Information Technologies Use in the Study of Functional Properties of Wheeled Vehicles

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Abstract

The influence of operational factors on the kinematic and dynamic characteristics of the pneumatic shock absorber of a wheeled vehicle has been studied in the article under discussion. An experimental stand has been developed, and some experimental studies of the kinematic and dynamic parameters of the pneumatic shock absorber of active type for a wheeled vehicle have been conducted. An algorithm for the obtained experimental data processing has been developed which is based on specialized software. Based on the processed experimental data, a comprehensive study of the shock absorber's functional characteristics was conducted and its optimal design and operational parameters were determined. The method of artificial neural networks was used to assess the experimental factors significance.

Keywords

Wheeled vehicle, controlled suspension, experimental stand, kinematic, dynamics, vibrations, information technologies, signal processing, artificial neural networks.

1. Introduction

In recent decades, there has been rapid development in the automotive industry in developed countries, and these trends are expected to continue in the future. Unfortunately, Ukraine lags significantly behind in this development due to various factors such as war, corruption in government, lack of favorable legislation, lack of investment in the industry, and some others. However, according to the experts' estimates, the potential benefit from investing in the transport industry for the domestic economy is around 8-10 billion dollars per year. In the pre-war period in Ukraine, the transport sector, terminal and warehouse management, postal, and courier services accounted for approximately 7% of GDP and 6% of employment among the total working-age population.

This entails the need for significant development and widespread application of information technology in modeling the impact of operational factors on the functioning of vehicles. The suspension system plays a crucial role in a wheeled vehicle design for its effective operation, as the longevity and efficiency of many of the vehicle systems depend on its reliable functioning. Taking into account all the above mentioned, it is reasonable to focus our efforts on researching the impact of operating factors on the functioning of suspension systems in wheeled vehicles using information technologies.

To improve the smoothness of motion of wheeled vehicles (WV), controlled suspension systems are widely used [1, 2, 3, 4]. The fundamentals of researching the dynamics of vehicles, which is an important part of both classical [5, 6] and modern automobile theory, were described in the following

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articles [7, 8, 9, 10, 11, 12, 13]. It is known that controlled suspension systems are widely used on wheeled chassis to improve the smoothness of motion of vehicles [1, 4, 9, 14].

The fundamentals of studying the dynamics of vehicles, which are an essential part of both classical [15, 16] and modern automobile theory, are laid out in the works [7, 8, 9, 10, 11, 12, 13].

In the articles [17, 18], some vibrations of wheeled vehicles caused by road roughness, which affects the smoothness of vehicle travel, have been thoroughly examined. The methods and results of experimental studies on the smoothness of travel, maneuverability, and stability of motion of multi-axle wheeled vehicles, as well as the determination of system parameters and characteristics, have been described in the articles [15, 16]. Some methods for improving the vibration protection properties of suspensions of different wheeled vehicles on a wheelbase using pneumatic, hydropneumatic springs, and hydraulic shock absorbers with self-regulating characteristics (due to vibration energy) have been presented in the articles [14, 19, 20, 21].

2. Study of a wheeled vehicle suspension

The analysis of the test equipment for studying the suspension of vehicles has revealed that existing developments in the investigation of suspension systems are too expensive and unable to fully address the problem of studying the oscillations of a wheeled vehicle [2]. Therefore, the aim of this work is to investigate the influence of kinematic parameters of motion and longitudinal-angular oscillations of the sprung mass of wheeled vehicles with a non-linear force characteristic of the suspension system on their maneuverability, with the goal of enhancing stability during movement along curved road sections of a bumpy road.

2.1. Information-technical support of experimental study

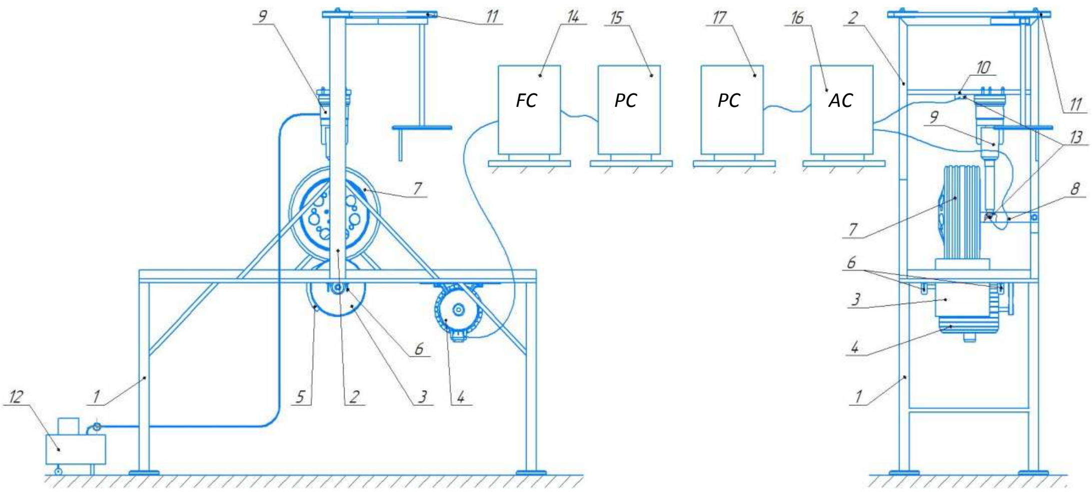
To conduct experimental research aimed at confirming the results of theoretical developments and refining relevant parameters, a test stand with a driving drum was designed and manufactured. This stand was intended for investigating the suspension system of wheeled vehicles. The structural scheme and overall view are depicted in Figures 2a and 2b, respectively. [22]. The essence of the test stand with a driving drum lies in the ability to conduct research under static loading conditions of the object under investigation (pneumatic shock absorber of a wheeled vehicle) and to record changes over time in the velocity of motion and changes in the critical steering angle, all under identical parameters. It also measures the critical value of the dynamic steering angle for the elastic characteristics of the shock absorbers under small amplitude longitudinal-angular oscillations [22].

The test stand with a drive drum is designed as a frame 1, on which the support 2 is fixed (Fig. 2).

