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Theoretical and Practical Studies of Determining the Force of the Lifting-Lowering of the Roll Box

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Abstract

The lifting and lowering mechanism of the roll box of the saw gin, being an integral part of the ginning process, is used when starting the electric motor of the saw cylinder until its rated speed is reached to prevent an increase in the load current on it, as well as to start the ginning process. The article defines the kinematics of the movement, and also studies the regularity of the movement of the roll box of the saw gin when lifting it with the help of a pneumatic drive. The kinematics of the roll box movement was determined through experimental studies. Knowing the equation of motion, using the second-order Lagrange equation, the regularity of the change in the lifting force of the roll box was determined. Here the system is closed, its degree of freedom is equal to one. The angle of rotation of the roll box is taken as a generalized coordinate. Numerical results were obtained using the Matlab software environment. The theoretical analysis and graphs for determining the lifting force of the roll box are presented. To study the kinematics of lifting the roll box, a method and a test bench have been developed. According to him, when the roll box was raised, its movement was recorded on video, the image was processed using the After Effect and CorelDraw programs, and the movement of the rod attachment point to the roll box was determined. And also the equation for changing the angle of rotation of the roll box is determined using the Matlab Curve Fiting program.

Keywords

Saw Gin, Roll Box, Pneumatic Cylinder, Rod, Angular Velocity, Angular Acceleration, Gravity Forces, Driving Force, Moment of Inertia, Function

1. Introduction

Cotton gin is the main machine in primary cotton processing enterprises, the function of which is to separate the fiber from the seed while preserving their natural properties [1]. The quality of the products, the productivity of the process largely depends on the process of the genie. The lag of the cotton primary processing machine in the field of application of information technologies, achievements of science and technology, modern mechanisms among machines used in the textile and light industry imposes even greater responsibility on the specialists of this industry. Despite the many successes achieved in the field of primary cotton processing, process control, machine automation, improvement of energy-saving mechanisms, improvement of the working conditions of operators working on them are the tasks of the present time. Raising and lowering the roll box is an integral part of the ginning process; currently, the position of the roll box is controlled by the operator using a lever mechanism. Starting with the gin brand DP (Uzbekistan), the design of mechanisms for raising and lowering the roll box began. But due to high energy consumption, operating costs, narrow scope of application, these mechanisms are not used in enterprises. In addition, the scientific foundations of the kinematics and dynamics of the process of raising and lowering the roll box have not been studied. And the lifting and lowering mechanisms that meet modern requirements were not taken into account by the specialists. To perform the above tasks, a device for lifting and lowering the roll box by a pneumatic system has been proposed [2]. As you know, the energy consumption of the device for lifting and lowering the roll box comes from the force sufficient to raise the roll box. For this purpose, the dynamics of the process of lifting the roll box has been studied.

2. Theoretical Part

Let us derive the equation of motion of the roll box when it is lifted with the help of a pneumatic cylinder. Unlike the steady state of operation, the acceleration and stop modes are unstable modes. This mode also includes the "start-stop" mode. The direct problem of dynamics is the determination of forces from a known motion. In one cycle of operation, the pneumatic cylinder 2 rotates the roll box 1 at an angle and holds it in the working position [3] (**Figure 1**).

Initial data:

m_1 —roll box weight, kg;

$O_1C = a$ —distance from the axis of rotation to the center of gravity of the roll box, m;

$O_1O_3 = b$ —distance from the axis of rotation to the point of installation of the pneumatic cylinder to the roll box, m;

$O_1O_2^* = l$ —horizontal distance between supports, m;

$O_2O_2^* = h$ —distance between supports in vertical direction, m;

$O_2D = d$ —length of the pneumatic cylinder body, m;

$O_3D = S$ —length of the rod of the pneumatic cylinder, m;

$\gamma = \angle CO_1O_3$ —the angle between the line passing from the axis of rotation through the point of installation of the pneumatic cylinder to the roll box and the

