Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 97 **2017**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2017.97.11

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Melnychuk, S., Vitiuk, I., Bovsunivskyi, I., Beherskyi, D., Kubrak, Y. Vehicle suspension system modelling and simulation in the SolidWorks software environment with motion analysis applications. *Scientific Journal of Silesian University of Technology. Series Transport*. 2017, **97**, 117-130. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2017.97.11.

Serhiy MELNYCHUK[1], Ivan VITIUK[2], Ihor BOVSUNIVSKYI[3], Dmytro BEHERSKYI[4], Yuriy KUBRAK[5]

VEHICLE SUSPENSION SYSTEM MODELLING AND SIMULATION IN THE SOLIDWORKS SOFTWARE ENVIRONMENT WITH MOTION ANALYSIS APPLICATIONS

Summary. An N1 vehicle model is created, which allows for changing suspension parameters and conditions of experimental performance. A methodology of computer testing performance for vehicle ride comfort and stability service properties' characterization in a virtual environment is proposed. Vehicle suspension system modelling and simulation are performed. The results of the N1 vehicle suspension system from full-scale laboratory and road tests are given.

Keywords: stability; ride comfort; testing methodology; vehicle suspension; cushioning; roll; vibration frequency

[1] Department of Automobile and Transport Technologies, Zhytomyr State Technological University, 103, Chernyakhovskogo Str., 10005 Zhytomyr, Ukraine. E-mail: sergij.m@mail.ru.
[2] Department of Automobile and Transport Technologies, Zhytomyr State Technological University, 103, Chernyakhovskogo Str., 10005 Zhytomyr, Ukraine. E-mail: vnvik74@gmail.com.
[3] Department of Automobile and Transport Technologies, Zhytomyr State Technological University, 103, Chernyakhovskogo Str., 10005 Zhytomyr, Ukraine. E-mail: bovigorbov@gmail.com.
[4] Department of Automobile and Transport Technologies, Zhytomyr State Technological University, 103, Chernyakhovskogo Str., 10005 Zhytomyr, Ukraine. E-mail: begerskiy@gmail.com.
[5] Department of Automobile and Transport Technologies, Zhytomyr State Technological University, 103, Chernyakhovskogo Str., 10005 Zhytomyr, Ukraine. E-mail: kubrak79@ukr.net.

1. INTRODUCTION

Given that, in the process of building mathematical models of vehicle motion or its suspension systems, designers and engineers face difficulties in relation to copious factors, simplifications are often applied. In the majority of cases, introducing simplifications can significantly affect a product. Taking into an account this fact, along with modern scientific progress, computer technological development, advances in powerful engineering software products for difficult mechanical systems and process descriptions, computer modelling and simulation are used for new machines and assembly engineering.

Computer modelling and simulation significantly speed up manufacturing processes at the planning stage, allow for tests to be performed with the possibility to change a design and provide test conditions that increase the quality of a product, promotes its implementation and reduces its price.

Even at the planning stage, modern methods of vehicle development allow for researching and developing cushioning and vibrodamping systems, while estimating such characteristics as ride comfort, stability and carrier system load by means of computer modelling and simulation [3]. Methods of computer modelling and simulation can account for a majority of suspension parameters that influence vehicle operation and its motion safety.

Modelling task priority lies in the definition of system work parameters and the explanation of processes, which regulate recognition and definition.

2. LITERATURE REVIEW AND PROBLEM STATEMENT

The analysis of recent publications confirms that computer modelling and simulation are important parts in the study of systems' technological processes.

The modern market proposes a wide range of computer-aided design (CAD) software products. Therefore, one of the most critical tasks involves the choice of the software environment that will satisfy the needs of designers, engineers and executives.

Software must ensure a project's design execution speed, a great source of software, a wide range of parametric characteristics, the quality of the work performed, simplicity and ease of professional service, work reliability, an easy mastering process, and constant improvement. The most popular CAD systems in engineering were studied, with their possibilities analysed and software packages compared, including their features and functional peculiarities. In turn, the most appropriate system to meet modern demands for software products created for home engineering enterprises was defined.

Nowadays, the most popular CAD systems include SolidWorks, T-Flex and Компас, all of which satisfy appropriate needs and requirements and are more often used in engineering.

SolidWorks CAD software, manufactured by the SW Corporation, offers 3D design solutions of parts and assemblies with possibilities to perform analyses of different types and create design documentation.