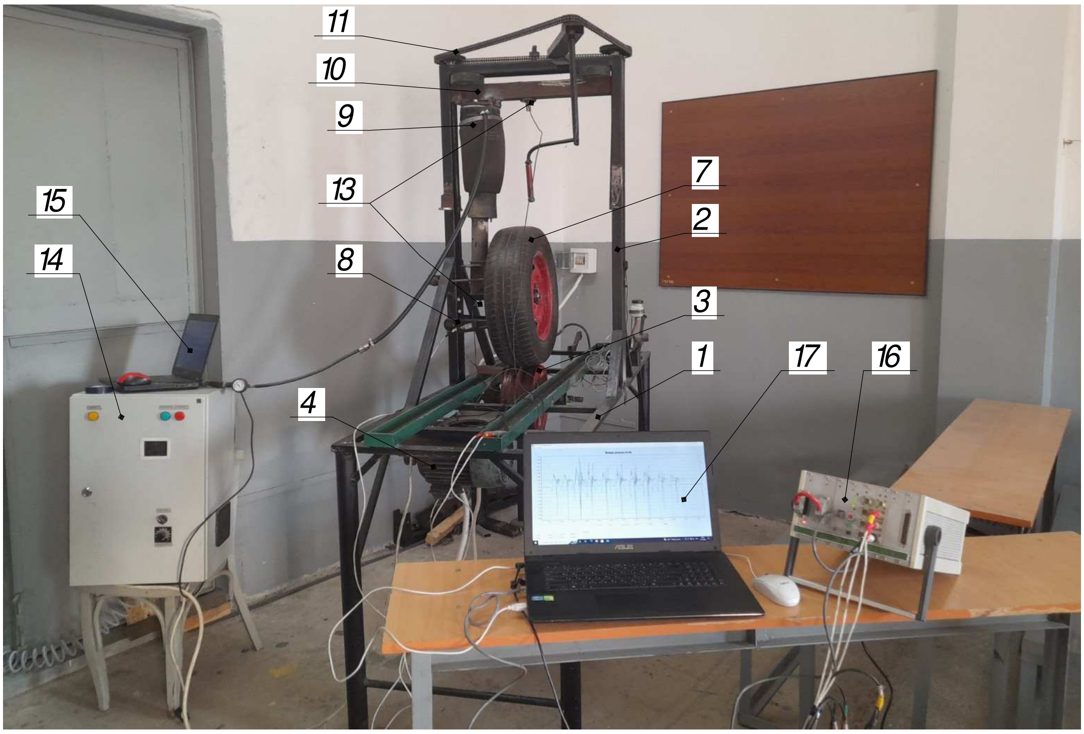
The drive drum 3 with an obstacle 5, which is driven by an electric drive 4, is mounted on brackets 6 in the frame 1 with the possibility of vertical displacement. The support 2 has a beam 10 to which the pneumatic shock absorber 9 with a wheel 7 is attached. The pneumatic shock absorber 9 with the wheel 7 is also attached to the lower lever 8, which is vertically mounted in the support 2. Adjustment of the parameters of the pneumatic shock absorber 9 is carried out by the loading mechanism 11 and the pressure of the compressor 12 of the pneumatic chamber of the pneumatic shock absorber 9.

During the suspension testing of the vehicle with experimental equipment for measuring the tested characteristics under static load, an electronic dynamometer (not shown in the figure) is used. For this purpose, a DE 0.5-0.5 electronic dynamometer sensor is installed between the lower end of the pneumatic shock absorber (movable part) 9 and the frame (fixed part of the frame structure) 1.

Next, to obtain relevant data in static conditions, the loading of the object is carried out according to the developed methodology. During the study of the pneumatic shock absorber of a wheeled vehicle with experimental equipment for fixing the investigated characteristics of the drive during dynamic loading, a frequency converter (Altivar 71) 14 is used, the control of which is carried out from a personal computer (PC) 15 using the Power Suite software version 2.3.0, and an accelerometer 16 with data visualization on a personal computer 17. The research is carried out as follows. After the signal is sent from the PC 15 through the frequency converter 14 to the electric drive 4, the latter sets in motion the drive drum 3 with the obstacle 5. Due to the friction force, the drive drum 3 rotates the wheel 7, which rolls on it, occasionally encountering the obstacle 5.



a)



b)

Figure 1: A stand with a drive drum for studying the car suspension with experimental equipment for fixing the studied characteristics under static load: a) structural scheme; b) overall view

This triggers the pneumatic shock absorber 9, which begins to move vertically, the magnitude of which is recorded by the accelerometer 16 with data visualization on the personal computer 17. The parameters of the pneumatic shock absorber of the vehicle are adjusted by changing the pressure in the pneumatic chamber of the shock absorber 9 with the compressor 12 and the loading mechanism 11.

During experimental studies aimed at expanding its capabilities, the drive drum test stand (Fig. 2) is equipped with brackets 6 that allow for vertical displacement of the drive drum 3 with obstacle 5 (Fig. 3), enabling the replacement of wheels of different diameters. Additionally, it is possible to replace obstacle 5 on the drum 3 with obstacles of varying height and to install multiple obstacles.

The rotation speed of the drum 3 is set from a personal computer (PC) 15 using Power Suite software version 2.3.0 through a frequency converter 14 (Altivar 71) during the experimental testing.

The Power Suite software version 2.3.0 is used to control the operation of the electric drive 4 (correspondingly, of the drum 3 and the wheel 7), and it makes smooth increase and decrease of the drum rotational speed within the range of 0 to 1480 revolutions per minute possible, which enables conducting the research at a wide range of speeds. The data on energy consumption and the value of the torque on the electric drive shaft are displayed periodically as tabular data and graphical dependencies on the computer monitor display as percentages of nominal values. The general interface view of the Power Suite program during the experiment is shown in Figure 2.

