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

Azimov Bahtiyor Magrupovich, Kamalov Nadjimitdin Zaynutdinovich, Igamberdiev Jamshid Khusanovich, Kamalov Jamoliddin Nadjimitdinovich

Scientific and Innovation Centre of Information and Communication Technologies Under IT University, Tashkent, Uzbekistan

Email address
informatika-energetika@mail.ru (A. B. Magrupovich)

Citation

Received: August 25, 2017; Accepted: December 1, 2017; Published: January 18, 2018

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 $M_1 = 950 \text{ rpm}$; 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-1 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 $M_2 = 920 \text{ rpm}$; 11- coupling; 12 - reducer 2$^4$I-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 $M_3 = 920 \text{ rpm}$; 19 - pulley with a diameter 100 mm; 20- V-belt drive; 21 - a pulley with a diameter of 200 mm; 22 - reducer 2$^4$I-80-i-40; 23 - the system of levers; 24- cam shaft V;

- the fourth link: the drive of the saw cylinder (PC): engine $M_4 = 730 \text{ rpm}$; 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 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]:

\[ f_j(\dot{x}_j, x_j, u_j) = M_d - c_{sd}(\dot{x}_j) - c_{fr}(\dot{x}_j) \]
\[ f_j(\dot{x}_j, x_j, u_j) = i_1 c_{sd}(\dot{x}_j) + i_1 c_{fr}(\dot{x}_j) - M_m - J_m \dot{\theta}_m \]
\[ J_m \dot{\theta}_m = M_c - M_e_c \]
\[ J_m \dot{\theta}_m = M_c - M_e_c \]  

(1)

Where \( f_j, f_{SD}, f_{FR} \) - Moment of inertia of the engine SD, Drive FR (DFR) and SD, \( HM \), \( c^2 \); \( \Phi_j, \Phi_{sd}, \Phi_{fr} \) - Angular movements of the rotating masses of the engine, SD and FR, rad; \( \Phi_j, \Phi_{sd}, \Phi_{fr} \) - Angular velocities of the rotating masses of the engine, SD and FR, \( c^2 \); \( b_{sd}, b_{fr} \) - coefficient of viscous drag SD and FR, \( N\cdot m/s/\text{rad}; c_{sd}, c_{fr} \) - Belt stiffness factor SD in FR, \( N/m/\text{rad}; i \) - gear ratio; \( M_c, M_e_c, M_e_c \) - driving moments of the engine, variation and moments of resistance in SD and FR, \( HM \).

4. Solution of Optimal Control Problem

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

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

\[ \Phi_j(0) = \Phi_{sd}(0), \quad \dot{\Phi}_j(0) = \dot{\Phi}_{sd}(0). \]  

(2)

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

\[ \Phi_j(t) = \Phi_{sd}(t), \quad \dot{\Phi}_j(t) = \dot{\Phi}_{sd}(t), \quad 0 \leq t \leq T. \]  

(3)

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

\[ J(\Phi_j, u(t), \Phi_{sd}) = \int_{t_0}^{t} \left[ f(\Phi_j, \dot{\Phi}_j, u(t)) \right] dt. \]  

(4)

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

\[ \dot{\Phi}_j(t) = f(\Phi_j, \dot{\Phi}_j, u(t)), \quad u(t) \in U, \quad t_0 \leq t \leq T, \]  

(5)

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

\[ H = (\phi, u, t), \psi_1, \psi_2) = -f^0(\phi, u, t) + \langle \psi_1, u \rangle \]  

(7)

And the conjugate system

\[ \frac{d\psi_1}{dt} = -\frac{\partial H}{\partial \phi}, \quad \frac{d\psi_2}{dt} = -\frac{\partial H}{\partial u} \]  

(8)

With restriction on management \( u \leq 1 \).