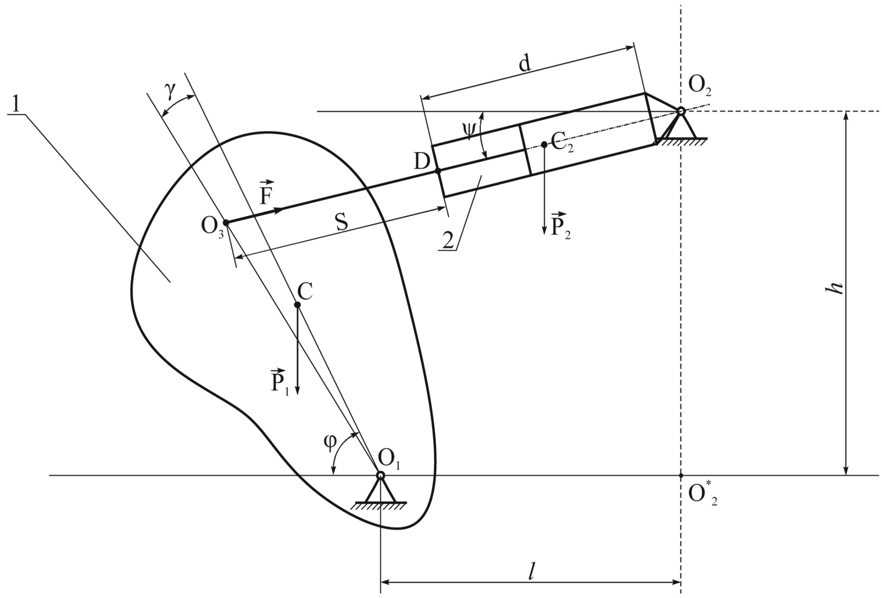

Figure 1. Roll box lifting scheme, 1—roll box, 2—pneumatic cylinder.

line connecting the center of gravity of the roll box with the axis of its rotation ($\gamma = const$);

F—internal force generated by air pressure in a pneumatic cylinder, N;

P_1, P_2 —respectively, the gravity of the roll box and the housing of the pneumatic cylinder, N;

J_{O1} —moment of inertia of the roll box in relation to the axis of rotation, kg·m²;

$J_{O1}^{(n)}$ —moment of inertia of the pneumatic cylinder in relation to the point O_2 , kg·m².

The system is a closed system and its degree of freedom is one [4]. To determine the state of the system, we take the angle $\angle\varphi = \angle CO_1O_3$.

To determine the position of the pneumatic cylinder, we use the angle ψ between its axis and the horizontal, and in turn, denote δ the vertical distance between the two supports. To determine the relationship between these two variables, we will use the following vector expression:

$$\boldsymbol{O_1O_3} + \boldsymbol{O_3O_2} + \boldsymbol{O_2O_2^*} = \boldsymbol{O_1O_2^*} \tag{1}$$

Projecting the vector ratio on the coordinate axis, we form the following system of equations:

$$\left.\begin{aligned} ox:\ & b\cos(\varphi-\gamma) + (d+S)\cos\psi = l \\ oy:\ & b\sin(\varphi-\gamma) + (d+S)\sin\psi = h \end{aligned}\right\} \tag{2}$$

Let us introduce the notation: $\varphi - \gamma = \theta$. Then Equation (2) will come to the following form:

$$\left.\begin{aligned} (d+S)\cos\psi &= l - b\cos\theta \\ (d+S)\sin\psi &= b\sin\theta - h \end{aligned}\right\} \tag{3}$$

That is, between the three variables φ, ψ, S two relationships are formed.

From System (3), we divide the second expression by the first:

$$tg\psi = \frac{b\sin\theta - h}{l - b\cos\theta} \tag{4}$$

We also squared both sides of System (3) and summarize:

$$S = \sqrt{l^2 + b^2 + h^2 - 2b\left(l\cos\theta + h\sin\theta\right)} - d \tag{5}$$

So, Expressions (4) and (5) are the equations of communication between variables φ, ψ, S.

Since the equations in the system consist of geometric expressions, the system has the second order Lagrange equations [5]:

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial T}{\partial \dot{q}_1}\right) - \frac{\partial T}{\partial q_1} = Q_1 \tag{6}$$

where $q_1 = \varphi$ angle; Q_1—generalized force corresponding to the coordinate φ, N.

Kinetic energy of the system:

$$T = T_1 + T_2 + T_3$$

where: T_1—kinetic energy of the roll box, kgf·m;

T_2—kinetic energy of the pneumatic cylinder body, kgf·m;

T_3—kinetic energy of the rod of pneumatic cylinder, kgf·m.