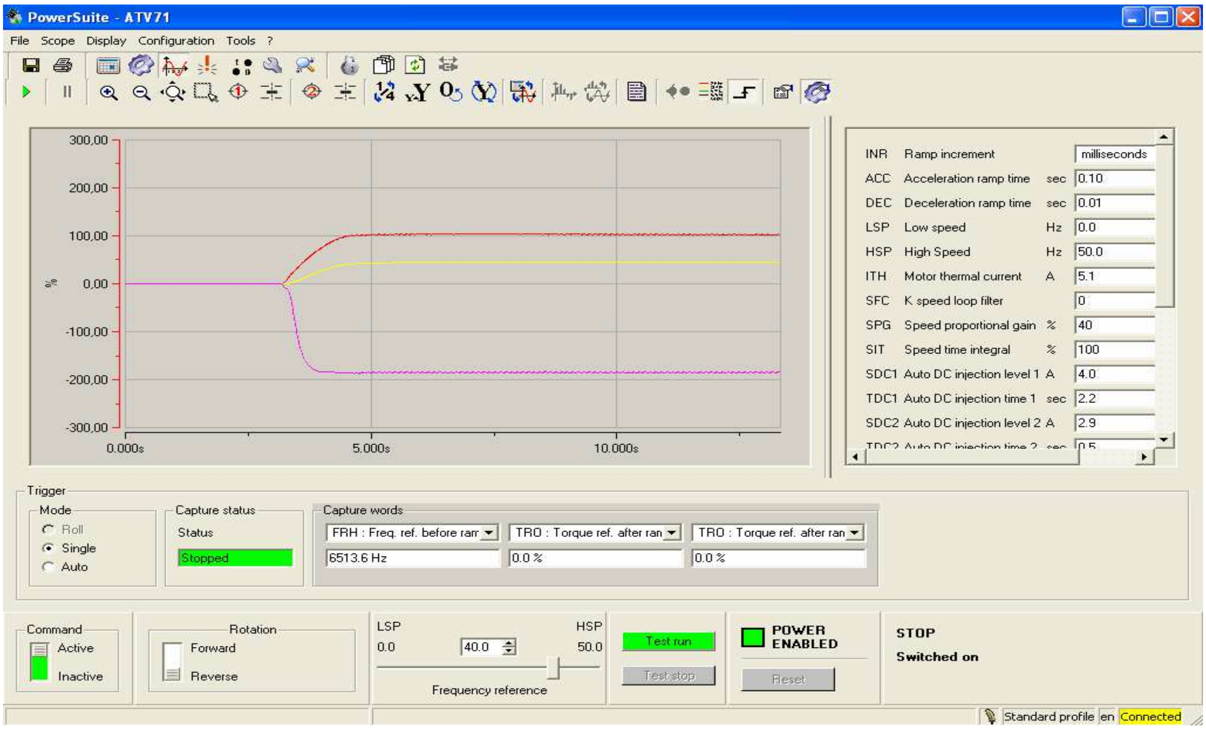


Figure 2: General view of the control panel of the frequency converter Altivar71 using the software Power Suite

The control signals for the stand drive obtained from the Altivar 71 frequency converter are displayed in percentages of nominal values (Fig. 3).

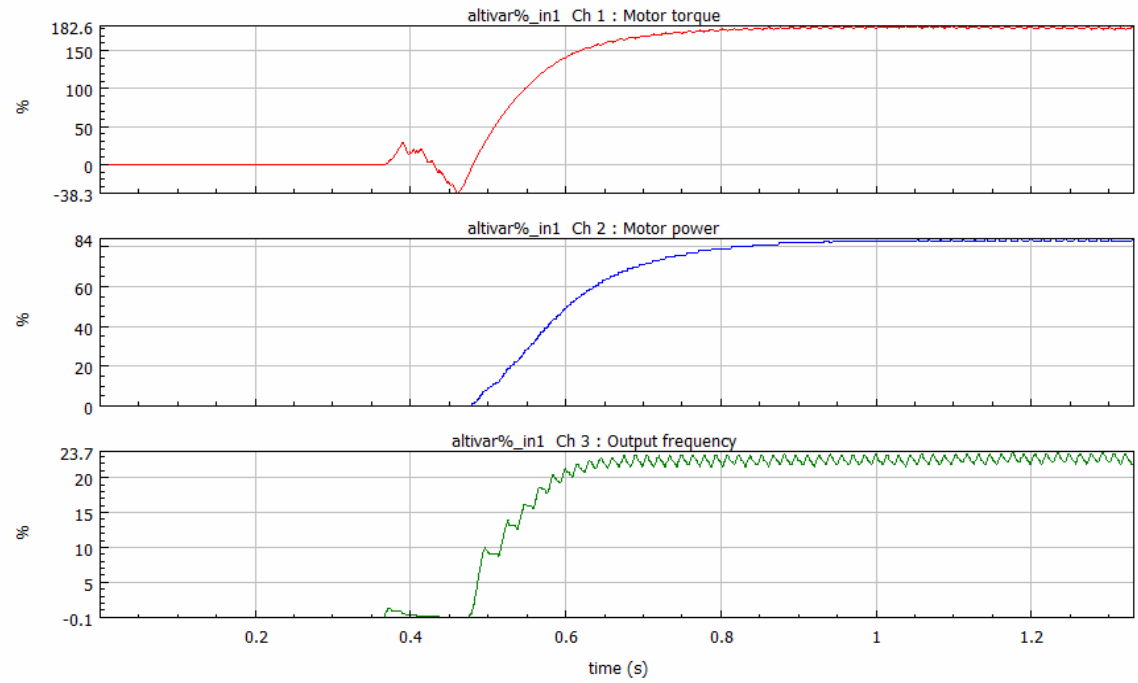


Figure 3: Curves of changes in time of the output parameters of the frequency converter Altivar 71 (are displayed in percentages of nominal values)

The same signals are converted from a display in percentages of nominal values to a display in actual absolute values (Fig. 4). Thus, this allows for the curves of changes in rotation frequency, drive power, and torque on the motor shaft to be obtained.