In [6,7,8,9,11], a wide range of CAD usage possibilities are presented in order to model and simulate assemblies' interaction processes, as well as define basic development and existing simulation models' improvement streamlines. On the ADAMS/Car platform, a module to analyse vehicle motion stability has been developed. The software allows for changing suspension stiffness and damping parameters, the centre of mass etc. It enables software users to input values of parameters for different types of vehicle. But the software has many disadvantages as well, including the simplification of many processes, which significantly affects the end result.

Notwithstanding a large amount of the literature dedicated to the vehicle and its components modelling and simulation, the issue of defining dependence of parameters of vehicle ride comfort and stability on the quality of the work of its suspension system needs further investigation. Moreover, existing models partly reflect processes in the suspension systems.

3. AIM AND OBJECTIVES OF THE STUDY

The aim of this paper is to forecast parameters of N1 vehicle ride comfort and stability by means of computer modelling and simulation in the process of suspension system design. The research objectives in this study are listed as follows:

- To develop a computer model of N1 vehicle motion, which allows for investigating ride comfort and stability and accounting for design parameters of the suspension system.
- To perform laboratory and road tests of the N1 vehicle suspension system.
- To create a computer model and simulation of the N1 vehicle suspension system under conditions similar to the performed full-scale tests and to compare results in order to state the adequacy of the computer model.
- To use the developed computer model in order to investigate the designed suspension system on the basis of a four-bar linkage assembly.

4. MATERIALS AND METHODS OF THE STUDY OF OPERATIONAL PARAMETERS OF AN N1 VEHICLE: RIDE COMFORT AND STABILITY

A vehicle was chosen as a simulation model on the basis that it is widely used in cities due to its mobility and versatility. The cargo and passenger vehicle peculiarity involves significant pressure difference in the sprung mass, which mostly occurs in the rear axle (loaded-unloaded), while its operation in cities includes a turn, a three-point turn and road positioning. Therefore, there are high expectations of ride comfort and stability provision under different operational conditions with such a vehicle.

For the purposes of the study, a full-size simulation model of the experimental N1 vehicle was developed with all its operational qualities. The Izh 2715 was chosen as an experimental vehicle. All the necessary parameters and dimensions for developing a simulation model were measured on this vehicle

The structural scheme represents simulation model components in Fig. 1.

The analysis of modern scientific works on N1 vehicle simulation model development and modelling and simulating mechanical systems interaction has shown that, among a large number of CAD products, the SolidWorks CAD software, manufactured by the SW Corporation, is one of the most powerful and polyfunctional products.

SolidWorks software is developed for designing parts and assembles, creating drawings, and testing performance to obtain different types of data. The main advantage of this system is that the most powerful manufacturers in the world have chosen it as standard. With powerful SolidWorks solutions, modern machines and transfer lines are designed and produced within automobile manufacturing enterprises. Unification reduces service and logistics costs, while raising product quality.

To model and simulate vehicle motion kinematics parameters, the Motion Analysis application was used, which is intended for modelling and simulating dynamic systems in the SolidWorks software environment and for assemblies' motion simulation with allowance for kinematics and force factors. The application is fully integrated with SolidWorks and creates a geometric model, while calculation parameters and results notation are also carried out in the SolidWorks model.

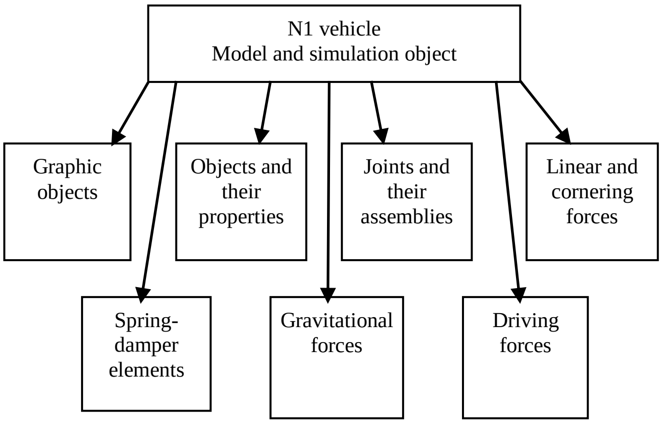

Fig. 1. The structural scheme of the vehicle simulation model components

The data input procedure that was defined in order to create a model is shown in Fig. 2.

Next, the SolidWorks assembly was analysed by means of the Motion Analysis application, while its conversion to a nominal model was performed with the parts' mass-inertia characteristics taken into account. The inertia parameters were taken from the SolidWorks parts geometry, with the density parameter set for each element separately, irrespective of the geometric form. Then, a motion differential equation set was proposed, which was later solved by means of a difference scheme. Subsequently, the software displayed the processed numerical results in a form suitable for representation. At this point, the system again interacted with real geometry. The computational kinematics model representation (in the form of thumbnails) and results were performed in the SolidWorks graphics window on the background of the SolidWorks assembly.

