Efficiency evaluation of energy recovery in the bunk of a timber truck based on the results of simulation modelling

V I Posmetev1, V O Nikonov and V V Posmetev

Department of production, repair and operation of machines, Voronezh State University of Forestry and Technologies named after G F Morozov, 8 Timiryazev Street, 394087, Voronezh, Russian Federation

1E-mail: prem@vglta.vrn.ru

Abstract. The main reasons restraining the efficiency of timber trucks (hauling tractors with semi-trailers) have been considered. A promising direction has been proposed making it possible to increase the efficiency of hauling tractors with semi-trailers. This direction consists in the development and study of a recuperative bunk device for a timber haulage site, installed on a logging tractor. The aim of the research consisted of two stages. At the first stage, a mathematical model for the functioning of the recuperative bunk device of the logging site, installed on a timber truck has been developed. At the second stage, a computer program for a preliminary assessment of the efficiency of the proposed recuperative system has been created. The time dependence of the current recuperative power when hauling tractor moves along an insufficiently equipped timber road has been obtained. The regularity of the influence of the diameter of the hydraulic cylinder of the recuperative bunk device on the average values of the recovered power has been revealed.

1. Introduction
Russia has the largest reserves of forest resources in the world. The forest complex is the most important component of its economy. Correct choice of the required arrangement of the truck-and-trailer combination set has a significant impact on the costs when carrying out the process of hauling timber to the consumer. This choice depends on the operating conditions; devices used for loading and unloading, as well as type of hauling timber. Among the well-known layouts of truck-and-trailer combination sets, timber trucks (timber tractors with semi-trailers) equipped with timber platforms with rotary bunks have significant advantages for the removal of long timber from the upper warehouse to consumers. The use of timber trucks makes it possible to significantly increase the turnover of timber harvesting enterprises. However the efficiency of using timber tractors with semi-trailers is constrained for the following reasons. The first reason is the design flaws of the rotary bunkers of the timber platforms and susceptibility to various breakdowns. The second reason is lack of reliability of the structure, high metal consumption, manufacturing cost and laboriousness of repair. The third reason is susceptibility of rubbing pairs (in rotary bunks) to intense wear. Such wear is accompanied by a loss of mobility of the mating elements of the rubbing pairs. The fourth reason is absence of damping devices in the design that reduce the load on the hauling tractor from the transported long-tailed timber. The fifth reason is the absence of a recuperative device in the rotary bunk design of the timber-carrying area. The use of such a device with frequent braking of a timber tractor with a semitrailer enables it to accumulate and reuse heat energy unproductively dissipated into space. In this regard, a promising direction is development
and study of a recuperative bunk device. It helps to reduce fuel consumption of a timber truck when it moves on insufficiently equipped logging roads.

Posmetyev V I [1] in his research showed that the efficiency of the recuperative spring-hydraulic fifth-wheel coupling device of a timber truck grew with an increase in the parameters of irregularities and the number of obstacles on the timber road. The optimal value of the inner diameter of the hydraulic cylinder cavity in recuperative spring-hydraulic fifth wheel coupling equal to 56 mm enables recuperation of power up to 6 kW with an average acceleration of the semitrailer relative to the timber tractor of 0.8 m/s². Nikonov V O [2] showed that maximum recuperative power during the operation of recuperative pneumohydraulic towing hitch was achieved during the movement of a hauling truck with semitrailer on an insufficiently equipped timber road at a speed of 32 km/h. Pugi L [3] offered a new innovative solution for trucks equipped with hydraulic equipment for garbage disposal, based on the recuperation of hydraulic energy during braking. The use of such a system reduced environmental pollution by reducing fuel and noise consumption. Bravo R R S [4] wrote that the use of recuperative hybrid power units in trucks made it possible to increase their overall energy efficiency. It was achieved due to the possibility of accumulating hydraulic energy during braking in the pneumatic hydraulic accumulator for subsequent useful use. Mohamed A A Abdelkareem [5] in his article considered automobile vehicles as a source of vibrations arising in the suspension in the process of overcoming irregularities and obstacles on the road. He proposed to use this unproductively dissipated energy in shock absorbers by means of its accumulation in energy storage devices. He found that the recovered power increased with the number of irregularities on the road, as well as with an increase in the aggressiveness of car driving. In the work of Lianpeng Xia [6], the efficiency of accumulation and further use of the potential energy of the boom of a hydraulic excavator during loading operations was considered. The effectiveness of the proposed integrated system with a recuperative hydraulic drive was substantiated by the results obtained in simulation modeling and pilot production tests. Wei Yu [7] examined various energy recovery technologies used in vehicles. Energy recovery systems in the suspension and in the running wheels of the vehicle were proposed. The results of the work confirmed high efficiency of the functioning of these systems. Li J performed an analysis of various hybrid regenerative drives used in automobiles. It was found that flywheel energy recovery systems had the highest specific power, increased energy consumption, longer service life and insignificant impact on the environment [8]. The article by Ranjan P described a promising hybrid system that made it possible to convert potential gravitational energy from the hydraulic drive (excavator boom) operation into the pressure energy of the working fluid accumulated in the pneumohydraulic accumulator. The results showed that the use of this hybrid system, in comparison with the traditional system, improved the energy efficiency of the process by 10% [9]. Pipitone E performed a preliminary assessment of various kinetic energy recovery systems in a vehicle equipped with an internal combustion engine based on mathematical modeling. This estimate showed that the use of supercapacitors for energy storage saved about 20% of energy [10].