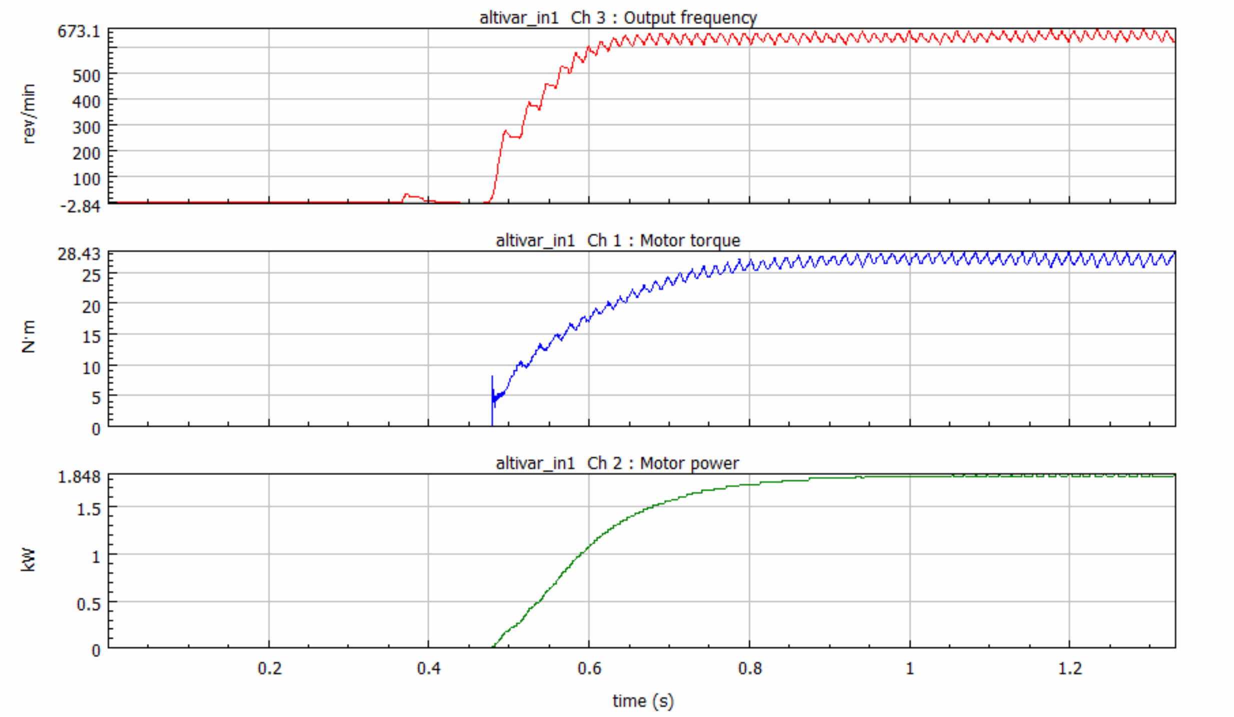


Figure 4: Curves of changes in time of the output parameters of the frequency converter Altivar 71 (are displayed in actual absolute values)

During the experiment, the rotational speed of the motor shaft (drive drum), the pressure in the chamber of the adjustable pneumatic shock absorber, and the height of the load on the drive drum (simulation of the wheel hitting an obstacle or entering a pothole) were used as the variable parameters.

The range of the electric motor shaft rotational speed change was 10Hz, 20Hz, 30Hz, and 40Hz, corresponding to the speed of the wheel movement of 15 km/h, 30 km/h, 45 km/h, and 60 km/h, respectively.

The pressure in the pneumatic chamber of the active type shock absorber varied within the range of 1 atm, 1.5 atm, 2 atm, and 2.5 atm for each of the values of the electric motor shaft rotation frequency of the drive drum.

The investigated parameter was the magnitude of the vibration acceleration on the adjustable support of the vehicle (channel 7) and on the frame of the support mounting (channel 6).

During the dynamic loading experiments on the 9-wheel vehicle, changes in the initial state of the shock absorber 9 of a wheeled vehicle (the results of displacement in vertical direction) were measured using an accelerometer 16 with data visualization on personal computer 17. The main technical parameters of the universal recording system (accelerometer 16) include the sampling frequency ranging from 1 Hz to 2 kHz per channel and an error in measurement values of no more than 4% (1% - due to accelerometer specifications and up to 3% - due to installation errors) [23].

The experimental data were recorded using a special digital measuring system, whose universal measuring channels allowed us to connect the resistive sensors and sensors with output signals in the form of direct current voltage. The digital data of the experimental research are stored as binary files with the ".dat" extension.

2.2. Processing of experimental signals

Specialized software for processing a large amount of data, nCode GlyphWorks, was used to process the obtained experimental data. It is a multi-channel, multi-file, and multi-format environment that allows interactive data analysis processes to be represented in a graphical form using built-in modules called “glyphs” - calculation templates with embedded algorithms for performing certain functions and the ability to adjust various properties parameters. A set of glyphs with functional connections makes up the working project of the study [27].

To implement the experimental data processing procedure according to the methodology described in [28, 29], a working project was built that contains the following structural elements (glyphs): Excel Input, Multi Column To Time Series, Butterworth Filter, Meta Data Display, Time Series To Multi Column Output, Frequency Spectrum, and XY Display. The overall interface of the experimental data processing working project in the nCode GlyphWorks environment is shown in Figure 5.