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

\[ H(\phi(t), u(t), t, \psi_1, \psi_2) = \max_{u \in U} H(\phi(t), u(t), t, \psi_1, \psi_2). \]  

(9)

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

\[ \phi_0 = \dot{y}_1, \quad \dot{\phi}_1 = \dot{y}_2, \quad \dot{y}_2 = u_t - J_0^{-1} \left[ b_{sd}(y_2 - \dot{y}_2) + c_{sd}(y_2 - \dot{y}_2) \right], \]
\[ \phi_{sd} = \dot{y}_3, \quad \phi_{fr} = y_3, \quad \dot{y}_4 = J_0^{-1} \left[ b_{fr}(y_2 - \dot{y}_2) + c_{fr}(y_2 - \dot{y}_2) \right], \]
\[ \phi_{fr} = y_5, \quad \dot{y}_6 = J_0^{-1} \left[ b_{fr}(y_2 - \dot{y}_2) + c_{fr}(y_2 - \dot{y}_2) \right], \quad \phi = \phi_0, \phi_{sd}, \phi_{fr} \]  

(10)

And obtain a mathematical model characterizing management \( u_t = \frac{1}{J_0} M_0 \) Movement of SD and FR, where

\[ u_t = \frac{1}{J_0} M_0 \sin \omega t = u_0 + \omega^0 \sin \omega t (M_0) \quad \text{Amplitude of vibration of the moment of resistance in relation to its average value } M_0. \]

Since, if \( f^0 \equiv 1 \), to \( J(\Phi_j, u(t), \Phi_{sd}) = T - \int_0^T \) - 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.

\[ f(t, y, u) = f(y, u), \quad U(t) = U \]  

(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 \( (\psi_1(t), \psi_2(t)), \psi(t) \in R^6 \) satisfying the conditions (9); the maximum condition (7)

\[ \psi_0(t) = \text{const} \leq 0 \]  

(12)

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

\[
\psi_0(t) = -1 \quad 0 \leq t \leq T. \quad (13)
\]

From the conditions \( \max H \) should be \( u = \text{sign}\psi_2 \) at \( \psi_2 \neq 0 \). Then the boundary value problem of the maximum principle is written in the form:

\[
\begin{align*}
\phi = y_1, \quad \dot{\phi} = y_2, \quad \ddot{\phi} = \text{sign}\psi_2 - f(t) + c(t) \left[ b(t)(y_2 - i(t)y_3) + c(t)(y_1 - i(t)y_3) \right], \\
\phi_{\text{in}} = y_3, \quad \phi_{\text{out}} = y_6, \quad \phi_{\text{out}} = \text{sign}\psi_2 + \text{sign}\psi_2,
\end{align*}
\]

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

\[
H_0 = \psi_0 + \psi_1y_2 + \psi_2y_2, \\
H_{\text{in}} = \psi_0 + \psi_1y_4 + \psi_2y_4, \\
H_{\text{out}} = \psi_0 + \psi_1y_6 + \psi_2y_6.
\]

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

\[
H = -f^0u + \psi_2(t)u_0, \\
(16)
\]

In this case

\[
u_k = \text{sign}\psi_2(t) = \begin{cases} 1, & \psi_2(t) > 1, \\
-1, & \psi_2(t) < 1, \\
k=2,4,...,2n; \end{cases}
\]

i.e. management \( u(t) \) can only have one switching point.

To determine the auxiliary functions (8) by a numerical method, the conjugate system with variation of design parameters \( b, c, f_i \).

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.