Analysis of scientific works of Russian and foreign scientists has shown that the use of hydraulic energy recovery in vehicle structures will significantly increase their efficiency. This will be achieved by increasing reliability and reducing cost of their operation. However, at present, constructions of rotary bunks of the timber haulage platforms have not yet been created. These constructions would enable it to perform the following three functions simultaneously. The first is to recuperate energy from the working fluid. The second is to improve the reliability of timber trucks. The third is to improve driver's working conditions by reducing dynamic loads on hauling tractors from the transported long-tailed timber. This circumstance allowed the authors (in earlier works) to propose a promising design of a recuperative bunk device for a hauling tractor with semitrailer.

The purpose of the work consists of two stages. The first stage is to develop a mathematical functioning model of rotary bunk device, installed on a timber truck. The second stage is to create a computer program for preliminary assessment of efficiency indicators for the proposed recuperative system of bunk devices.
2. Material and methods

Frequent braking of timber trucks when driving on an insufficiently equipped timber road is accompanied by the impact of significant forces on the rotary bunks from the side of long timber. The proposed recuperative bunk device enables converting the pinching force in the pintle of rotary bunk into the working fluid energy. Energy of working fluid accumulated in pneumohydraulic accumulators is reused in the technological process of loading and unloading timber by a hydraulic manipulator. A mathematical movement model of timber trucks on an insufficiently equipped timber road has been developed to estimate the effectiveness of the use of a recuperative bunk device.

The methods of classical mechanics were the basis for the compilation of this mathematical model. The requirement of correct representation of the investigated bodies moving in space was observed developing the mathematical model. These bodies were a hauling tractor, semi-trailer, log bundle, suspension, wheels, and timber road with specified relief parameters. Hauling tractor, semi-trailer, log bundle were described as separate absolutely solid bodies contacting each other when moving along the timber road (figure 1). They had the corresponding masses $m_{HT}$, $m_{ST}$ and $m_{LB}$ and moments of inertia $J_{HT}$, $J_{ST}$ and $J_{LB}$.

![Figure 1. Design diagram of hauling tractor with recuperative bunk device with semi-trailer and log bundle.](image)

The position of hauling tractor, semi-trailer and log bundle in space was described in a mathematical model by the Cartesian coordinates of their centers of gravity $(x_{HT}, y_{HT}, z_{HT})$, $(x_{ST}, y_{ST}, z_{ST})$ and $(x_{LB}, y_{LB}, z_{LB})$, and angles of deviation of the local coordinate system from base coordinates $(\phi_{xHT}, \phi_{yHT}, \phi_{zHT})$, $(\phi_{xST}, \phi_{yST}, \phi_{zST})$ and $(\phi_{xLB}, \phi_{yLB}, \phi_{zLB})$.