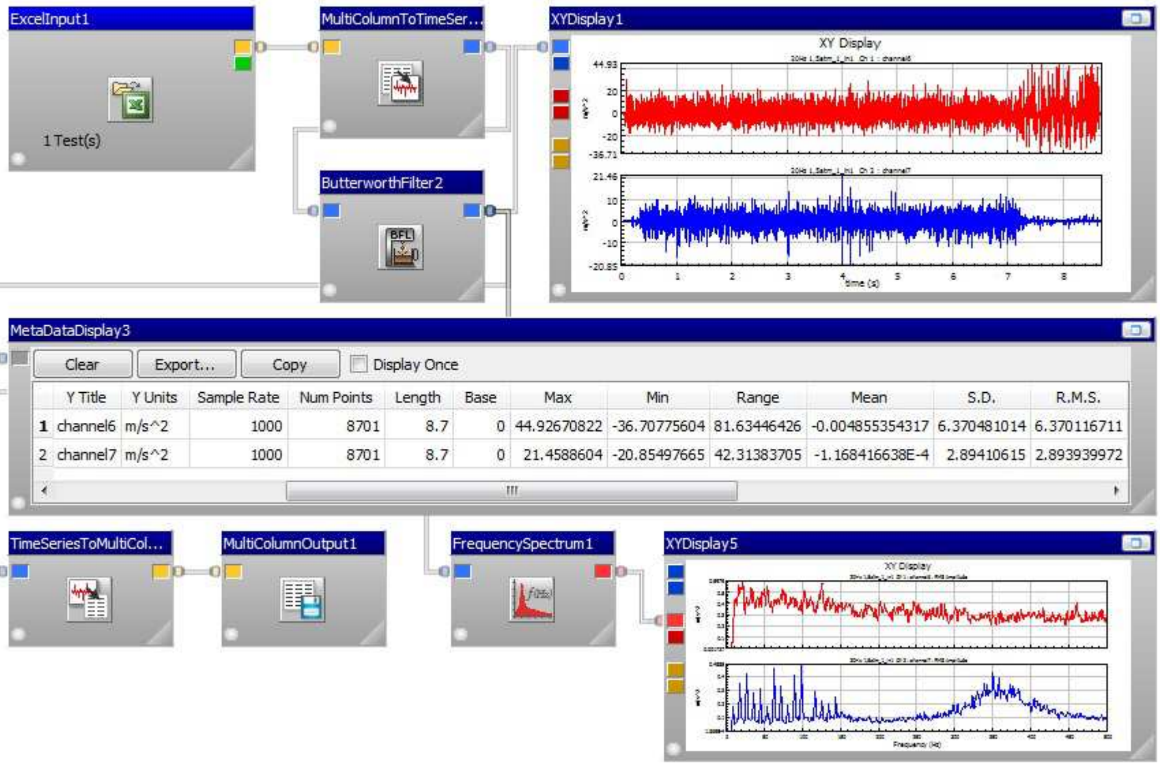


Figure 5: General view of the working project in the environment nCode GlyphWorks

The functional purpose and structural relationships between the glyphs are described below.

The Excel Input glyph is intended for entering test data into the working project. To do this, a file with the extension ".xls" was created, into which columns of data from binary files of experimental research results were entered. The channel name (Channel6 and Channel7) and measurement units (m/s^2) are indicated above the data columns.

The Multi Column To Time Series glyph is intended for transforming multi-column data into the Time Series format, which is used by most of the glyphs in this environment.

The Butterworth Filter glyph is configured to filter high-frequency, low-amplitude oscillations in order to eliminate drift of experimental data caused by external environmental factors or internal factors of the measuring equipment.

The Meta Data Display glyph allows obtaining and displaying general information about experimental data, including the results of statistical processing.

The Frequency Spectrum glyph allows obtaining the frequency spectrum of the root mean square deviation of experimental data by amplitude, power or energy.

The XY Display glyphs provide the output of graphical information on the monitor screen.

The Time Series To Multi Column Output glyph allows converting data from the Time Series format into multi-channel arrays and saving them in the ".csv" format.

For example, the results of processing experimental data using nCode GlyphWorks for individual combinations of investigated parameters are shown in Figures 6 to 9.

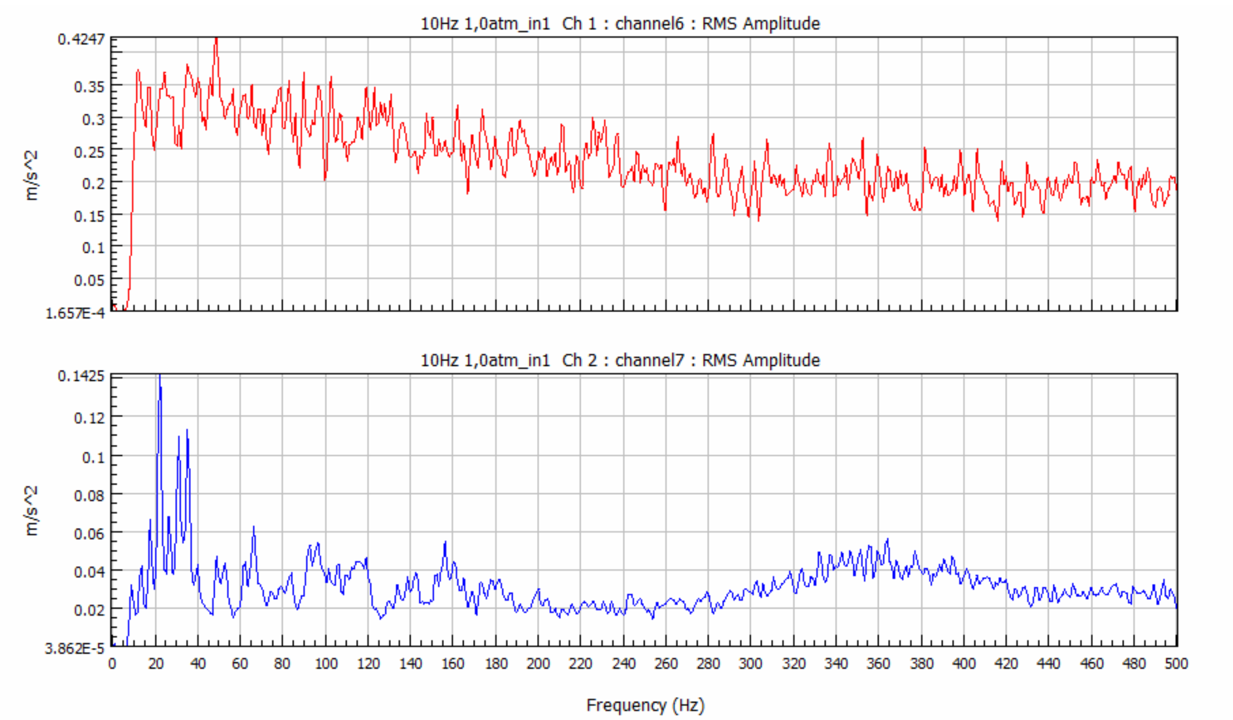


Figure 6: The frequency spectrum of the root-mean-square deviation of acceleration amplitude (10 Hz, 1.0 atm)