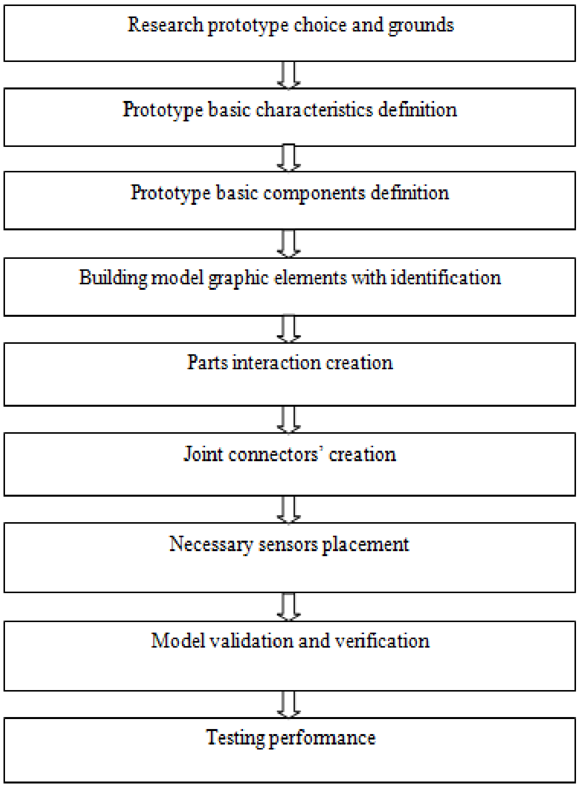

Fig. 2. The model building procedure

5. RESULTS

5.1. The study of N1 vehicle stability using a simulation model

The study of N1 vehicle stability was performed on the basis of the developed computer model.

From the laboratory measurements [2], the vehicle suspension system's basic characteristics were obtained, which were used for the main virtual model of an experimental vehicle in SolidWorks Motion, along with the basic suspension system and the suspension system, on the basis of the four-bar linkage assembly.

These models (Fig. 3) include the vehicle and its elements, along with all the mass-geometric parameters, inertia forces, friction in the levers, damping elements, friction of a tyre with a bearing surface, gravitational forces and other parameters.

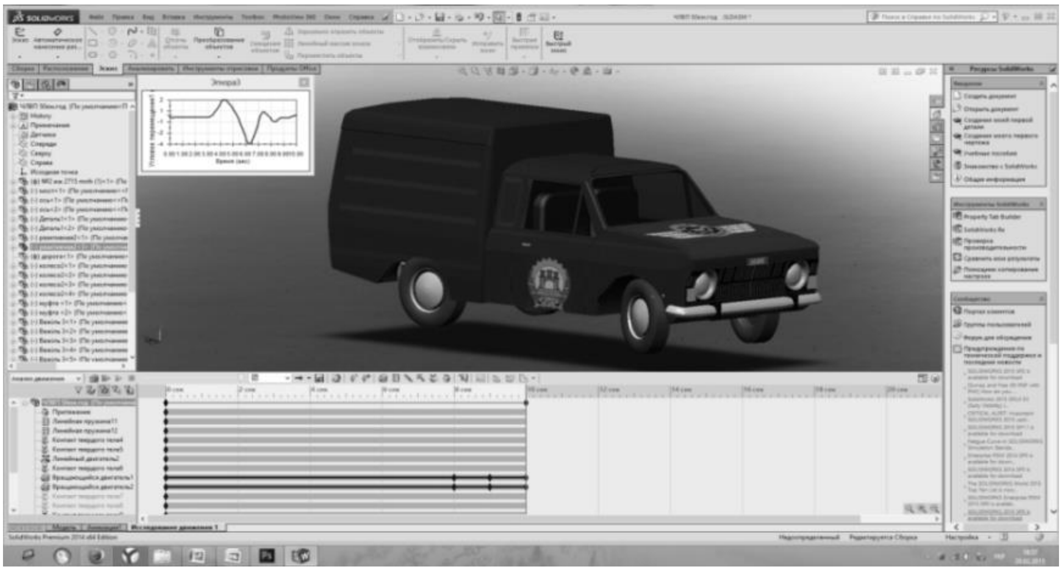

Fig. 3. N1 vehicle computer model developed to study ride comfort and stability parameters

The simulation model was developed in such a way that, at the beginning of the research, the vehicle moved parallel to the X-axis, which was directed along a road. The N1 vehicle motion was studied at the time interval t=10 s until the vehicle came to a complete stop. As a result of numerical modelling by means of SolidWorks Motion, we obtained data on the vehicle body position at any time with an interval part of 0.04 s at the 10-s interval [10].