According to the general theory:

$$T_1 = \frac{1}{2} J_{O1}\dot{\varphi}^2;\ T_2 = \frac{1}{2} J_{O2}^{(n)}\dot{\psi}^2;\ T_3 = \frac{1}{2} m_{ш}\left(S^2\dot{\psi}^2 + \dot{S}^2\right)$$

where: $m_{ш}$—weight of rod, kg.

So,

$$T = \frac{1}{2}\left(J_{O1}\dot{\varphi}^2 + J_{O2}^2\dot{\psi}^2 + m_{ш}\left(S^2\dot{\psi}^2 + \dot{S}^2\right)\right) \tag{7}$$

The angular velocity $\dot{\psi}$ and linear velocity v_{c1} from the Expression (7) will be calculated in relation to (4) and (5).

From both sides of Expression (4) we obtain the time derivative:

$$\dot{\psi} = \frac{b\left(\cos\theta\left(l - b\cos\theta\right) - \sin\left(b\cos\theta - h\right)\right)}{\left(l - b\cos\theta\right)^2} \cdot \cos^2\psi \cdot \dot{\theta} \tag{8}$$

Taking into account $\cos^2\psi = \frac{1}{1 + tg^2\psi}$, from Expression (4) we get:

$$\cos^2\psi = \frac{1}{1 + \left(\frac{b\sin\theta - h}{l - b\cos\theta}\right)^2} = \frac{\left(l - b\cos\theta\right)^2}{\left(l - b\cos\theta\right)^2 + \left(b\sin\theta - h\right)^2} \tag{9}$$

We substitute Expression (9) into (8):

$$\dot{\psi} = \frac{b\left(\cos\theta\left(l - b\cos\theta\right) - \sin\left(b\cos\theta - h\right)\right)}{\left(l - b\cos\theta\right)^2 + \left(b\sin\theta - h\right)^2} \cdot \dot{\theta} \tag{10}$$

We introduce the designation:

$$\frac{b\left(\cos\theta\left(l-b\cos\theta\right)-\sin\left(b\cos\theta-h\right)\right)}{\left(l-b\cos\theta\right)^2+\left(b\sin\theta-h\right)^2}=B\left(\theta\right)$$

We take into account:

$$\dot{\psi}=B\left(\theta\right)\cdot\dot{\theta}=B\left(\varphi-\gamma\right)\cdot\dot{\varphi} \tag{11}$$

We introduce the designation:

$$B\left(\varphi-\gamma\right)=B_1\left(\varphi\right)$$

In this case, Expression (11) will come to the following form:

$$\dot{\psi}=B_1\left(\varphi\right)\cdot\dot{\varphi} \tag{12}$$

Now we define the expressions for the variables $S,\dot{S}$ in kinetic energy through θ ($\theta=\varphi-\gamma$) and, in Expression (5), we introduce the notation:

$$\sqrt{l^2+b^2+h^2-2b\left(l\cos\theta+h\sin\theta\right)}-d=D_1\left(\theta\right)=D_1\left(\varphi-\gamma\right)$$

Then

$$S=D_1\left(\varphi-\gamma\right) \tag{13}$$

$$\dot{S}=D\left(\theta\right)\cdot\dot{\theta}=D\left(\varphi-\gamma\right)\cdot\dot{\varphi} \tag{14}$$

Expressions (12), (13) and (14) are substituted into Equation (7) of the kinetic energy of the system:

$$T=\frac{1}{2}\left(J_{O1}+J_{O2}^{(n)}\cdot B_1^2\left(\varphi\right)+m_{ш}\left(D_1^2\left(\psi\right)B_1^2\left(\varphi\right)+D^2\left(\varphi\right)\right)\right)\cdot\dot{\varphi}^2 \tag{15}$$

We introduce the designation:

$$J_{O1}+J_{O2}^{(n)}\cdot B_1^2\left(\varphi\right)+m_{ш}\left(D_1^2\left(\psi\right)B_1^2\left(\varphi\right)+D^2\left(\varphi\right)\right)=I\left(\varphi\right)$$

Then Expression (16) takes the following form:

$$T=\frac{1}{2}I\left(\varphi\right)\cdot\dot{\varphi}^2 \tag{16}$$

Now let's calculate the generalized force:

If we do not take into account the forces of friction, the force of gravity of the roll box $\boldsymbol{P}_1$, the force of gravity of the body of the pneumatic cylinder $\boldsymbol{P}_2$ and the force arising from the air pressure in the pneumatic cylinder $\boldsymbol{F}$, does the work (here the force of gravity of the rod of the pneumatic cylinder is not taken into account due to its small mass).