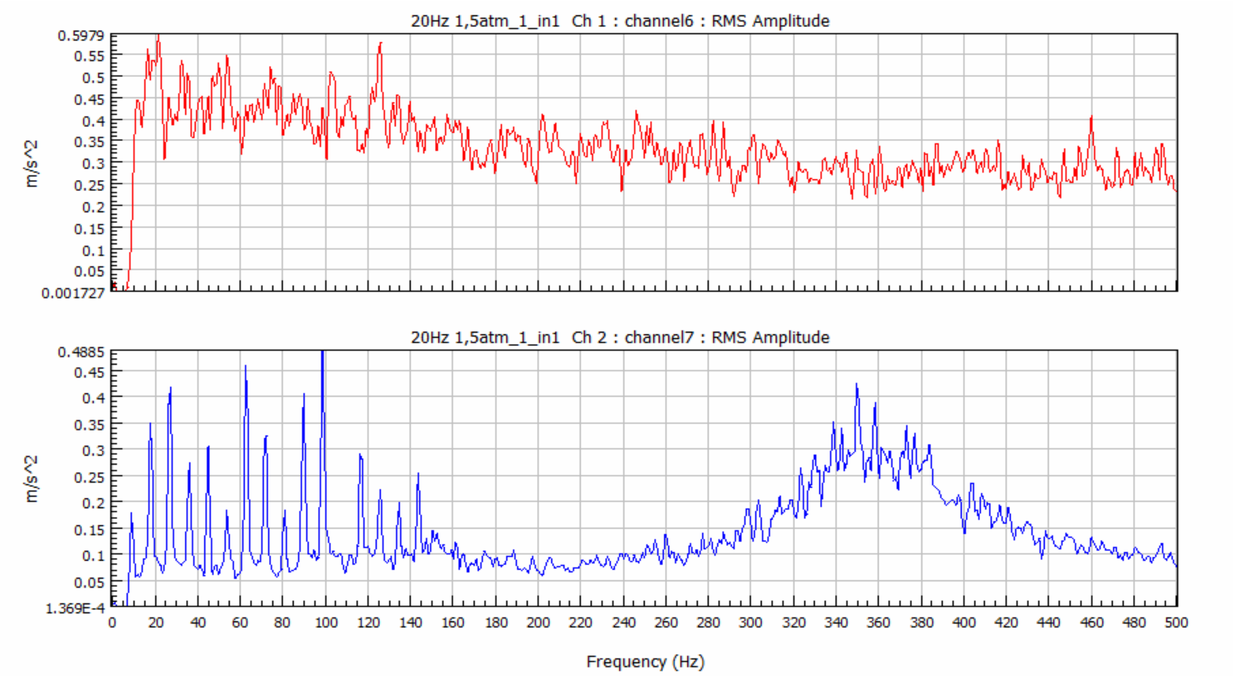


Figure 7: The frequency spectrum of the root-mean-square deviation of acceleration amplitude (20 Hz, 1.5 atm)

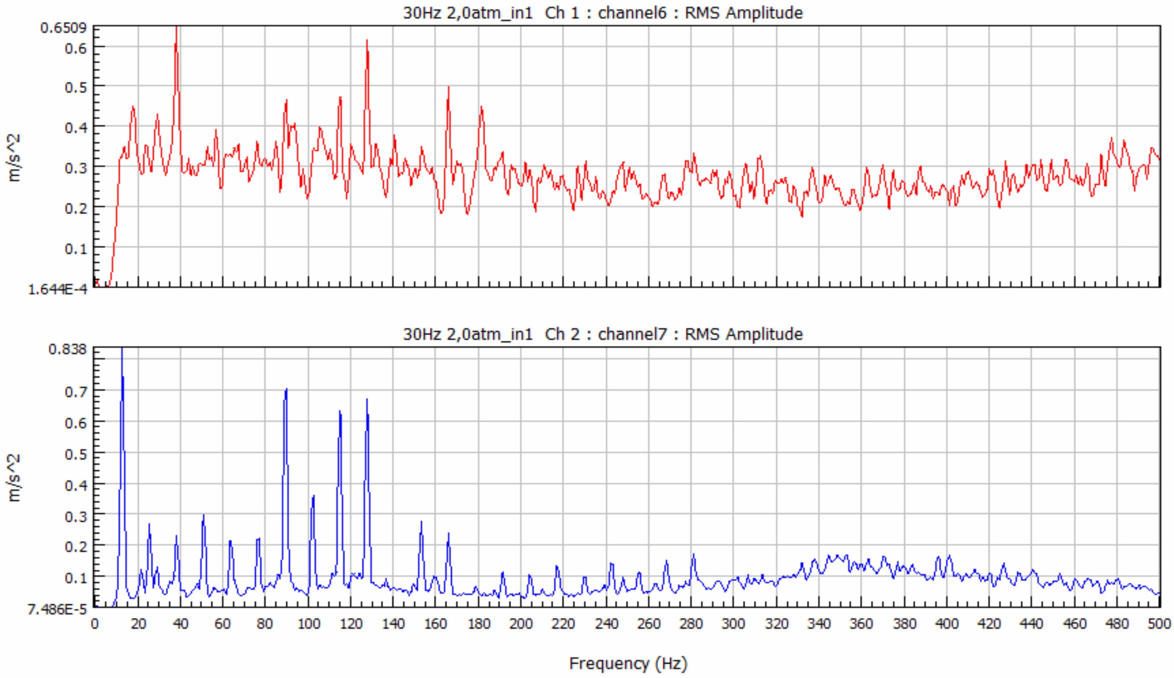


Figure 8: The frequency spectrum of the root-mean-square deviation of acceleration amplitude (30 Hz, 2.0 atm)