<p>| Table 1. The values of the parameters of functioning of the engines SD, DFR and FR. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T. c | ( \phi_1 ) rad/s | ( \phi_2 ) rad/s | ( \phi_3 ) rad/s | ( \phi_4 ) rad/s | ( M_{\text{in}} ) Nm | ( M_{\text{out}} ) Nm | ( M_{\text{in}} ) rad/s | ( M_{\text{out}} ) rad/s | ( \phi_1 ) rad/s | ( \phi_2 ) rad/s | ( \phi_3 ) rad/s | ( \phi_4 ) rad/s |</p>
<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>263.95</td>
<td>7.9185</td>
<td>0</td>
<td>-8.13</td>
<td>-0.732</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-0.009</td>
<td>-0.012</td>
</tr>
<tr>
<td>0.1</td>
<td>10.15</td>
<td>65.931</td>
<td>1.97</td>
<td>5.68</td>
<td>147.84</td>
<td>13.3</td>
<td>5.11</td>
<td>163.46</td>
<td>7.846</td>
<td>0.126</td>
<td>4.07</td>
<td>5.09</td>
</tr>
<tr>
<td>0.2</td>
<td>20.07</td>
<td>65.96</td>
<td>1.97</td>
<td>11.24</td>
<td>147.83</td>
<td>13.3</td>
<td>10.66</td>
<td>163.48</td>
<td>7.846</td>
<td>0.26</td>
<td>4.07</td>
<td>5.09</td>
</tr>
<tr>
<td>0.3</td>
<td>39.99</td>
<td>66.23</td>
<td>1.98</td>
<td>16.79</td>
<td>147.67</td>
<td>13.9</td>
<td>16.22</td>
<td>163.54</td>
<td>7.85</td>
<td>0.4</td>
<td>4.079</td>
<td>5.098</td>
</tr>
<tr>
<td>0.4</td>
<td>59.83</td>
<td>66.61</td>
<td>1.98</td>
<td>22.35</td>
<td>147.83</td>
<td>13.3</td>
<td>21.77</td>
<td>163.61</td>
<td>7.85</td>
<td>0.54</td>
<td>4.08</td>
<td>5.1</td>
</tr>
<tr>
<td>0.5</td>
<td>79.75</td>
<td>68.62</td>
<td>2.05</td>
<td>27.9</td>
<td>146.28</td>
<td>13.16</td>
<td>27.33</td>
<td>163.63</td>
<td>7.85</td>
<td>0.678</td>
<td>4.08</td>
<td>5.1</td>
</tr>
<tr>
<td>0.6</td>
<td>99.67</td>
<td>66.25</td>
<td>1.98</td>
<td>33.46</td>
<td>147.7</td>
<td>13.3</td>
<td>32.88</td>
<td>163.42</td>
<td>7.84</td>
<td>0.817</td>
<td>4.076</td>
<td>5.095</td>
</tr>
<tr>
<td>0.7</td>
<td>119.67</td>
<td>66.13</td>
<td>1.98</td>
<td>39.02</td>
<td>147.67</td>
<td>13.29</td>
<td>38.44</td>
<td>163.47</td>
<td>7.84</td>
<td>0.95</td>
<td>4.07</td>
<td>5.09</td>
</tr>
<tr>
<td>0.8</td>
<td>139.59</td>
<td>66.01</td>
<td>1.98</td>
<td>44.57</td>
<td>147.83</td>
<td>13.3</td>
<td>43.99</td>
<td>163.45</td>
<td>7.84</td>
<td>1.09</td>
<td>4.07</td>
<td>5.09</td>
</tr>
</tbody>
</table>

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.
6. Determining of Energy State

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

$$|P_z - P_r| \leq \varepsilon,$$  \hspace{1cm} (18)

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

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

$$\frac{dH}{dt} = \sum_{i=1}^{n} \left( - \frac{\partial H}{\partial \dot{q}_i} + \frac{\partial \dot{H}}{\partial \dot{q}_i} \right) \dot{q}_i = \sum_{i=1}^{n} Q_i \phi_i$$  \hspace{1cm} (19)

Let SD- be a stationary object with constant parameters, a given power, and has a common coordinate of the connection $\phi_1$. Then, substituting (19) in (18), we obtain the energy balance equation:

$$\varepsilon = P_z - P_r = \sum_{i=1}^{n} \left[ \left( - \frac{\partial H}{\partial \phi_i} + \frac{\partial \dot{H}}{\partial \dot{q}_i} \right) \dot{q}_i \right] = \sum_{i=1}^{n} Q_i \phi_i,$$  \hspace{1cm} (20)

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

Substituting the angular velocity values $\dot{\phi}_i$, 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.

<table>
<thead>
<tr>
<th>t, s</th>
<th>0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{e,kW}$</td>
<td>0</td>
<td>0.02</td>
<td>0.04</td>
<td>0.06</td>
<td>0.08</td>
<td>0.1</td>
<td>0.118</td>
<td>0.138</td>
<td>0.157</td>
<td>0.177</td>
<td>0.2</td>
</tr>
<tr>
<td>$P_{r,kW}$</td>
<td>0</td>
<td>0.0755</td>
<td>0.15</td>
<td>0.223</td>
<td>0.3</td>
<td>0.367</td>
<td>0.445</td>
<td>0.52</td>
<td>0.6</td>
<td>0.666</td>
<td>0.74</td>
</tr>
<tr>
<td>$P_{p,kW}$</td>
<td>0</td>
<td>0.04</td>
<td>0.08</td>
<td>0.127</td>
<td>0.17</td>
<td>0.2</td>
<td>0.257</td>
<td>0.3</td>
<td>0.345</td>
<td>0.388</td>
<td>0.43</td>
</tr>
<tr>
<td>$P_{fr,kW}$</td>
<td>0</td>
<td>0.0006</td>
<td>0.0013</td>
<td>0.002</td>
<td>0.0027</td>
<td>0.0034</td>
<td>0.0048</td>
<td>0.0055</td>
<td>0.0062</td>
<td>0.007</td>
<td></td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
<th>№</th>
<th>Name of parameters</th>
<th>Unit of measurement</th>
<th>Initial value</th>
<th>Estimated value</th>
<th>Set value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Electric motor power</td>
<td>kWt</td>
<td>3.2</td>
<td>0.2</td>
<td>0.2-1.1</td>
</tr>
<tr>
<td>2</td>
<td>Rated speed</td>
<td>rpm</td>
<td>950</td>
<td>950</td>
<td>980</td>
</tr>
<tr>
<td>3</td>
<td>Rated angular velocity of the shaft</td>
<td>rad/s</td>
<td>99.43</td>
<td>99.43</td>
<td>99.43</td>
</tr>
<tr>
<td>4</td>
<td>Rated torque on the motor shaft</td>
<td>Nm</td>
<td>22.126</td>
<td>2.015</td>
<td>2-11</td>
</tr>
</tbody>
</table>