$$\delta\varphi:\quad \delta A=\boldsymbol{P}_1\cdot\delta\boldsymbol{r}_c+\boldsymbol{P}_2\cdot\delta\boldsymbol{r}_{c2}+F\cdot\delta S=-P_1\cdot\delta y_c-P_2\cdot\delta y_{c2}+F\cdot\delta S$$

where

$$y_c=a\sin\varphi\Rightarrow\delta y_c=a\cos\varphi\cdot\delta\varphi$$

$$y_{c2}=\frac{d}{2}\sin\psi\Rightarrow\delta y_{c2}=\frac{d}{2}\cos\psi\cdot\delta\psi$$

According to (12)

$$\delta\psi = B(\varphi-\gamma)\cdot\delta\varphi$$

Taking into account (4):

$$\cos\psi = \frac{1}{\sqrt{1+tg\psi}} = \frac{l-b\cos\theta}{\sqrt{(l-b\cos\theta)^2+(b\sin\theta-h)^2}}$$

Then

$$\delta y_{c2} = \frac{d}{2}\frac{l-b\cos\theta}{\sqrt{(l-b\cos\theta)^2+(b\sin\theta-h)^2}}\cdot B(\varphi-\gamma)\cdot\delta\varphi$$

Introduce the notation:

$$\frac{l-b\cos\theta}{\sqrt{(l-b\cos\theta)^2+(b\sin\theta-h)^2}}\cdot B(\varphi-\gamma) = B_2(\varphi)$$

$$\delta y_{c2} = \frac{d}{2}B_2(\varphi)\cdot\delta\varphi$$

Possible stem movement:

$$\delta S = \frac{-2l(h\cos\theta-b\sin\theta)\cdot\delta\theta}{2\sqrt{b^2+l^2+h^2-2l(b\cos\theta+h\sin\theta)}}$$
$$= -\frac{l(h\cos\theta-b\sin\theta)\cdot\delta\theta}{\sqrt{b^2+l^2+h^2-2l(b\cos\theta+h\sin\theta)}}$$

Taking into account Expression (15), the equation takes the following form:

$$\delta S = \frac{\partial D_1}{\partial\varphi}\cdot\delta\varphi$$

there $\delta\theta = \delta\varphi;\ \theta = \varphi-\gamma$.

Substituting values,

$$\delta A = \left(-P_1 a\cos\varphi - P_2\frac{d}{2}B_1(\varphi) + F\frac{\partial D_1}{\partial\varphi}\right)\delta\varphi = Q_\varphi\delta\varphi$$

Hence the generalized force is defined as follows:

$$Q_\varphi = -P_1 a\cos\varphi - \frac{d}{2}P_2 B_1(\varphi) + F\frac{\partial D_1}{\partial\varphi}$$

Now we turn to the definition of the equation of motion:

$$\frac{\partial T}{\partial\dot\varphi} = I(\varphi)\cdot\dot\varphi;\quad \frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial T}{\partial\dot\varphi}\right) = I\ddot\varphi + \frac{\partial T}{\partial\varphi}\cdot\dot\varphi^2 = I(\varphi)\cdot\varepsilon + \frac{\partial T}{\partial\varphi}\cdot\omega^2;$$
$$\frac{\partial T}{\partial\varphi} = \frac{1}{2}\frac{\partial I}{\partial\varphi}\cdot\dot\varphi^2 = \frac{1}{2}\frac{\partial I}{\partial\varphi}\cdot\omega^2$$

Substitute the expressions into the II-order Lagrange equation::

$$I(\varphi)\ddot\varphi + \frac{\partial I}{\partial\varphi}\cdot\dot\varphi^2 - \frac{1}{2}\frac{\partial I}{\partial\varphi}\cdot\dot\varphi^2 = -P_1 a\cos\varphi - \frac{d}{2}P_2 B_1(\varphi) + F\frac{\partial D_1}{\partial\varphi}$$

or

$$I(\varphi)\varepsilon + \frac{1}{2}\frac{\partial I}{\partial\varphi}\cdot\omega^2 = -P_1 a\cos\varphi - \frac{d}{2}P_2 B_1 + F\frac{\partial D_1}{\partial\varphi} \tag{17}$$

From here we find the force in the pneumatic cylinder:

$$F = \frac{I(\varphi)\varepsilon + \frac{1}{2}\frac{\partial I}{\partial \varphi}\cdot\omega^2 + P_1 a\cos\varphi + \frac{d}{2}P_2 B_1}{\frac{\partial D_1}{\partial \varphi}} \tag{18}$$

As can be seen from the equation, with an increase in the moment of inertia of the system, the gravity of the roll box and pneumatic cylinder, their angular velocity and acceleration, the force in the pneumatic cylinder also increases.

