System of adaptive transmission control in a trailer-truck with activated trailer link

Alexander Lepeshkin*, Il'ya Lepeshkin and Alexander Mihajlin
Moscow Polytechnic University, B. Semenovskaya str., 38, Moscow, 107023, Russia

*a.v.lepeshkin@mospolytech.ru

Abstract. The article describes the methodology of development of systems of automatic adaptive transmissions control of activated trailer links in the trailer-trucks providing the improvement of their cross-country ability and energy efficiency. The proposed method is based on the analysis of the results of the study of developed mathematical model of steady rectilinear motion of the trailer-truck with activated trailer link on the non-deformable bearing surface. Here are presented the results of mathematical modeling of the trailer-truck under consideration for different conditions of its operation, on the basis of which the law is formulated to regulate operating mode of the trailer link transmission to provide maximum energy efficiency of the trailer-truck. Presented technique can be recommended for use in creating such systems of automatic adaptive transmission control for other multi-drive transport and traction machines with stepless adjustable individual propulsion drive.

1. Introduction
Now in the real sector of the economy has been expanding the use of trailer-trucks, allowing to increase the performance of rolling stock and reduce transportation costs. The main disadvantage that limits the use of modern trailer-trucks is their low maneuverability, especially when driving on bad roads and off the road. As you know, this shortcoming can be minimized through enhanced trailed links of trailer-trucks. It is proved [1, 2] that it is most advisable to use stepless adjustable transmissions for the wheel drive of trailer links, namely: hydrostatic and electric drives, which possess a number of advantages compared with mechanical drives [3, 4].

This paper considers the hydrostatic transmission (HST) with automatic control system [3, 4, 5, 6] as the wheel drive of trailer link, regulating the power forwarded to the wheels. This allows the diversity of possible options for you to choose the mode of operation of the HST and, consequently, of the whole trailer-truck, ensuring maximum efficiency of "vehicle-engine-transmission-motor-bearing surface" system.

As the object of research here is an auto-timber truck KrAZ-643701 (6×6.2), consisting of a tractor with a traditional transmission with manual gearshift and trailer-dissolution GKB-9362, activated using HST. This trailer-truck is a vehicle with a combined transmission, in which at least two different types of drive are used to supply power for different groups of driving wheels.

In this trailer-truck, with a view to harmonizing the work of the driving wheels of the tractor and the trailer should be used the System of automatic adaptive control (SAAC) of stepless hydrostatic drive of the driving wheels of the trailer link. The technique of synthesis of regulatory law for this system is proposed in this article.
The structural layout in figure 1 was used when developing the mathematical description [7] of functioning of HST of driving wheels of the trailer. The steady rectilinear movement of the trailer-truck is considered.

![Figure 1](image1.png)

Figure 1. Structural layout of HST of the trailer link: 1 – ICE (internal combustion engine), mounted on the trailed link; 2 – adjustable pump; 3 – dual hydromotor; 4 – driving wheels of the trailer; 5 – adapting reducer; 6 – gauge of ICE operating mode; 7 – differential pressure sensor.

The system of equations constituting the mathematical description of the established work of HST of driving wheels of the trailer with the symmetrical load, includes a set of known [8, 9] expressions that define the magnitude of costs and losses in pipelines, as well as differential pressure in hydraulic machines. A distinctive feature of this description is to use formulas of K.I. Gorodetsky when evaluating losses in hydraulic machines [10]; these formulas determine the relative volumetric and mechanical losses in hydraulic machines, as well as their change in function of parameters describing their work. The selection of elements of HST (including hydraulic machines) of trailer link is based on traction-dynamic calculation on the methodology of "Bosch Rexroth", resulting in [11] the maximum working volumes of pump and hydraulic motors, as well as the necessary gear ratio of the matching gears $i_n$ and $i_u$ (figure 1).

2. Research results of the developed mathematical model
For the solution of mathematical models has been used the algorithm of calculation, taking into account the parameters of motion and external conditions that apply to an object of studies [7, 12, 13].

![Figure 2](image2.png)

Figure 2. The nature of the capacity changes being implemented when driving the trailer-truck, from the relative gear ratio of the trailer driving wheels $i_s$. 


Figure 2 gives examples of graphs of dependency of implemented capacity $N$ when driving the considered trailer-truck on 10-th degree rise with a cargo of 300 kN with a speed of 1.3 m/s on the size of the relative transmission ratio of the trailer driving wheels $i_x = \omega_x / \omega_{x1}$, where $\omega_{x1}$ is the angular speed of the rotation of the tractor driving wheels.

The graph (figure 2) uses the following designations of capability characteristics when driving the trailer-truck: 1 – power needed for towing the trailer-truck with the wheels disconnected from the transmission; 2 – power, which goes through the transmission of the trailer-truck to its driving wheels; 3 – total power consumed by two engines; 4 – power, exercisable on the input drive shaft of the leading link of the tractor; 5 – power consumed by the tractor engine; 6 – power, exercisable on the shaft of the dual hydroengine; 7 – the power consumed by the pump of the engine installed on the trailer.

Analysis of the results of the research showed [14, 15, 16], that efficiency of HST in considered conditions of driving does not exceed 0.87 and significantly reduces in the area of small values of transferred capacity.

The energy efficiency of the trailer-truck operation was estimated [14, 15] by the indicator $K_N$ representing the ratio of the power spent on towing of the considered machine with the wheels disconnected from the transmission when moving at a speed $V_x$ to the power that should be supplied from the engines of the machine through the transmission of the self-propelled machine to its driving wheels.