\[
\begin{align*}
\frac{d^2x_k}{dt^2} &= \sum_{i=1}^{3} \frac{3}{i} F_{x_i} + \sum_{i=1}^{3} \frac{3}{j} F_{y_j} + \sum_{i=1}^{3} \frac{3}{k} F_{z_k}; \\
\frac{d^2y_k}{dt^2} &= \sum_{i=1}^{3} \frac{3}{i} F_{y_i} + \sum_{i=1}^{3} \frac{3}{j} F_{x_j} + \sum_{i=1}^{3} \frac{3}{k} F_{z_k}; \\
\frac{d^2z_k}{dt^2} &= -m_g \cdot g \sum_{i=1}^{3} \frac{3}{i} F_{z_i} + \sum_{i=1}^{3} \frac{3}{j} F_{y_j} + \sum_{i=1}^{3} \frac{3}{k} F_{x_k}; \\
J_{sk} \frac{d^2\varphi_{sk}}{dt^2} &= \sum_{i=1}^{3} M^{(s)}(F_{x_i}) + \sum_{i=1}^{3} M^{(s)}(F_{y_i}) + \sum_{i=1}^{3} M^{(s)}(F_{z_i}); \\
J_{sk} \frac{d^2\varphi_{sk}}{dt^2} &= \sum_{i=1}^{3} M^{(s)}(F_{y_i}) + \sum_{i=1}^{3} M^{(s)}(F_{x_i}) + \sum_{i=1}^{3} M^{(s)}(F_{z_i}); \\
J_{sk} \frac{d^2\varphi_{sk}}{dt^2} &= \sum_{i=1}^{3} M^{(s)}(F_{z_i}) + \sum_{i=1}^{3} M^{(s)}(F_{y_i}) + \sum_{i=1}^{3} M^{(s)}(F_{x_i});
\end{align*}
\]
where \( t \) – time; \( k \) – the number of a body moving in space (hauling tractor, semi-trailer, log bundle); \( F_{Hi} \) and \( F_{Si} \) – forces perceived by the sides of hauling tractor, semi-trailer from wheels and suspension; \( F_{kj} \) – interaction forces of the considered bodies \( k \) and \( j \); \( M_i \) – moments of forces \( F_{Hi}, F_{Si}, F_{kj} \) about the axis \( i \).

The interaction of bodies in the mathematical model was carried out by hinge and contact of the point with the supporting surface of the timber road. In the first case, the interaction of a timber truck took place. In the second case, a hauling tractor, recuperative bunk device, log bundle and lo, as well as a trailer-dismantling, a recuperative conic device and a package of timber were interacting bodies. At the initial stage of the study, a simplified mathematical wheel model was applied. Its distinctive features are absence of wheel deformation, as well as suspension work due to distance changes from the body of the timber truck to the supporting surface of the timber road. The support forces from the wheel on the body of a hauling tractor with semitrailer were determined by the formula:

\[
F_{ii}^z = c_i \left( z_{wi}(x, y) - R_w - z_{wi} \right) - d_i \left( \frac{\partial z_{wi}(x, y)}{\partial t} - \frac{\partial z_{ki}}{\partial t} \right)
\]

(2)

where \( i \) – wheel number; \( c_i \) – stiffness coefficient of viscoelastic interaction; \( z_{wi}(x, y) \) – vertical coordinate of the supporting surface of the timber road under the wheel; \( R_w \) – wheel radius; \( z_{wi} \) – vertical coordinate of the wheel mounting point on the body of a hauling tractor with semitrailer; \( d_i \) – damping coefficient of viscoelastic interaction.

Recuperative bunk device (\( P_{RT1} \) point in figure 2) was represented in the model by a combination of two subsystems: mechanical and hydraulic ones. Mechanical subsystem consisted of a movable platform with a bunk clamping device (figure 2). The platform moved along the guides of the cylindrical section and has one degree of freedom. It was characterized by one variable – longitudinal coordinate of the platform \( x_P \). In addition to the movement in longitudinal direction, the bunk platform pin-jointly connected the log bundle and body of the hauling tractor. In addition, it allows you to change the angles between the package of timber and body of the hauling tractor in vertical and horizontal planes.

Hydraulic subsystem of the recuperative bunk device was represented by a two-sheet hydraulic cylinder (figure 2). On the one hand, hydraulic cylinder exerted a resistance force \( F_c \) to the movement of bunk platform, which participated in (formula 1) and was equal to

\[
F_c = \sin(n(v_L)) \cdot P_{ci} \cdot \frac{\pi D_{HC}^2}{4},
\]

(3)

where sign() – function returning the sign of the argument; \( v_L \) – longitudinal speed of movement of the bunk platform; \( P_{ci} \) – pression and participating in the creation of pumping effect (it is assumed that pressure in the second cavity was equal); \( D_{HC} \) – inner diameter of hydraulic cylinder.