Numerical solution of the obtained Expression (18), with the known regularity of the movement of the roll box, determines the amount of required force.

3. Experimental Part

The definition of the law of motion of the roll box was carried out in the following sequence (Figure 2).

In order to study the kinematics of the movement of the roll box 1 during its lifting and lowering, a video recording of the process was made. The roll box is attached through a pair of hinges 3 at the bottom of the body 2 of the machine. For one lifting cycle, the point of attachment of the pneumatic cylinder was taken to the observation focus, and the video camera 5 was installed on the same horizontal plane with this point (Figure 3). The movement of the attachment point of the pneumatic cylinder to the roll box was observed using recording. Figure 3 depicts a stand for removing video recording of the lifting of the roll box of the saw gin. With the help of it, the state of the roll box was observed through the movement of the center 4 of the hinge at the end of the pneumatic cylinder rod during its rise.

The material obtained with a high-frequency (60 fps) video recorder was processed using Adobe After Effects, each frame was exported in JPEG format

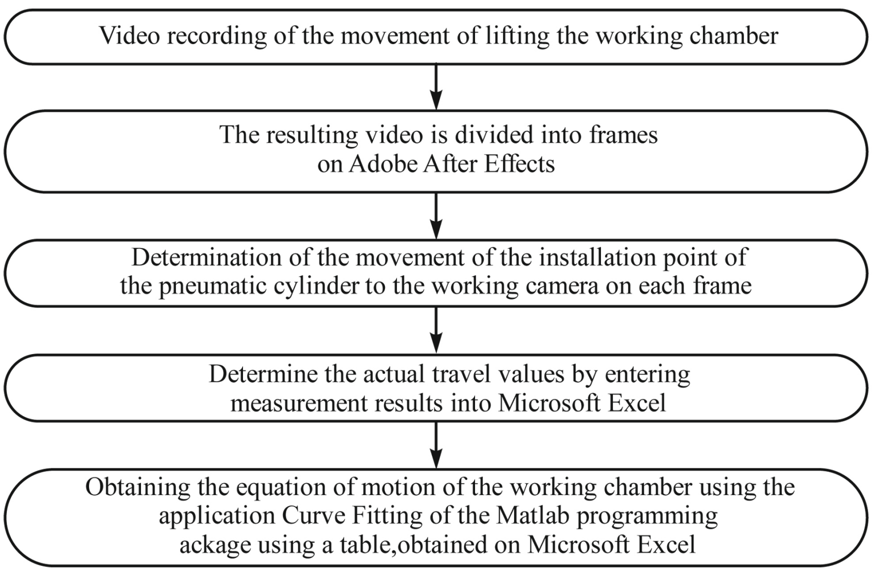

Figure 2. The sequence of determining the laws of motion of the roll box.

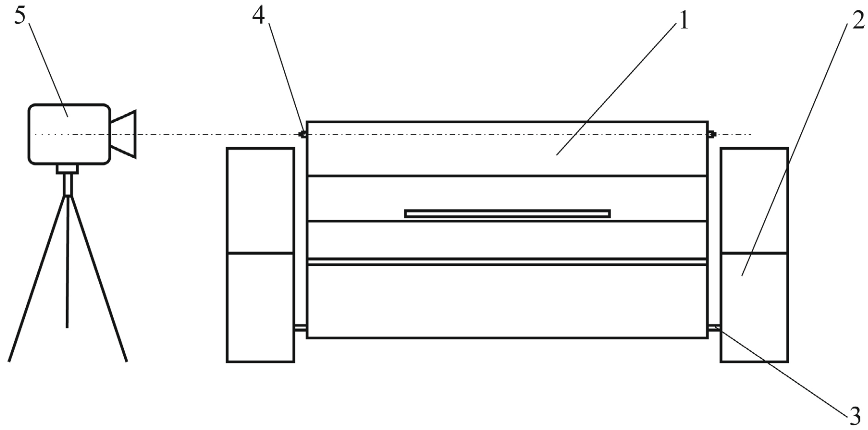

Figure 3. Scheme of video recording of lifting and lowering of the roll box. 1—roll box, 2—machine body, 3—support of the roll box, 4—attachment point of the pneumatic cylinder to the roll box, 5—video camera.