6. Determining of Energy State

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

$$|P_z - P_r| \leq \varepsilon,$$  \hspace{1cm} (18)

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

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

$$\frac{dH}{dt} = \sum_{i=1}^{n} \left( - \frac{\partial H}{\partial \dot{q}_i} + \frac{\partial \dot{H}}{\partial \dot{q}_i} \right) \dot{q}_i = \sum_{i=1}^{n} Q_i \phi_i$$  \hspace{1cm} (19)

Let SD- be a stationary object with constant parameters, a given power, and has a common coordinate of the connection $\phi_1$. Then, substituting (19) in (18), we obtain the energy balance equation:

$$\varepsilon = P_z - P_r = \sum_{i=1}^{n} \left[ \left( - \frac{\partial H}{\partial \phi_i} + \frac{\partial \dot{H}}{\partial \dot{q}_i} \right) \dot{q}_i \right] = \sum_{i=1}^{n} Q_i \phi_i,$$  \hspace{1cm} (20)

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

Substituting the angular velocity values $\dot{\phi}_i$, 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.

<table>
<thead>
<tr>
<th>t, s</th>
<th>0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{e,kW}$</td>
<td>0</td>
<td>0.02</td>
<td>0.04</td>
<td>0.06</td>
<td>0.08</td>
<td>0.1</td>
<td>0.118</td>
<td>0.138</td>
<td>0.157</td>
<td>0.177</td>
<td>0.2</td>
</tr>
<tr>
<td>$P_{r,kW}$</td>
<td>0</td>
<td>0.0755</td>
<td>0.15</td>
<td>0.223</td>
<td>0.3</td>
<td>0.367</td>
<td>0.445</td>
<td>0.52</td>
<td>0.6</td>
<td>0.666</td>
<td>0.74</td>
</tr>
<tr>
<td>$P_{p,kW}$</td>
<td>0</td>
<td>0.04</td>
<td>0.08</td>
<td>0.127</td>
<td>0.17</td>
<td>0.2</td>
<td>0.257</td>
<td>0.3</td>
<td>0.345</td>
<td>0.388</td>
<td>0.43</td>
</tr>
<tr>
<td>$P_{fr,kW}$</td>
<td>0</td>
<td>0.0006</td>
<td>0.0013</td>
<td>0.002</td>
<td>0.0027</td>
<td>0.0034</td>
<td>0.0048</td>
<td>0.0055</td>
<td>0.0062</td>
<td>0.007</td>
<td></td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
<th>№</th>
<th>Name of parameters</th>
<th>Unit of measurement</th>
<th>Initial value</th>
<th>Estimated value</th>
<th>Set value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Electric motor power</td>
<td>kWt</td>
<td>3.2</td>
<td>0.2</td>
<td>0.2-1.1</td>
</tr>
<tr>
<td>2</td>
<td>Rated speed</td>
<td>rpm</td>
<td>950</td>
<td>950</td>
<td>980</td>
</tr>
<tr>
<td>3</td>
<td>Rated angular velocity of the shaft</td>
<td>rad/s</td>
<td>99.43</td>
<td>99.43</td>
<td>99.43</td>
</tr>
<tr>
<td>4</td>
<td>Rated torque on the motor shaft</td>
<td>Nm</td>
<td>22.126</td>
<td>2.015</td>
<td>2-11</td>
</tr>
</tbody>
</table>
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 of the drives, and design parameters \( b, c, j \), 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.

References


