# Modeling the Load Mode of Transmission of a Heavy Truck in Case of Starting with a Clutch Release

N. Maltseva, V. Anchukov, A. Alyukov

*Abstract*— **The safety of the vehicle, its stability and controllability, as well as passability, attract the attention of a large number of researchers, testers and designers and are considered in the modern automobile industry as one of the strategic directions that determine the complex of the most important operational properties. In this regard, there is a need to study the dynamics of the movement of vehicles with the use of modeling tools. The article deals with the loading mode of the truck transmission for the typical case of operation - starting with a clutch release. A mathematical model of a truck with a 4x2 wheel arrangement is implemented, which helps to simulate the process of starting a vehicle with a clutch release.**

***Index Terms*— heavy truck, simulation, transmission, loading mode.**

## I. Introduction

The safety of the vehicle, its stability and controllability, as well as passability attract the attention of a large number of researchers, testers and designers and are considered in the modern automobile industry as one of the strategic directions that determine the complex of the most important operational properties. In this regard, there is a need to study and the dynamics of the movement of vehicle with the help of innovative computer modeling tools.

Simulation modeling of the process of vehicle movement is becoming more widespread in the world scientific practice. The main reason for this is the possibility of obtaining the necessary characteristics of the developed product without carrying out experimental measures, i.e. at the design stage, which positively affects the overall quality of the products and reduces its cost.

The work has been performed with the financial support of the Ministry of education and science of the Russian Federation as a part of complex project to create a high-tech production “Development of high-tech production of new generation energy efficient transmissions for trucks and buses” by agreement No. 02.G25.31.0142 d.d. December, 01, 2015 concluded between the Ministry of education and science of the Russian Federation and Public Joint-Stock Company “KAMAZ” in cooperation with the head executor “NIOKTR” - Federal State Autonomous Educational Institution of Higher Education “South Ural State University (National Research University)”.

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Currently, there are many approaches to modeling the dynamics of the vehicle, but not all of them are universal. Let's consider some of them.

In [1, 2], the authors developed mathematical models of heavy trucks. In [3] the mathematical model of bench tests of the car is presented, which allows simulating a number of standardized bench tests. The methods of simulation modeling are widely developed, they have been considered sufficiently in the following papers [4, 5, 6].

In the work of Keller A. V., Murog I. A. [7, 13] the authors solve the scientific problem of providing the required level of passability with the help of mathematical modeling.

Analyzing the works discussed above, it can be concluded that at the present time the issues related to the assessment of the dynamics of the vehicle movement taking into account the dynamic processes in all the main subsystems of the vehicle (engine, transmission, suspension and wheels) have not been fully studied. Thus, the creation of an adequate and sufficiently detailed model of motion is a completely logical stage in the development of the problem of estimating the dynamics of a vehicle.

## II. Mathematical model description

The dynamics of the movement of vehicles is a complex process, the study of which is advisable to break down into several main stages. It is proposed to begin with studying dynamics when starting, and at the next stage to investigate the dynamics of the vehicle's motion along the deformable ground with controlled power distribution mechanisms.

To conduct research, LMS Amesim software was used – the integrated 1D modeling platform for constructing and analyzing heterogeneous (multi-physical) intelligent systems and predicting their interdisciplinary characteristics, in which the components of the product are described by analytical models representing the interaction processes of mechanical, hydraulic, pneumatic and electrical subsystems.

To create a simulation model of the system in LMS Amesim, large set of library components from different physical areas is used. With the help of the software, a model based on physical processes was created, which in turn allowed to simulate the behavior of intelligent systems before the creation of detailed CAD geometry. For the correct and reliable realization of the model of the vehicle in the Amesim, the elements necessary for creating the model were studied and selected. From the selected elements, the model was collected and the necessary parameters were set. As a result, the model of a truck was fully realized, which was fully consistent with the real object.

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The creation of a model of a 4x2 wheeled truck begins with the study of its transmission. The development of the calculation model of the transmission began with the determination of the composition of nodes and elements, then all the parameters necessary for modeling and the transmission scheme were compiled.

The transmission consists of the following main elements:

- engine;
- clutch;
- gear box;
- main drive of the rear axle;
- differential of the rear drive axle;
- rear driving wheels.

Consider in more detail the processes that take place inside the machine during the start-up, as well as the main elements of the transmission.