(**Figure 4**).

Sequential time frames, separated for one cycle of lifting the roll box, were processed using the CorelDraw program in the same scale. At the same time, on each frame, the movements of the center of the roll box hinge were measured and entered into the Microsoft Excel program.

To prevent errors during measurements and processing, to obtain data in the form of a ready-made table, results in a graphical and analytical form, the application of the Curve Fitting subsystem (cftool) of the Matlab programming package was used. This application is used to construct maximum approximate mathematical functions or curves (smoothing) of these points [6] [7].

In **Figure 5** shows a graph of the angular velocity of the roll box obtained on the Matlab program.

As you can see from the graph, the acceleration of the roll box is more intense at the beginning of the movement than at the stop. And at the end of the stop, it decelerates steadily. This is due to the braking system in the pneumatic cylinder [8].

Let's get the equation of motion of the roll box in the window Resuts (results) of the program. In this case, the angle of rotation is converted to radians, since for a numerical solution, the Maple program takes the angle in radians:

$$\varphi = 0.043t^4 - 0.45t^3 + 0.114t^2 + 0.21t + 1.21 \tag{19}$$

where φ -roll box rotation angle, t-time (the interval of its change $0 \le t \le 2.57\,\text{sec}$).

According to the general theory, the derivative obtained from the angle of rotation with respect to time gives the regularity of the change in the angular velocity, and the derivative of the second degree—the angular acceleration. By introducing Expression (19) into the Matlab program, having determined the patterns of change in the angle of rotation, angular velocity and angular acceleration, their graphs were obtained (**Figure 6**).

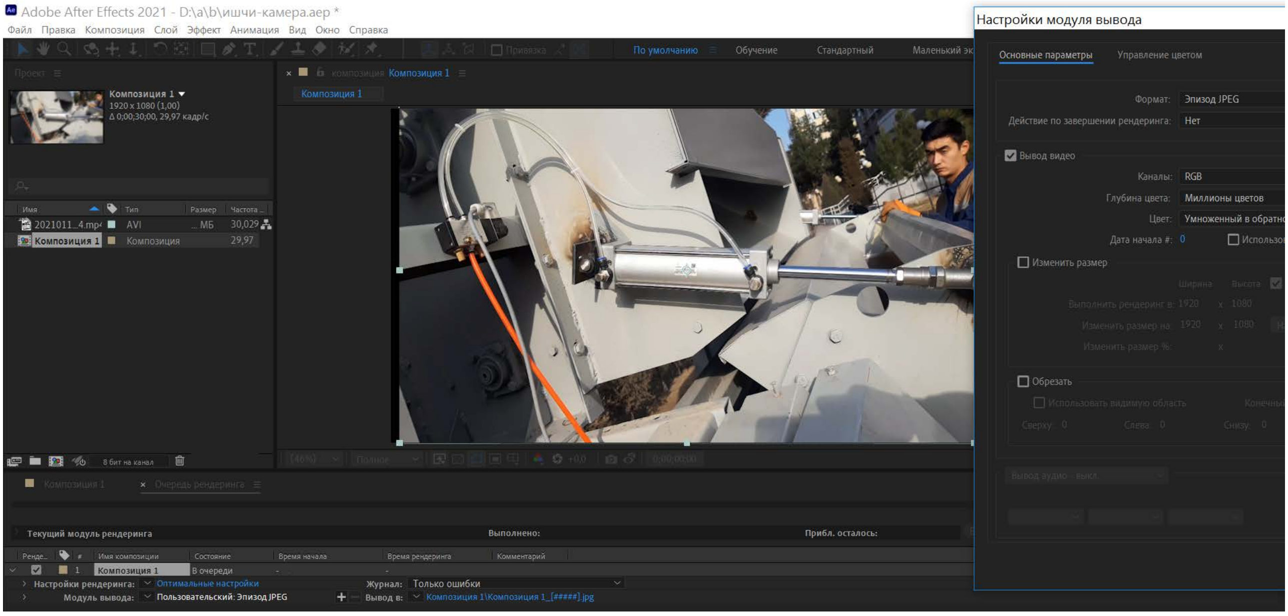

Figure 4. Adobe after effects window.