On the other hand, mechanical movement of the piston, rigidly connected to the movable bunk platform, led to the displacement of the working fluid from one cavity and filling the other cavity. That is, the fluid was pumped into the recuperative subsystem. This simplified model made it possible to estimate the characteristic value of the current recuperative power \( N_{pc} \), emitted by the recuperation system:
\[ N_p = \left| \frac{x_p^\tau - x_p^{\tau-1}}{\Delta \tau} \right| P_p \frac{\pi D_{\text{le}}^2}{4}, \]  

(4)

where \( x_p^\tau \) and \( x_p^{\tau-1} \) – position of movable bunk platform in the coordinate system associated with hauling tractor (current \( \tau \) and previous \( \tau - 1 \) time moments); \( \Delta \tau \) – integration step over time of equations of mechanical motion of bodies; \( P_p \) – characteristic pressure in the recuperative system (in particular, ultimate pressure of pneumatic-hydraulic accumulator).

Instantaneous recuperative power changed significantly when a timber truck moved on an uneven supporting surface of a timber road. In this regard, in the future, the average recuperated power, determined by averaging over the time of the computer experiment will be used to assess the efficiency of recuperation system:

\[ N_p = \frac{\Delta \tau}{t_2 - t_1} \sum_{i = 1}^{N_O} \left| \frac{x_i^\tau - x_i^{\tau-1}}{\Delta \tau} \right| P_p \frac{\pi D_{\text{le}}^2}{4}, \]  

(5)

where \( t_1 \) and \( t_2 \) – time of beginning and end of the computer experiment when a logging tractor with a dismantling trailer moved along an uneven supporting surface of a logging road. Square brackets in the formula characterize the absolute value of the number. This is due to the fact that the recuperative system gave off recuperative power when the bunk platform moved forward and backward.

Due to the force of resistance to the movement of the bunk platform provided by the hydraulic cylinder, the semi-trailer and log bundle may experience additional unfavorable accelerations. To control the smoothness of movement of semi-trailer and log bundle, average longitudinal acceleration \( a_{\text{ac}} \) of semi-trailer was used during the experiment:

\[ a_{\text{ac}} = \frac{\Delta \tau}{t_2 - t_1} \sum_{i = 1}^{N_O} \left[ \frac{x_i^\tau + x_i^{\tau-1} - 2x_i^{\tau-2}}{(2\Delta \tau)^2} \right] \]  

(6)

where \( x_i \) – coordinate of semitrailer in the global coordinate system. It should be noted that in all subsequent computer experiments the hauling tractor moved at a constant longitudinal speed \( v_t \).

The more complex the surface relief of the timber road, the more travel was provided in the recuperative bunk device. This allowed, using the developed mathematical model, to check the operation of the recuperative bunk device when a hauling tractor moved along an insufficiently equipped timber road.

In the mathematical model, the relief of the supporting surface of the timber road was taken. It included the following two types of highs. The first one was hills with a length of 2 to 5 m. The second was obstacles with a length of 0.2 to 0.5 m. Within the framework of the developed mathematical model, a function of the height of the supporting surface of a timber road from the coordinates of the wheel contact point \( z(x, y) \) was set. This function was determined by the superposition of Gaussian peaks with such parameters as \( x_i, y_i \) (location of highs), \( \sigma_i \) (width of highs) and \( H_i \) (height of obstacle):

\[ z(x, y) = \sum_{i = 1}^{N_O \times N_H} H_i \exp \left( -\frac{(x-x_i)^2 + (y-y_i)^2}{\sigma_i^2} \right), \]  

(7)

where \( N_O, N_H \) – the number of obstacles and hills, respectively.

The distribution of Gaussian peaks and their parameters \( (H_i = 0-0.1 \text{ m and } \sigma_i = 0.05-0.15 \text{ m}) \) on the control section of the timber road \( (500 \times 5 \text{ m}^2) \) was carried out according to a uniform law in a random manner. Due to the fact that the function \( z(x, y) \) was a function of two variables, transforming this function, two functions of one variable were obtained. The first one was for the wheels of the left side of a hauling tractor with a semitrailer \( z(x, -B / 2) \). The second was for the starboard wheels \( z(x, B / 2) \). Two functions of one variable were dependent on the track \( B \) of the timber tractor with semitrailer.