The torque from the engine installed in the front of the vehicle is transmitted through the clutch onto the gearbox. From the gearbox, the torque is transmitted through the cardan gear to the rear drive axle, inside which the main gear is housed, the differential and the axle of the drive wheels. The vehicle starts to move in lower gears with a increasing frequency from idling to the maximum speed of the engine's crankshaft.

The clutch of the vehicle is located between the engine and the gearbox. It is intended for a short-term detachment of the engine from the transmission and their smooth connection when changing gears, as well as protecting the transmission elements from overloading and damping of vibrations.

Clutch has two modes of operation:

1) clutch is off, i.e. engine and transmission are not connected. At this time, the torque is not transmitted from the engine to the gearbox, which allows to switch gears without jerking or stalling the engine;

2) clutch is on, i.e. engine and transmission are connected. At this time there is synchronization of the engine torque with the gearbox, due to the friction of the flywheel.

The clutch model is a mathematical model of the transmission of torque with the help of frictional forces of rotating clutch parts (disks). Mass moments of inertia of rotating parts are taken into account in the model. The control action is a binary signal: 0 - corresponds to the engaged clutch state, 1 - to the disabled state. In this case, it is possible to realize intermediate states of cohesion, i.e. incomplete on or off.

The law of increasing frictional moment in the clutch is modeled in the corresponding block (No. 16 in Figure 1), determined by the type and parameters of the drive and described with sufficient accuracy by the exponential dependence:

$$f_c = 1 - e^{-kt},$$

where k - constant characterizing the rate of engagement of the clutch ($k$=3/$t_c$), $t_c$ - time of full clutch engagement.

For the clutch of KAMAZ vehicles, the time for full engagement is set to $t_c$ = 0.1 s [9].

The main transmission block (No. 15 in Figure 1) is a physically oriented operator of the mechanics library of the LMS Amesim package operating on the principle of a reducer. The main parameter is the gear ratio, the amount of which increases the torque and reduces the speed of rotation. A similar operator is used to convert the torque in the gearbox.

The differential is designed to transfer, change and distribute the torque between the two half-axles, combined with the wheels, and provide, if necessary, their rotation with different angular speeds. The differential is used to distribute the power that is to be transmitted from the engine to the wheel.

Developed mathematical model in LMS Amesim is shown on Figure 1.

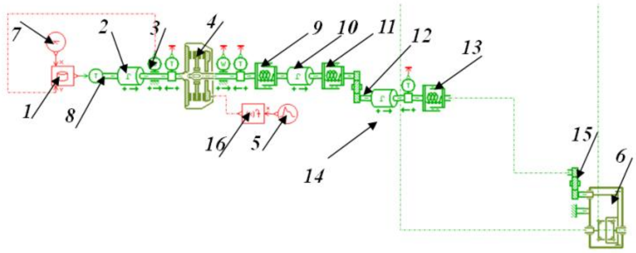


Figure 1 – Developed mathematical model in LMS Amesim

Here, 1 - external speed characteristic signal; 2 - reduced moment of inertia of the engine; 3 - sensors that measure the engine speed and torque; 4 - clutch; 5 - a signal of inclusion of clutch; 6 - the inter-wheel differential; 7 - a signal of fuel supply; 8 – engine torque; 9, 11, 13 - the elastic elements of the transmission; 10, 14 - given moments of inertia at an input and an output shafts of transmission; 12 - gear ratio; 15 - main gear; 16 – clutch friction moment.

After the creation of the transmission model and its debugging, the next stage of modelingis the creation of the chassis of the car, as a system consisting of sprung and unsprung masses. For this purpose, the mass-inertial characteristics of the vehicle were determined, such as the coordinates of the center of gravity. The sketch of the complete model is shown in Figure 2.

The car body model is a solid body with corresponding mass-inertial characteristics, to which external influences, determined by the driving regime, are transmitted.

In the model of spatial motion of the vehicl, a tire model is used from the library of the LMS Amesim package. The model uses a complex approach to describe the interaction of the wheels with the road. The model is described with sufficient accuracy using the formula "Pacejka 1989" [12] and is implemented in this model, the type of pavement and microprofile are specified by the elements "Roadmodel" and "Adherence generator" (Figure 2).

