.1-89	PC.	2	2	2
15.	Stiffness ratio of drive belt SD	N/m	1000÷12000	9000	9000
16.	Viscosity coefficient of drive belt SD	Nc/m	1÷24	18.2	18.2
17.	Moment of inertiaSD	Nms^2	0.08÷1.3	0.09	0.09
18.	Belt drive FR B (Б) -140, GOST 1284.1-89	PC.	1	1	1
19.	Stiffness ratio of drive belt FR	N/m	500÷6000	4800	4800
20.	Viscosity coefficient of drive belt FR	Nc/m	0.5÷12	9.7	9.7
21.	Moment of inertia DFR	Nms^2	0.02÷0.6	0.048	0.048
22.	Moment of inertia FR	Nms^2	0.5÷3	1.25	1.25
12.	Angular velocity FR	rad/s	1.392	1.37	1.392
23.	Moment of resistance FR	Nm	0.012	0.012	0.012

7. Conclusion

Thus, the stability of the operation of SD and FR depends on the mass and parameters of the elastic transmissions of the drive mechanisms, the values of which are determined by the numerical solution of the coupled system with the variation of the motion parameters $M_д$ and design parameters b, c, j_i at given technological resistance. By solving the boundary value problem of Pontryagin's maximum principle, transient processes for solving system (1) are obtained. As a result, optimal values of the design parameters were obtained, which ensure the uniformity of the motion of the SD and FR.

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