Differential equations were solved using well-known numerical Runge-Kutta method:
$$\begin{align*}
    x_{t+1} &= x_t + v_{xt} \cdot \Delta t + \frac{F_{xt}}{m} \cdot \frac{(\Delta t)^2}{2}; \\
    v_{xt+1} &= v_{xt} + \frac{F_{xt}}{m} \cdot \Delta t,
\end{align*}$$

(8)

Similarly, numerical integration was performed for other Cartesian components \(y\) and \(z\), as well as for three spatial angles defining body orientation in space. At the same time, the integration was carried out for three investigated bodies: the body of the timber tractor, the body of the semitrailer, and the package of timber. In this case, the integration step was \(\Delta t = 0.0002\) s. In the process of solving such differential equations by the method under consideration, the functions of the time dependencies of the angles and coordinates of the location of the timber tractor, the semitrailer and the package of timber were found. These functions were further used to evaluate the efficiency of the recuperative bunk device.

3. Results and discussion

For the subsequent study of the obtained mathematical model, a computer program "Program for modeling the movement of a hauling tractor with a semi-trailer equipped with a recuperative bunk device" was developed. It enables simulations of the operation of a recuperative bunk device when a timber truck moves along an insufficiently equipped timber road. The main purpose of this study is to assess the efficiency of the proposed recuperative device, as well as to determine its optimal design parameters. The developed computer program takes into account a large number of geometric, mechanical and hydraulic parameters of a timber truck. In addition, it provides great opportunities for studying the movement process of a timber truck. The most important three parameters have been selected for the study. The first parameter was the diameter of the recuperative hydraulic cylinder \(D_{hc}\). The second one was the speed of movement of a timber truck \(v\). The third parameter was the average height of the supporting surface irregularities of timber road \(h_{aver}\). In a further theoretical study, it is necessary to establish the influence of the listed design and technological parameters on the efficiency indicators of the recuperative bunk device.

About 50 computer experiments were carried out in the process of theoretical study of the developed recuperation system. A model timber truck covered a distance of 500 m along the random uneven relief of a timber road in the course of each computer experiment. The duration of one computer experiment was about 1 minute of computer time. At the initial moment of time, the three main bodies of the model (the body of hauling tractor, the body of semitrailer, the package of timber) were located at a certain distance from each other and obviously higher than the supporting surface of the timber road. In the initial 5-10 sec of the modeling time, the individual bodies were connected to a timber truck loaded with timber. Then it was put to the supporting surface of the timber road and came to a state of stable equilibrium. After that, the computer experiment began (time \(t_1\)). The experiment was terminated when the timber truck overcame the 500 m distance (time \(t_2\)).

In the process of timber truck movement on an uneven supporting surface of a logging road, bunk platform carried out oscillatory movements relative to the body of the logging tractor with an amplitude of about 0.2 m (figure 3). At the same time, at the moments of significant movements of the logging platform, the pumping effect of the recuperation system was the most pronounced one. This leads to the appearance of peaks on the graph of the instantaneous power versus time (figure 3b). The longitudinal acceleration of semi-trailer, provided by the recuperation system, was small and lied within the range of \(-0.5-0.5\) m/s\(^2\) (figure 3c). In most computer experiments, the speed of movement of a timber tractor with a dismantling trailer was \(v = 30\) km/h, the average height of the irregularities of the timber road was \(h_{aver} = 0.5\) m; inner diameter of the hydraulic cylinder \(D_{hc} = 60\) mm. The theoretical study was carried out according to the "star-shaped" scheme. The main parameters were changed one at a time, keeping the rest of the parameters at the baseline values.

The efficiency of the recovered power and the smooth movement of the timber tractor, semi-trailer and the log bundle depended on the parameters of the recuperation system. The most important parameter of the recuperation system was the inner diameter of the hydraulic cylinder \(D_{hc}\). A series of
Figure 3. Time dependence of the bunk platform position $x_{pp}$ (a), current recuperative power $N_p$ (b) and current acceleration of semi-trailer $a_{ac}$ (c) when timber truck is moving along an insufficiently equipped timber road.

Computer experiments were performed to study the dependence of the change in the performance indicators of the recuperative bunk device at different values of hydraulic cylinder diameter $D_{hc}$. In the course of these experiments, the diameter of the hydraulic cylinder $D_{hc}$ was increased with a step of 10 mm in the range of 20-80 mm. With a small diameter of the hydraulic cylinder (20-30 mm), the volume of the cavities of the hydraulic cylinder was too small to create a significant pumping effect. In this regard, the recovered power was rather small and did not exceed 4 kW (figure 4a). At the same time, the unfavorable longitudinal acceleration of the semi-trailer was also small and amounted to 0.76 m/s$^2$ (figure 4b).