This submodel represents the "tire-road" interaction with vertical force and longitudinal component of the force arising from the contact of the pneumatic tire with the road surface, due to rolling resistance and road obstacles taken into account. The longitudinal force depends on the vertical load. The vertical force is calculated taking into account the rigidity of the suspension, the wheels and the location of the center of gravity of the body. The connections of the car's wheels to the road's supporting surface are described by equations that take into account only elastic sliding (the wheels do not detach from the road).

Different road conditions are simulated with the help of specially oriented library elements (Figure 3), which allows

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to set different laws for changing and distributing the coefficient of adhesion and road micro profile. In the studied case, the type of road surface is dry asphalt with a coefficient of adhesion of 0.8, and the microprofile of the road is a straight road.

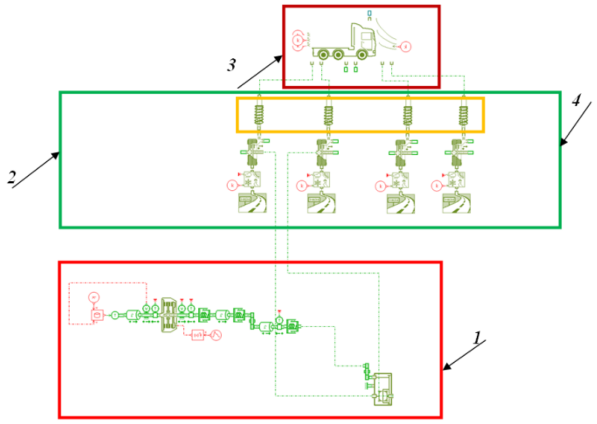


Figure 2 – Coordinate frames assignment of a 6WD truck
1 - engine-transmission unit, 2 - chassis, 3 - car body, 4 - suspension

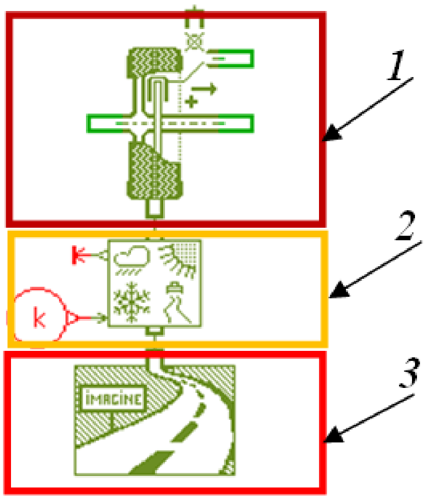


Figure 3 – Model of wheel-road interaction
1 - wheel model, 2 - model describing the type of pavement, 3 - model describing the microprofile of the pavement

For carrying out virtual tests and estimating the dynamics of the vehicle's movement, the following mode of driving was chosen: the vehicle starts moving on the road surface with a coefficient of adhesion of 0.8, which corresponds to the movement of off-road tires on the asphalt-concrete road surface. When simulating the starting process in the initial state, the vehicle is on an even horizontal section at rest. With idle speed (800 rpm), when the clutch pedal is depressed and the acceleration pedal is set to the limit, the engine is accelerated to the maximum speed of 2300 rpm of the crankshaft. Acceleration of the engine takes about 0.3 s. The first gear of the lowered gearbox is engaged. The engine torque is set by the external speed characteristic. Starting from 0.3 seconds, the clutch is engaged (Figure 4). The process takes 0.1 s. At the same time, the dynamic process of starting the vehicle begins.

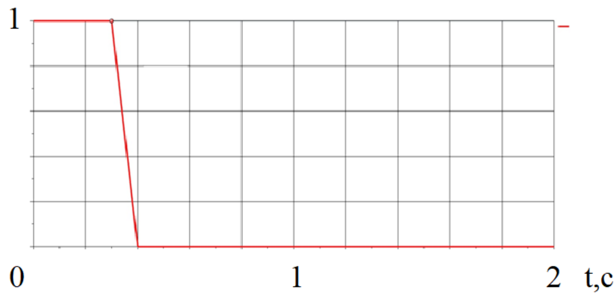


Figure 4 – The clutch engagement schedule (1 - off, 0 - on)

Graphical representation of the obtained results can be seen in Figures 5 and 6, 7, 8.