We performed the research on the vehicle dynamic model with visualization, which allows for representing a model's characteristic movement along the designed part of the road in accordance with the applied kinematics and force constraints and limitations.

The methodology was developed on the basis of GOST 52302-2004 in order to perform computer testing of a "20-m sharp lane change" (Fig. 4). According to the proposed methodology, the vehicle gained the necessary fixed speed and performed the "20-m sharp lane change" manoeuvre without braking and speeding-up over a 20-m road distance, with a 7-m road width.

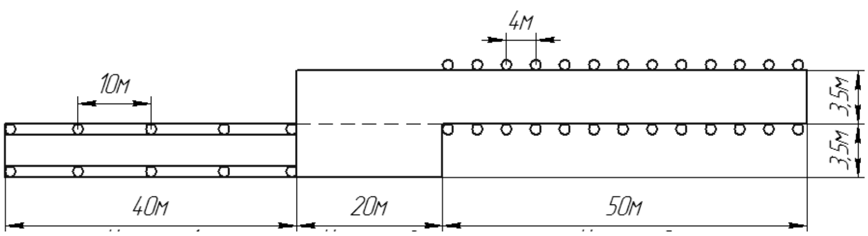

Fig. 4. The testing performance scheme for the "20-m sharp lane change"

The developed methodology allowed us to perform testing at different speeds with different vehicle workloads. The testing of a "20-m sharp lane change" by the vehicle model was performed at a speed of 20-50 km/h with a speed part of 5 km/h (Fig. 5). In the process of testing, a virtual angular movement sensor, which was placed on the vehicle model body and operated relative to the bearing surface, was used for the vehicle body roll registration.

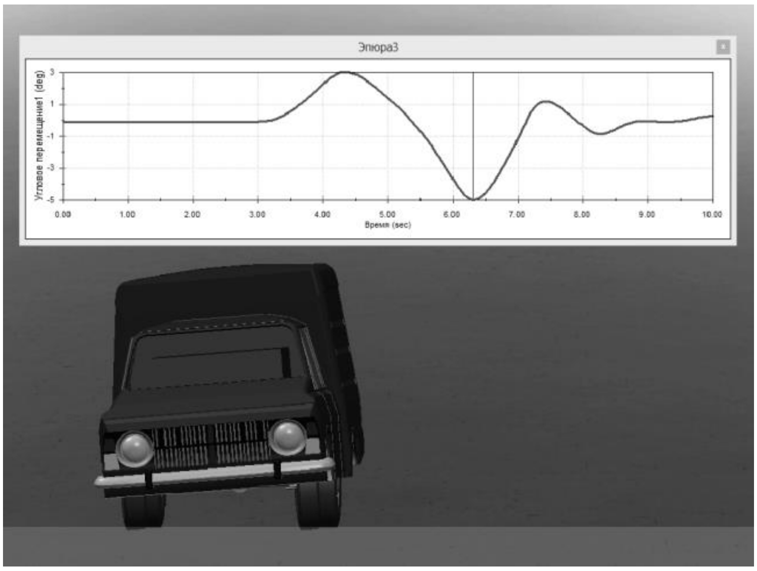

Fig. 5. The testing performance: the vehicle body rolled with the factory-made suspension system in the process of the “20-m sharp lane change” manoeuvre performance

Comparative graphs were created according to the performed computer and road testing (Figs. 6-7). In the process of the “20-m sharp lane change” manoeuvre performance at the speed of 50 km/h, the vehicle body roll with the factory-made suspension system added up to 4.24°, while that involving a suspension system on the basis of a four-bar linkage assembly amounted to 3.09° under the same conditions in the process of the manoeuvre performance.