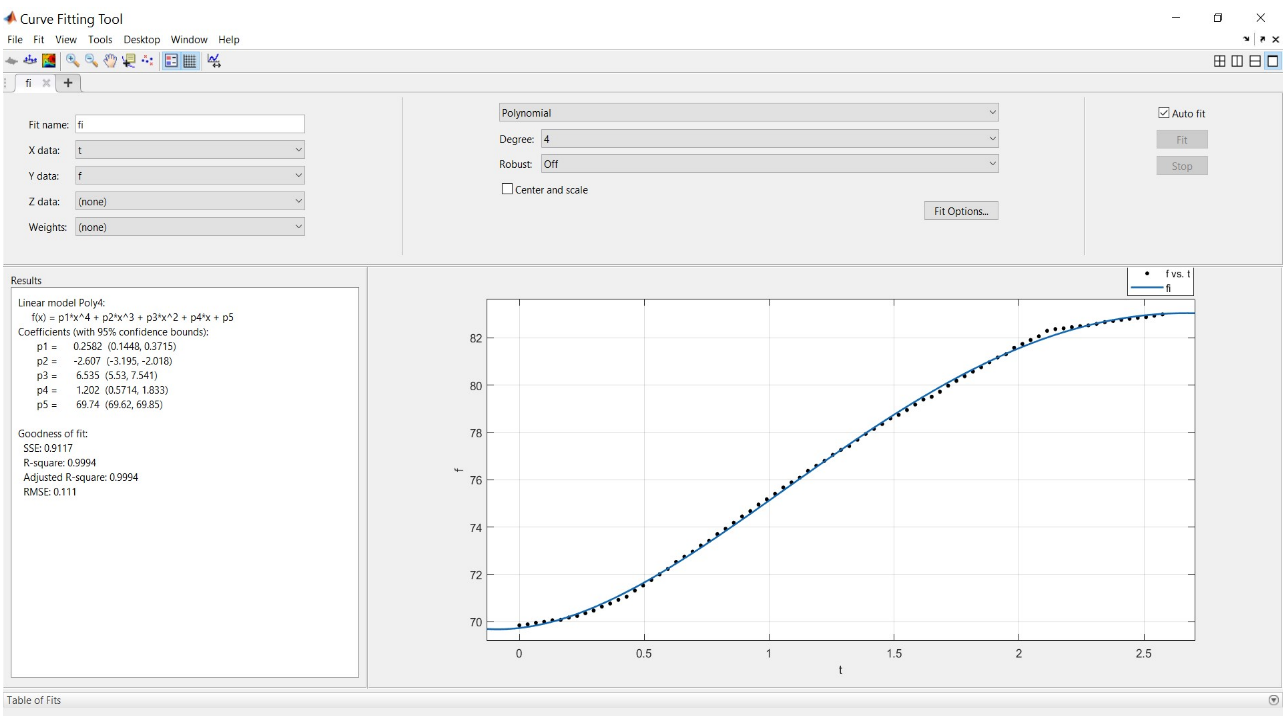

Figure 5. Plotting the change in the angular velocity of the roll box in the Curve Fitting application.

From Expression (18), we determine the driving force arising from the air pressure in the pneumatic cylinder:

$$F=\frac{I(\varphi)\varepsilon+\frac{1}{2}\frac{\partial T}{\partial\varphi}\cdot\omega^{2}+P_{1}a\cos\varphi+\frac{d}{2}P_{2}B_{1}}{\frac{\partial D}{\partial\varphi}}\tag{20}$$