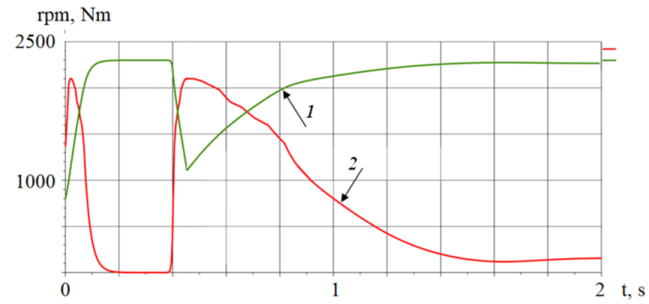


Figure 5 – Dependence of the torque (1) and the rotational speed (2) of the engine when starting with a clutch release

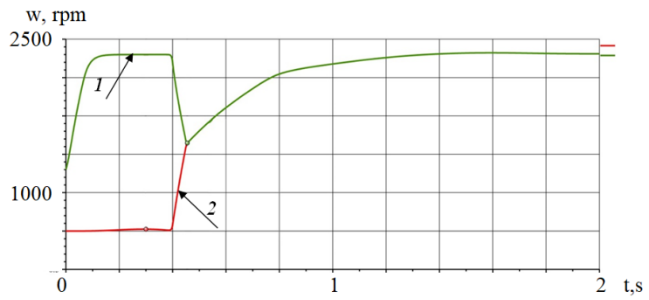


Figure 6 – Dependence of the angular velocities (1 – engine shaft rotational speed, 2 – rotational speed of the driven clutch disc)

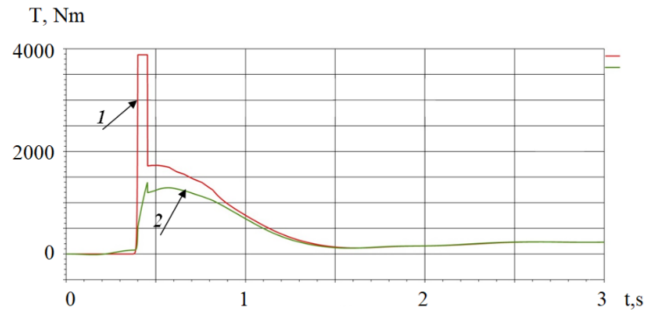


Figure 7 – Dependence of the torques when starting with the clutch release
(1 - the torque acting on the driven clutch disk, 2 - the friction torque of the clutch)

Figure 5 shows that at the moment of releasing the clutch the torque of the engine's crankshaft reaches a maximum value of 2100 N • m at 1109.2 rpm. This means that the external speed characteristic and the regulatory branch of the external characteristic are correctly taken into account: At a speed of rotation above 2000 rpm, the regulatory branch switches on and a sharp linear reduction of the torque to zero occurs at a maximum speed of 2300 rpm.

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Then there is an adequate change in the torque with a change in the engine speed of the crankshaft.

Figure 6 shows that after full engagement of the clutch at the 0.4th second of the simulated process, the angular velocity of the driven clutch disc begins to increase. In this case, the engine speed of the crankshaft and the drive clutch disc begin to fall. At the 0.455 second of the simulation, the speed of rotation of the friction discs becomes equal, the clutch closes. Further, the clutch disks rotate at the same angular velocities, without slipping.

In Figure 7, a sharp increase in the friction torque of the clutch can be seen as it starts, starting at 0.38 second. The frictional torque rises to its limiting values and remains constant until the clutch closes. When the clutch closes at 0.455 second, the frictional torque drops to values slightly less than the torque on the engine, with the difference in torque being spent on accelerating the flywheel and the crankshaft. After acceleration of the car, its speed is stabilized, and the moments noted above are equalized and reduced to steady values corresponding to the total moment of resistance from the friction forces applied to the driven clutch disk. In general, the characteristic of the engine, depending on the mode of operation, is a region bounded by branches of external and regulatory characteristics (Figure 8).

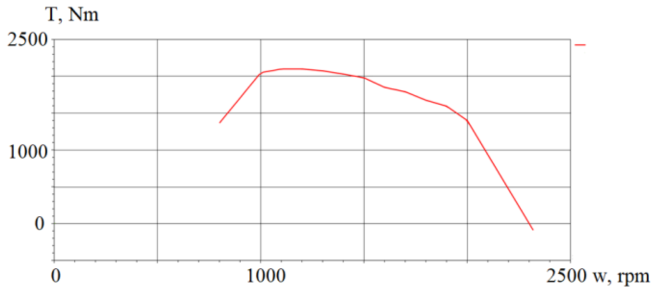


Figure 8 – Static engine characteristic

The results of virtual tests confirmed the overall performance of the model and the transmission of the vehicle. With the gradual release of the clutch pedal, the flywheel and the driven clutch plate are brought into contact. The torque from the engine is transmitted to the transmission, resulting in the rotation of the driven clutch disc. Elements of the transmission are twisted to some angle. When the flywheel and the clutch plate are in contact, the engine speed drops. A further increase in the clamping force between the flywheel and the driven clutch plate results in a comparison of their angular velocities and the closure of the clutch. The vehicle moves at a certain speed without slipping.