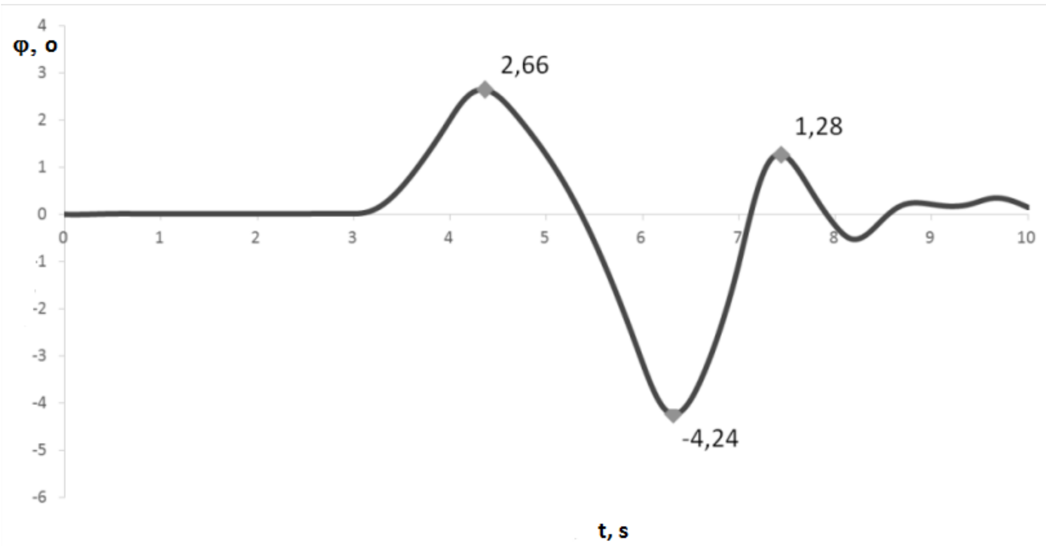

Fig. 6. The vehicle body roll with the factory-made suspension system in the process of the “20-m sharp lane change” manoeuvre performance

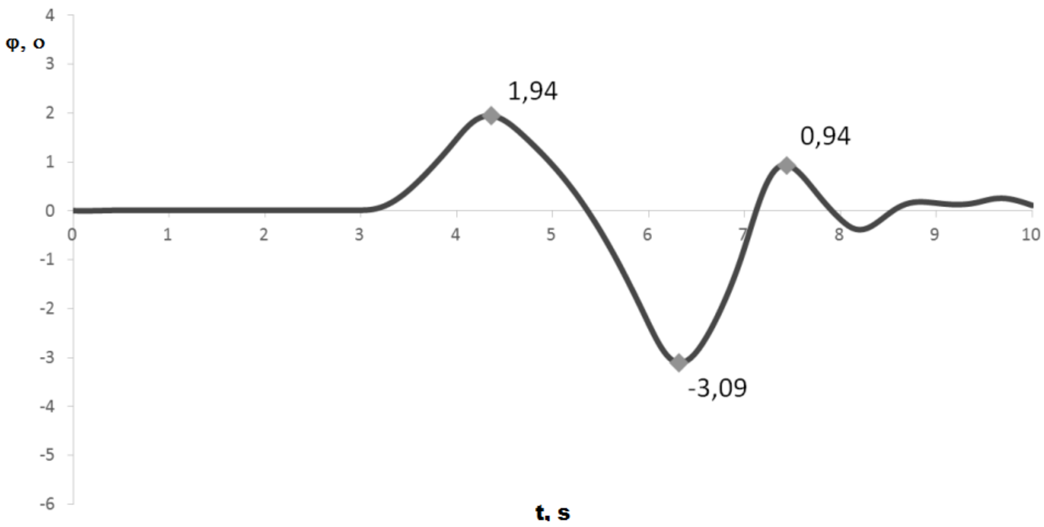

Fig. 7. The vehicle body roll with the suspension system on the basis of the four-bar linkage assembly in the process of the “20-m sharp lane change” manoeuvre performance

5.2. The study of N1 vehicle ride comfort using a simulation model

Using the developed computer simulation model, we investigated N1 vehicle ride comfort by means of a drop test method (Fig. 8).

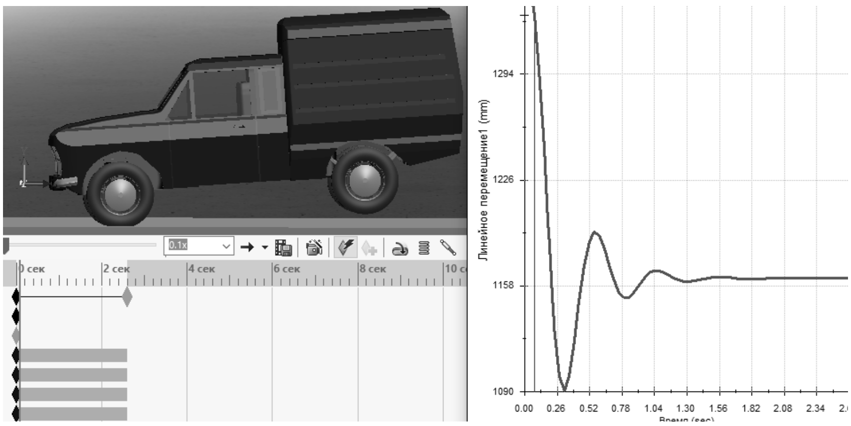

Fig. 8. The test performance: the drop test

To perform the computer simulation testing, the following vehicle computer research procedure by means of the drop test method was used [1,2]:

- The vehicle model was set on the virtual flat horizontal plane.
- The front wheels were fixed and did not turn.
- The front suspension system was fixed and did not vibrate.
- The virtual movement sensors were set.
- It was essential for the rear wheels’ height to comprise 55-65 mm relative to the measurement plane.
- The vehicle model was dropped, and the sprung and unsprung mass vibration process was fixed.

- The tests were repeated with a model load of 25, 50 and 75, and 100% of the vehicle load carrying capacity.
- Vibration process parameters were reported by means of the movement sensor embedded into the Motion module.

The testing was performed for both the vehicle with the factory-made suspension system (Fig. 9) and the one with the suspension system on the basis of the four-bar linkage assembly (Fig. 10).

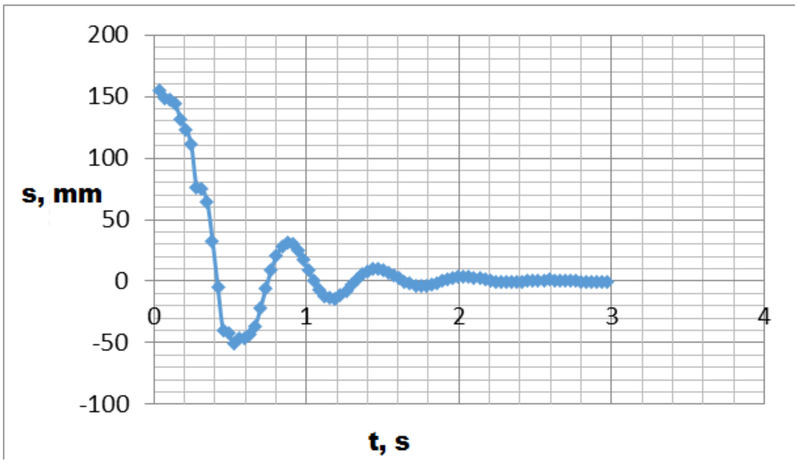

Fig. 9. The dependence of the vertical vibration displacement, which took place in the process of free vibrations of the sprung mass of the vehicle with the factory-made suspension system

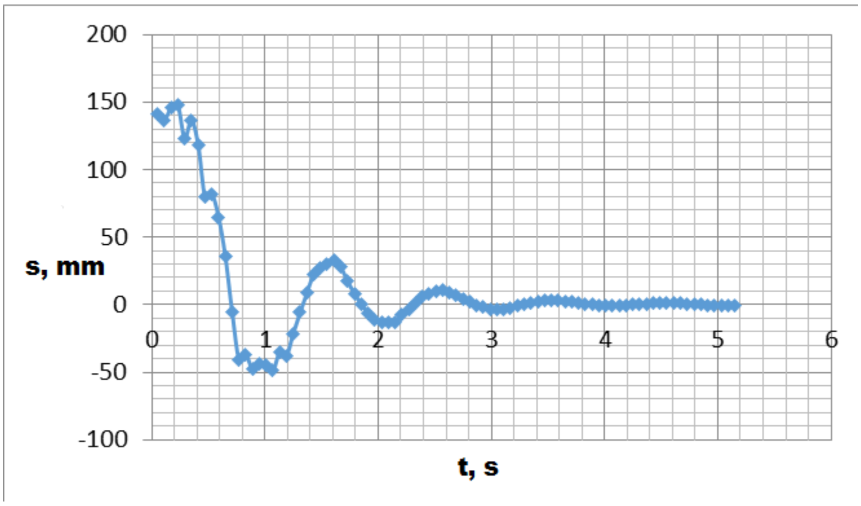

Fig. 10. The dependence of the vertical vibration displacement, which took place in the process of free vibrations of the sprung mass of the vehicle with the suspension system, on the basis of the four-bar linkage assembly

For the vehicle with the factory-made suspension system, the free vibrations frequency of the sprung mass changed in the range from 1.33 to 1.8 Hz, according to the quantity of the vehicle body load. The value of 1.33 Hz referred to the entirely loaded vehicle, and the value of 1.8 Hz referred to the unloaded vehicle, which corresponded to the actual values of the free vibrations frequency of N1 vehicles with the factory-made spring suspension system.