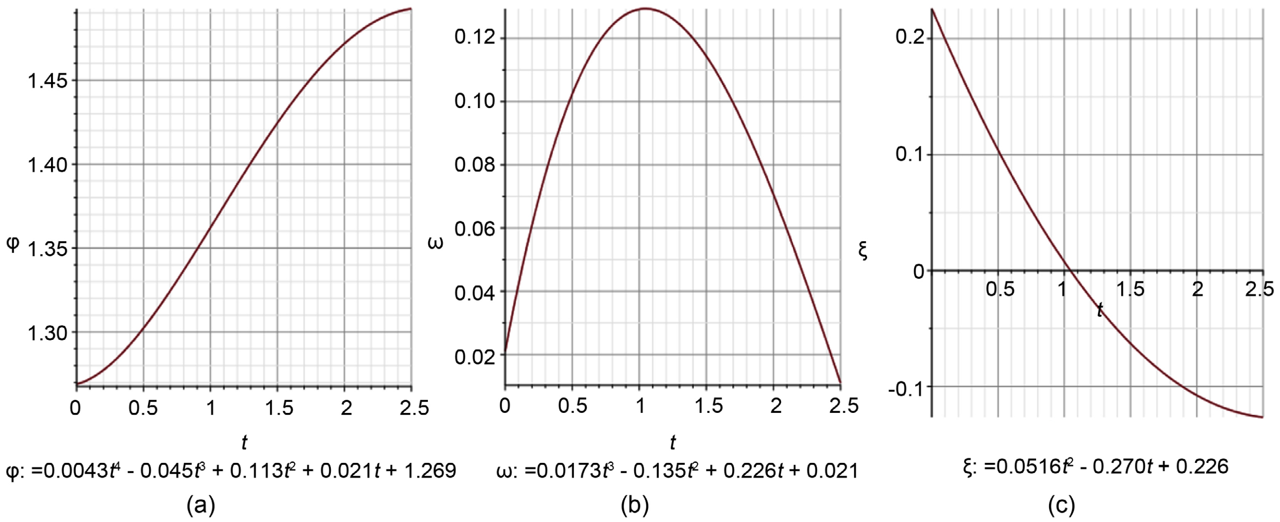

Figure 6. Regularities of changes and graphs of the angle of rotation (a), angular velocity (b) and angular acceleration (c).

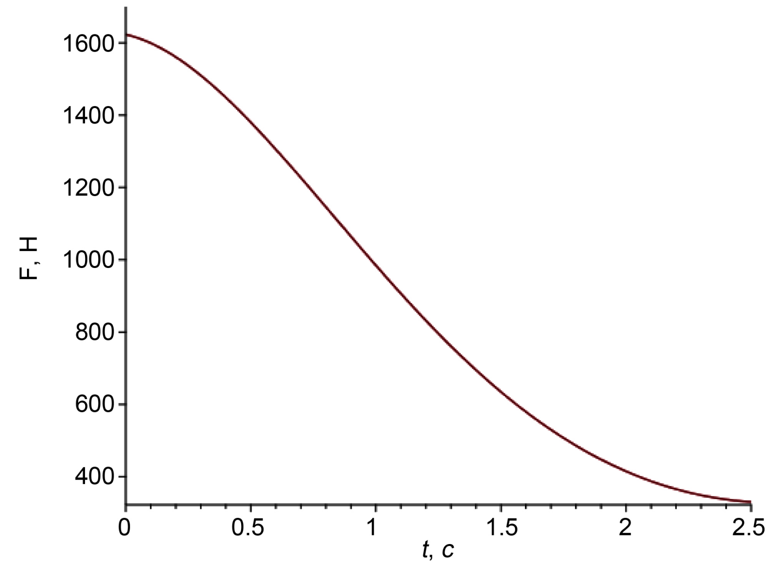

Figure 7. Graph of the change in the driving force when lifting the roll box.

The kinematics of the roll box has been determined under production conditions [9]. As mentioned above, according to the laws of motion, we will determine the driving force by a numerical method [10]. Having entered the initial data, the regularity of the movement of the roll box in the Maple program, the regularity of the change in force was determined (**Figure 7**).

As you can see from the graph, the maximum value of the force coincides with the beginning of the movement and decreases over time. At the beginning of the movement, this value is. And at the end of the movement, the value of the force approaches zero. This is explained, on the one hand, by the camera stopping at the end of the movement, and on the other hand, by the approach to the vertical of the center of gravity of the roll box, which constitutes the main part of the resistance force.

4. Conclusions

1) The equation for determining the force required from the pneumatic cylinder to lift the roll box has been obtained.

2) The regularity of the movement of the roll box, the equations expressing the change in its angular velocity and angular acceleration have been obtained.

3) An analytical expression for the regularity of the movement of the roll box is derived. From this expression, the regularity of the change in force is determined when the roll box is raised.

4) The regularities of the angle of rotation, angular velocity and acceleration of the roll box are expressed in the form of graphs, as well as, in accordance with them, the dependence of force on time.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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