Figure 4. Influence of the inner diameter of the hydraulic cylinder $D_{hc}$ in the recuperative conical device on the average recuperated power $N_p$ (a) and the average value of the longitudinal acceleration of semi-trailer $a_{ac}$ (b).

If the diameter of the hydraulic cylinder $D_{hc}$ had been too large (70-80 mm), high forces were required to move the piston. This also reduced the pumping effect, so the recovered power $N_p$ was small (3.8-4.2 kW). In this case, a more rigid mechanical connection was formed between the timber tractor and the dismantling trailer. Because of this, the longitudinal acceleration arc of the semi-trailer was large (0.87-0.93 m/s$^2$). The optimal inner diameter of the hydraulic cylinder $D_{hc}$ was 50-60 mm. The pumping effect of the recuperation system was most pronounced with this diameter of the hydraulic cylinder providing the maximum recuperative power and the required smoothness of semi-trailer movement. The value of the recovered power $N_p$ was about 4.4 kW. The value of the longitudinal acceleration $a_{ac}$ did
not exceed 0.81 m/s².

The intensity of the oscillatory movement of the bodies in the mechanical system depends on movement speed \( v \) of a timber truck on an uneven supporting surface of a timber road. Therefore, the movement speed should have a significant effect both on the process of power recovery and on the damping of mutual oscillations of the system bodies in the recuperative bunk device. A series of computer experiments was performed in order to reveal the dependence of the influence of the movement speed \( v \) of a timber truck on the change in the efficiency indicators of the recuperation system. In these experiments, the speed \( v \) was changed with the same step of 10 km/h in the range of 10-60 km/h. With an increase in travel speed, the recovered power increased approximately according to the square law (figure 5a), and the unfavorable longitudinal acceleration of the semi-trailer – approximately linearly (figure 5b). The developed recuperation system provided a sufficiently high recuperative effect (from 2 to 14 kW) and a sufficiently low longitudinal acceleration (from 0.2 to 1.6 m/s²) in a wide range of speeds (from 10 to 60 km/h).

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**Figure 5.** Influence of the speed \( v \) of timber truck movement on the average recuperated power \( N_p \) (a) and the average value of the longitudinal acceleration of semi-trailer \( a_{ac} \) (b).

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The intensity of vibrations of the timber truck body and the log bundle depended on the height of the irregularities of the supporting surface of the timber road. The more pronounced the irregularities, the greater the recuperative effect could be expected, but the greater the unfavorable longitudinal accelerations of the bodies could be. A series of computer experiments were performed in order to study the influence of the average height of irregularities \( h_{aver} \) on the value of the average recovered power \( N_p \). In these experiments, the average height of irregularities varied with a step of 0.2 m in the range from 0-1 m. Therefore, it is advisable to equip a timber truck with a recuperation system when driving on a timber road with significant irregularities. If the recuperation system was able to allocate about 2 kW of power with an average height of irregularities of 0.2 m (figure 6a), then, with an average height of irregularities of about 0.6 m, it was already 6.6 kW of power (figure 6b). At the same time, the recuperation system provides an acceptable longitudinal acceleration (no more than 2.5 m/s²) in the entire investigated range of irregularities heights.

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**Figure 6.** Influence of the average height of the irregularities of the timber road \( h_{aver} \) on the average recuperated power \( N_p \) (a) and the average value of the longitudinal acceleration of semi-trailer \( a_{ac} \) (b).
4. Conclusion

A preliminary assessment of the efficiency indicators of the recuperative bunk device, carried out on the basis of computer modeling, made it possible to formulate the following conclusions:

- The highest recuperative power is achieved at values of the inner diameter of the hydraulic cylinder from 50 to 60 mm and the required smoothness of the semi-trailer relative to the hauling tractor is maintained;
- An optimal ratio between the recuperated power and the permissible change in the longitudinal acceleration of the dismantling trailer is ensured when a timber truck moves at a speed of 40 km/h;
- Not only a significant increase in the recuperative power, but also the maintenance of the required level of smoothness of semi-trailer relative to the hauling tractor occurs with an average height of obstacle irregularities on the timber road up to 0.4 m;
- The use of a recuperative bunk device in the design of a timber truck will significantly reduce the fuel consumption by a hauling tractor due to the recuperation of hydraulic energy.

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