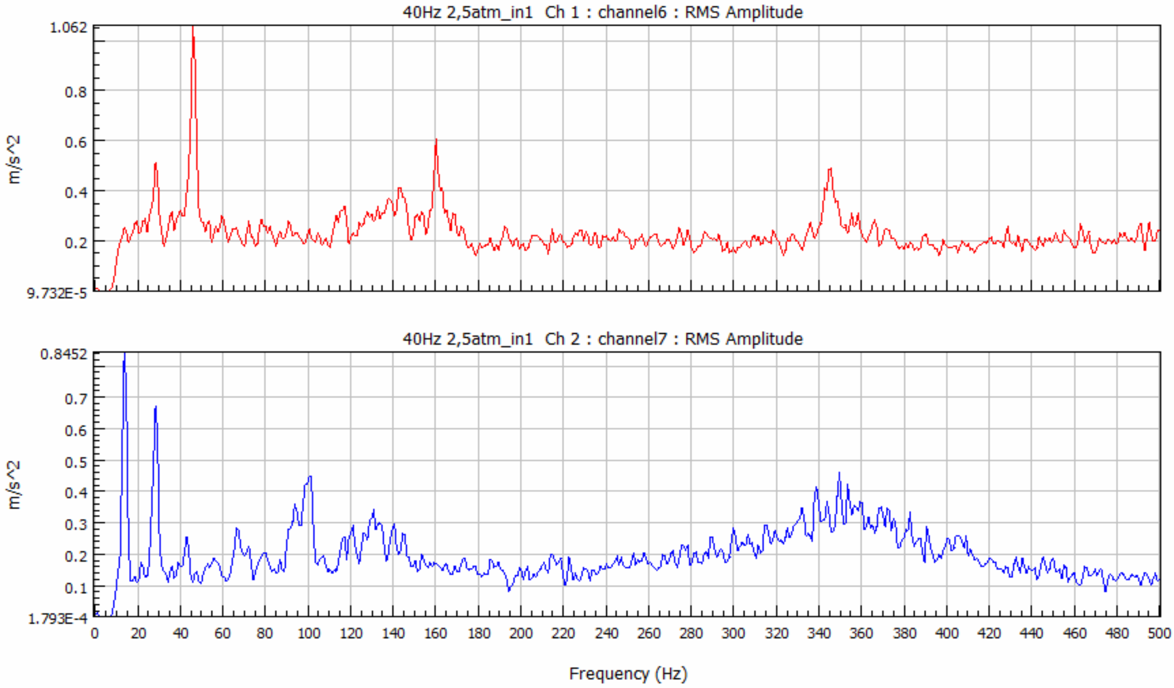


Figure 9: The frequency spectrum of the root-mean-square deviation of acceleration amplitude (40 Hz, 2.5 atm)

2.3. The experimental factors significance assessment

To assess the significance of the experimental factors, the method of artificial neural networks was used to determine the most influential factors, under which the vibration acceleration of the vehicle in the vertical direction during movement with obstacles was determined, namely, the speed of the vehicle, the pressure in the tires of the vehicle and the pressure in the pneumatic chamber of the shock absorber.

Identification of functional dependencies $y1 = f(x_1, x_2, x_3)$, $y2 = f(x_1, x_2, x_3)$, $y3 = f(x_1, x_2, x_3)$ was based on the general methodology of Data Science. In particular, the Input Data Set was randomly divided into Train Sample and Test Sample in the ratio of 75% and 25%.

To establish regression dependencies, the Extremely Randomized Trees algorithm was used to determine the vibration acceleration in the vertical direction of the vehicle during movement with obstacles within such limits of changes in input factors: $10 \le V \le 30$ (km/h), 1,632≤ $P_t \le 2.039$ (bar); 1.5≤ $P_p \le 2.5$ (atm).

The Extremely Randomized Trees algorithm was trained on the Train Sample, and the same algorithm was tested on the Test Sample.

The quantitative measure of the error of the Extremely Randomized Trees algorithm on the Test Sample was taken as Mean Absolute Percentage Error (MAPE), which is calculated according to the equation:

$$MAPE_y = \frac{1}{N}\sum_{i=0}^{N-1}\left|\frac{y_{true}^{test}(i) - y_{predict.}^{test}(i)}{y_{true}^{test}(i)}\right|, \quad (1)$$

where N – is the volume of test sample, $y_{true}^{test}(i)$ – is the true value of target variable on the test sample, $y_{predic.}^{test}(i)$ – is the predictive value of target variable on the test sample.

On the experimental studies basis, the parameters that characterize the algorithm operation were selected (table 1).

Table 1

Parameters of experimental studies and the most influential factors

Index	x_1	x_2	x_3	$y1$	$y2$	$y3$
0	10	1.632	1.5	0.098	2.71	0.11
1	12	1.645	1.5	0.113	3.2	0.12
2	15	1.723	1.5	0.125	3.8	0.16
3	17	1.835	1.5	0.186	4.4	0.17
4	23	1.849	1.5	0.250	4.79	0.18
5	25	1.878	1.5	0.375	5	0.21
6	27	1.945	1.5	0.500	5.8	0.28
7	30	2.039	1.5	0.555	6.75	0.31
8	10	1.632	2	0.560	3.22	0.21
9	12	1.645	2	0.590	3.53	0.31
10	15	1.723	2	0.625	3.3	0.19
11	17	1.835	2	0.677	3.2	0.18
12	23	1.849	2	0.724	2.61	0.15
13	25	1.878	2	0.750	7.4	0.42
14	27	1.945	2	0.840	10.9	0.53
15	30	2.039	2	0.842	11.53	0.68
16	10	1.632	2.5	0.939	5.79	0.17
17	12	1.645	2.5	0.970	6.6	0.21
18	15	1.723	2.5	1.240	7.3	0.32
19	17	1.835	2.5	1.250	7.4	0.39
20	23	1.849	2.5	1.347	9.47	0.41
21	25	1.878	2.5	1.382	12.3	0.62
22	27	1.945	2.5	1.682	14.1	0.84
23	30	2.039	2.5	1.844	17.2	1

Quantitative results characterizing the productivity of the Extremely Randomized Trees algorithm in predicting Target Variables are presented in Tables 2 – Tables 4.

Table 2

Table of $y1_{true}^{test}(i)$ and $y1_{predic.}^{test}(i)$

Index	$y1_{true}^{test}(i)$	$y1_{predic.}^{test}(i)$
21	1.382	1.182
1	0.098	0.078
6	0.500	0.400
17	0.970	0.830
20	1.347	1.147
18	1.240	0.940
	$MAPE_{y1} \approx 2,1\%$	

Table 3.