## III. Conclusion

Using the simulation method, the dynamics of the vehicle's movement during starting was studied. Experimentally proved the effectiveness of methods of computer modeling complex dynamic processes. The result is a developed adequate and reliable mathematical model of a truck with a wheel formula 4x2. The developed mathematical model of the truck allows to estimate the general dynamics of the vehicle when starting. The model takes into account the external dynamics of the car, the dynamics of all major units and nodes. By simulating a typical mode of motion, the dynamic loading of the transmission at the moment of starting from the place is estimated. In the course of the study, a direct calculation was made of the maximum dynamic torque on the input shaft of the main drive of the rear drive axle, which was 19740 Nm. Thus, the direct calculation of the dynamic torque gives lower values than the empirical relationship. At the same time, the moment obtained by the direct calculation method exceeds the time limited by the coupling properties of the road surface by 1.31 times. The obtained calculation results allowed to estimate the values and character of load distribution.

## References

[1] González-Cruz, C., Jáuregui-Correa, J., López-Cajún, C. et al., "Dynamic Behavior and Synchronization of an Automobile as a Complex System," ASME 45837, vol.1, 2014.

[2] Annicchiaricom, C., Rinchi, M., Pellari, S. and Capitani, R., "Design of a Semi Active Differential to Improve the Vehicle Dynamics," ASME 45837, vol.1, 2014. 5.

[3] Assadian, F., Hancock, M., Herold, Z., Deur, J. et al., "Modeling and Experimental Validation of Active Limited Slip Differential Clutch Dynamics," ASME 48784, 2008, pp. 295-304.

[4] Vantsevich, V. and Shyrokau, B., "Autonomously Operated Power-Dividing Unit for Driveline Modeling and AWD Vehicle Dynamics Control," ASME 43352, 2008, pp. 891-898.

[5] Federico Cheli. Integrated modeling of vehicle and driveline dynamics / Federico Cheli, Marco Pedrinelli, Andrea Zorzutti // ASME 8th Biennial Conference on Engineering Systems Design and Analysis. – 2006. – Vol. 2, pp. 235-244.

[6] Keller, A., Murog, I. and Aliukov, S., "Comparative Analysis of Methods of Power Distribution in Mechanical Transmissions and Evaluation of their Effectiveness," SAE Technical Paper 2015-01-1097, 2015, doi:10.4271/2015-01-1097.

[7] Dubrovskiy, A., Aliukov, S., Dubrovskiy, S., and Alyukov, A., "Basic Characteristics of Adaptive Suspensions of Vehicles with New Principle of Operation," *SAE Int. J. Commer. Veh.* 10(1):2017, doi:10.4271/2017-01-0404.

[8] Keller, A. and Aliukov, S., "Analysis of Possible Ways of Power Distribution in an All-Wheel Drive Vehicle," in Lecture Notes in Engineering and Computer Science: World Congress on Engineering 2015, pp. 1–5.

[9] Keller, A. and Aliukov, S., "Rational Criteria for Power Distribution in All-wheel-drive Trucks," SAE Technical Paper 2015-01-2786, 2015, doi:10.4271/2015-01-2786.

[10] Keller, A., Aliukov, S., Anchukov, V. and Ushnurcev, S., "Investigations of Power Distribution in Transmissions of Heavy Trucks," SAE Technical Paper 2016-01-1100, 2016, doi:10.4271/2016-01-1100.

[11] Reza N., "Vehicle Dynamics: Theory and Application," Spring, 2012, 455 p.

[12] PACEJKA, H. B. «The tyre as a vehicle component» / PACEJKA, H. B. FISITA – Congress Prague – june 16–23th 1996.

[13] Murog, I., Scientific methods of improving transmission and steering in the modernization of multi-purpose vehicles / PhD thesis/ Chelyabinsk, 2013.

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