For the vehicle with the suspension system, on the basis of the four-bar linkage assembly, the values of the free vibrations frequency changed in the range from 0.8 to 1.05 Hz under the same conditions.

The obtained data on the computer modelling and simulation of the vehicle model with different types of suspension systems pointed to the proposed model adequacy and the fact that, even under the limited conditions of the computer research, the suspension system, on the basis of the four-bar linkage assembly, operated in the expected frequency range.

5.3. The road testing of N1 vehicle stability

To validate and verify the available theoretical computer and mathematical stability studies, we decided to perform a full-scale testing of the factory-made suspension system of the experimental vehicle. For this purpose, we developed a methodology for the road testing of the "20-m sharp lane change" manoeuvre on the basis of GOST 52302-2004.

According to the proposed methodology, in a similar manner to the computer testing, the vehicle gained the necessary fixed speed on the hard bituminous concrete surface and performed the "20-meter sharp lane change" manoeuvre without braking and speeding-up over a 20-m road distance, with a 7-m road width, as previously indicated in the scheme (Fig. 4).

For recording vehicle motion speed, a reed sensor was used, which was placed on the vehicle drum and sent signals to the computer by means of an analogue-to-digital converter. For recording the vehicle body roll change, a gyro sensor was used, which was placed in the vehicle body above the rear axle. The testing was performed at a speed of 20-50 km/h with a speed part of 5 km/h. The vehicle body load was created by sacks containing 25 kg of sand. To improve accuracy, we repeated the testing four to five times under the same conditions. For the purposes of visual control and analysis, we also recorded the experiment with a high-speed camcorder with a frequency of 60 frames/second. We obtained the results in the form of graphs (Fig. 11).

The graph shows that, in the process of road testing, the vehicle body roll amounted to 4.42° at a speed of 50 km/h under conditions similar to those of the computer testing.

5.4. Full-scale laboratory testing of N1 vehicle ride comfort

To validate and verify the computer modelling and simulation by means of the drop test, we decided to carry out laboratory testing on the experimental vehicle using the same test.

For this purpose, we developed a procedure similar to computer testing, which included the vehicle rear axle dropping on the hard horizontal surface. The front axle was preliminarily fixed and did not turn or vibrate (in order to avoid swinging and obtain free vibrations of the vehicle rear axle). It was also necessary to fix an accurate ballast placement directly and evenly above the rear axle. For recording free vibrations, a high-accuracy accelerometer was used, which was placed in the middle of the body above the rear axle. To process a signal, the accelerometer data were sent to a special board, which communicated the signal to a personal computer. The data of the vertical vibration acceleration of the vehicle rear axle appeared on the personal computer by means of the special program (Fig 12).

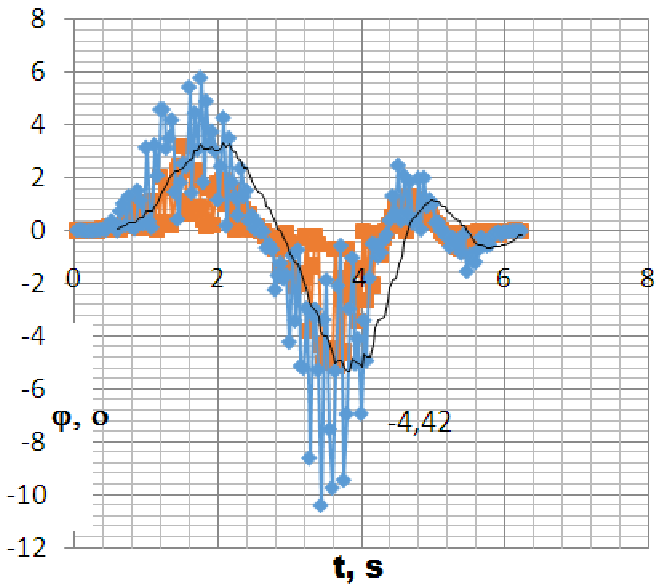

Fig. 11. The road testing: the vehicle body roll with the factory-made suspension system in the process of the "20-m sharp lane change" manoeuvre performance