From the physical point of view, the coefficient $K_N$ is an integral energy indicator of the efficiency of the implementation of the developed total power $N$ by the engines of the machine, by its transmission and wheel motors.

As an example, in figure 3, there’s a graph describing the change of $K_N$ of the trailer-truck, depending on the relative gear ratio of the trailer driving wheels $i_x$ when driving in 10-th degree rise with a cargo of 300 kN with the resulting longitudinal speeds on the current gear.

![Figure 3](image)

**Figure 3.** Dependence of indicator $K_N$ of the trailer-truck on the relative gear ratio of the trailer driving wheels for calculated speeds: 1 – 1.3 m/s; 2 – 2.67 m/s; 3 – 4.52 m/s; 4 – 6.87 m/s.

Graphs (figure 3) show that in each particular case of the trail-truck driving there is such a $i_x$, in which the indicator $K_N$ has the maximum value. This value $i_x$ considered to be the best and is denoted $i_{opt}$ [17, 18, 19]. Many of these values form a curve of maximums $K_{N\text{max}}$ and many of points at which the calculated horizontal component of effort in a link of the trailer-truck is close to zero, form a curve.
$T_x$. On this basis, the SAAC should not choose the optimal operating mode of HST, which can ensure the forcing in the trail-truck link equivalent to zero.

3. Getting the law regulating the HST of the trailer driving wheels while rectilinear motion of the trailer-truck

Further studies concerned the determination of the HST operation mode and the entire trailer-truck corresponding to the optimal gear ratio $i_{opt}$ in these conditions. As a result, for each of these modes, the parameters characterizing the operation of the trailer-truck and its elements at the maximum value of the indicator $K_N$ were determined. Of all the parameters, the relative normal load $z_R$ on the trailer wheel and the pressure drop on the pump $\Delta p$ were selected, which can now be reliably controlled when the trailer-truck is moving in real operation conditions by known methods. The obtained data was used in the synthesis of the HST regulation law necessary to ensure such regimes [16, 17, 18, 19, 20].

In the result of research figure 4 presents the example of interdependences $R_z = f(\Delta p)$.

![Figure 4](image)

**Figure 4.** An example of interdependences $R_z = f(\Delta p)$, the implementation of which provides the maximum value of the indicator $K_N$ in the movement of the considered trailer-truck.

The graph (figure 4) shows the interdependence of the relative normal load $R_z$ on the trailer driving wheel from the pressure at the pump $\Delta p$ for the different size of the transported goods $G_x$ at a speed of $\sim 1.3$ m/s on the dry asphalt, fulfilling these conditions ensures the trailer-truck movement with the maximum value of indicator $K_N$. Here the indicator $R_z$ means the ratio of the normal load on the trailer driving wheel to this average load on all wheels of the trailer-truck in these driving conditions. At the same time, the set of points belonging to each of the dependencies presented on the graphs corresponds to the changing angle $\alpha$ of the road ascent overcome by the trailer-truck or the corresponding acceleration intensity.

As can be seen from the graph (figure 4), interdependences $R_z = f(\Delta p)$ were almost linear. On the graph next to each curve the mathematical expression is shown describing the relevant trend line. And, in all cases, the reliability rank of the approximation held exceeds the value $R^2 = 0.99$.

A similar result is obtained in a solution of the mathematical description of rectilinear steady movement of the considered trailer-truck at other speeds and in other movement conditions. In this
regard, in the synthesis of the law regulating the work of HST of the trailer driving wheels it is proposed to use the expression of the form:

$$\overline{R}_z = a \cdot \Delta p + b$$

(1)

where $a$ and $b$ are regression coefficients that depend on the operating conditions of the considered trailer-truck.

Studies have shown that the coefficients $a$ and $b$ depend on the relative normal load $\overline{R}_{z/M_s=0}$ on the trailer driving wheel when a moment $M_s$ equal to zero is implemented on this wheel. Moreover, the coefficient $b$ is numerically equal to the relative normal load $\overline{R}_{z/M_s=0}$, whereas $a$ – identified by represented on figure 5 polynomial dependencies of the form:

$$a = -k_2 \cdot \left(\overline{R}_{z/M_s=0}\right)^2 + k_1 \cdot \overline{R}_{z/M_s=0} - k_0$$

(2)

Regression coefficients $k_0, k_1, k_2$ for every polynomial (2) are identified on the graph (figure 5) for the polynomial curves obtained depending on the longitudinal velocity $V_x$ of the trailer-truck movement.

![Figure 5. The dependence of the coefficient $a$ of equation (2) on $\overline{R}_{z/M_s=0}$ for the different longitudinal velocities $V_x$ of the trailer-truck movement.](image)

Thus, the studies can make the basis for the proposed laws regulating the work of HST of the trailer driving wheels of the trailer-truck while rectilinear driving in conditions of not deformable bearing surface.

4. Conclusions

The developed method of synthesis of the law regulating the SAAC of the trailer driving wheels of the trailer-trucks, including automatic control of the ratio of the stepless adjustable transmission, enables the increase of tractive-energy properties of the trailer-truck in considered conditions of its operation.

This method can be recommended for use in creating such systems of automatic adaptive control of transmissions of other multi-drive transport and traction machines with stepless adjustable motors drive.
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