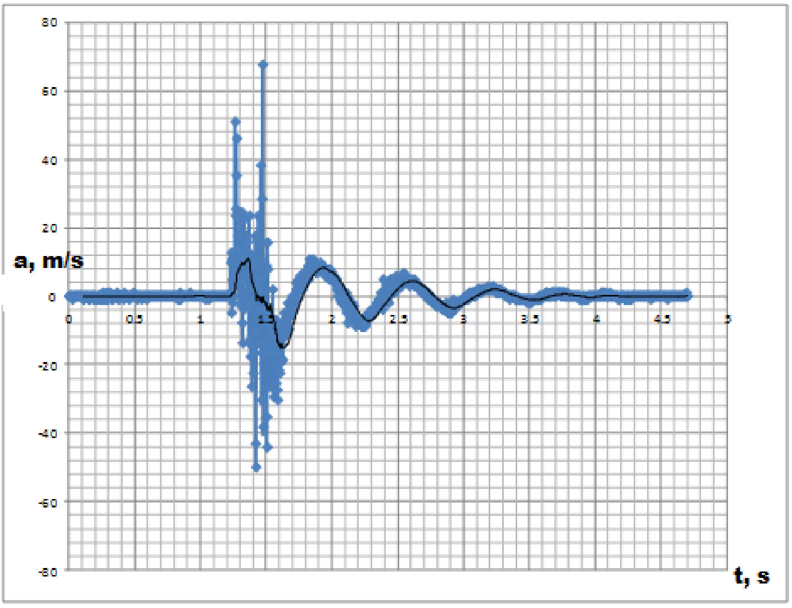

Fig. 12. The laboratory testing by means of the drop test: the vibration acceleration of the rear axle of the vehicle with the factory-made suspension system

The obtained experimental data validated both the theoretical calculations and the results of the computer modelling and simulation. Under the same conditions, the factory-made suspension system operated in the range of 1.33 to 1.67 Hz, while the proposed system, on the basis of the four-bar linkage assembly, operated in the range of 0.91 to 1.17 Hz. In comparison with the computer model, the regularity of distribution of the operating frequencies, at which the suspension systems being studied operated, remained. This validated the chosen procedure and validated the necessary evidence resulting from the performed research.

6. DISCUSSION OF THE RESEARCH RESULTS OF N1 VEHICLE RIDE COMFORT AND STABILITY

Using the developed simulation model, testing was performed to define the vehicle service properties. We managed to improve ride comfort and stability by means of changing the vehicle's factory-made spring suspension system into one on the basis of a four-bar linkage assembly.

In the process of "20-m sharp lane change" experiment, at a speed of 50 km/h, the maximum roll angle of the vehicle with the factory-made suspension system amounted to 4.24°; in the process of testing the suspension system on the basis of the four-bar linkage assembly, the roll angle added up to 3.09°. Furthermore, the critical speed of the manoeuvre performance was defined: the critical speed with the factory-made suspension system amounted to 60 km/h, while the one with the suspension system on the basis of the four-bar linkage assembly added up to 65 km/h. Thus, the testing results proved that, under the same conditions, the vehicle performed the manoeuvre with more stability using the suspension system being studied.

Having analysed the obtained value of the sprung mass vibrations frequency reported in the modelling and simulation results (Figs. 9-10), it may be concluded that the sprung mass vibrations frequency for the factory-made suspension system added up to 1.33 Hz with the entire load (sprung mass of 520 kg), while the one for the suspension system on the basis of the four-bar linkage assembly amounted to 0.8 Hz [5].

The results of the performed research pointed to the fact that using the new suspension system significantly improves the vehicle's ride comfort and stability parameters. Thus, the proposed N1 vehicle suspension system is both practical and expedient in terms of usage.

7. CONCLUSIONS

A virtual model of the vehicle was developed in order to perform computer testing of the ride comfort and stability parameters. The proposed model allowed for the fast changing of such parameters as vehicle weight, height of the centre of mass and suspension system types. Besides, the model can easily adapt to different research conditions. Thus, the proposed model is suitable for performing research on the vehicle ride comfort parameter by means of such methods as the drop test, a head-on crash and driving on setts, and the vehicle stability parameter by means of a sharp lane change, a turn or a moose test.

The standard research procedures of the ride comfort and stability parameters, by means of the drop test and the sharp lane change, were adapted for use in the proposed vehicle computer model.

Research on the stability parameters of the vehicle with the factory-made suspension system and with the suspension system on the basis of the four-bar linkage assembly was performed. The vehicle with the suspension system on the basis of the four-bar linkage assembly demonstrated a 60% decrease in the free vibrations frequency of the sprung mass, compared with the vehicle with the factory-made suspension system. Research on the ride comfort of the vehicle with the factory-made suspension system and with the suspension system on the basis of the four-bar linkage assembly was also performed. The vehicle with the suspension system on the basis of the four-bar linkage assembly demonstrated a decrease in the roll angle of 37%, compared with the vehicle with the factory-made suspension system, and a decrease in the critical speed under the condition of an 8.3% stability loss.

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Received 10.08.2017; accepted in revised form 11.11.2017