Table of $y2_{true}^{test}(i)$ and $y2_{predic.}^{test}(i)$

Index	$y2_{true}^{test}(i)$	$y2_{predic.}^{test}(i)$
15	11.53	9.83
2	3.8	3.44
21	12.3	11
9	3.53	4.22
10	5.3	5.21
12	3.3	4.88
	$MAPE_{y2} \approx 9\%$	

Table 4

Table of $y3_{true}^{test}(i)$ and $y3_{predic.}^{test}(i)$

Index	$y3_{true}^{test}(i)$	$y3_{predic.}^{test}(i)$
10	0.19	0.21
18	0.32	0.17
6	0.28	0.3
20	0.41	0.3
23	1	0.84
5	0.21	0.18
	$MAPE_{y3} \approx 17,1\%$	

Also, the influence of factors x_1, x_2, x_3 on Target Variables $y1$, $y2$, $y3$ was quantified on the basis of Fisher's test, which is shown in Figures 10 to 12.

The Figures 10 - 12 show that increasing the decrement in the tires reduces the vibrations of the vehicle with an improved suspension system, respectively, within 10% when driving with obstacles.

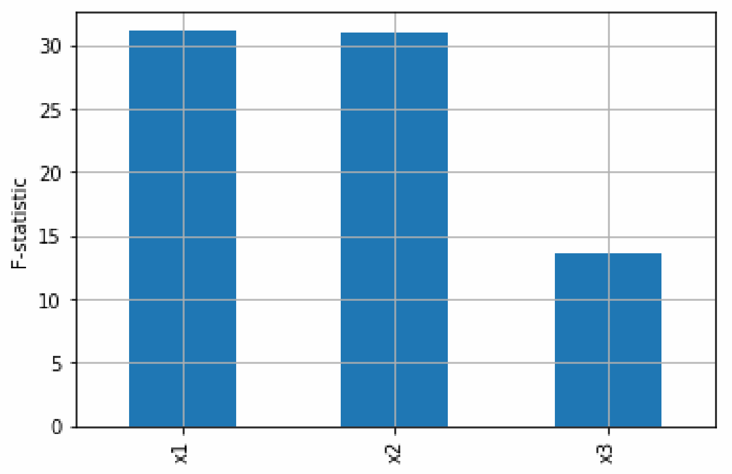


Figure 10: Influence of factors x_1, x_2, x_3 on the Target Variable $y1$

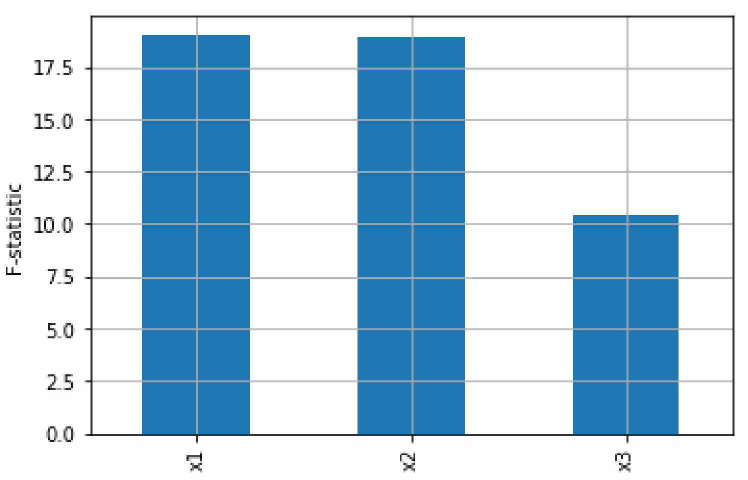


Figure 11: Influence of factors x_1, x_2, x_3 on the Target Variable $y2$

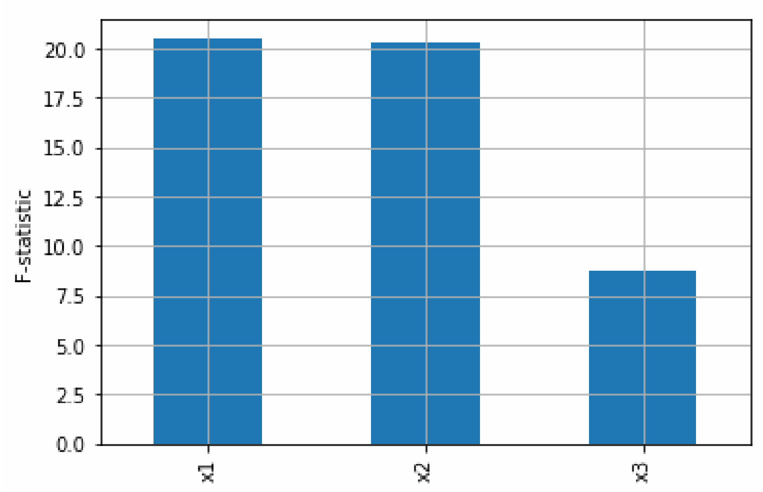


Figure 12: Influence of factors x_1, x_2, x_3 on the Target Variable $y3$

3. Conclusion

The designed experimental stand with a drive drum for experimental research on the shock absorber of a wheeled vehicle makes it possible to determine the impact of kinematic parameters of motion and longitudinal-angular oscillations of the suspended mass of vehicles with a non-linear force characteristic of the suspension system on their maneuverability and increased stability of motion along curved sections of the bumpy road.

During the experiment, the rotation speed of the electric motor shaft, the pressure in the pneumatic chamber of the adjustable shock absorber, and the height of the overlay on the drive drum (simulation of hitting an obstacle or entering a pothole) were used as the variable parameters. The experiment was conducted under dynamic loading using progressive experimental equipment and software (information-technical support) to record the investigated characteristics, namely: an electronic dynamometer DE 0.5-0.5, a frequency converter Altivar 71 with Power Suite software version 2.3.0, a universal registration system, and the software nCode GlyphWorks to process the experimental data.

The values of the vibration acceleration on both the adjustable shock absorber of the vehicle and on the frame of the shock absorber mounting have been obtained, which allowed us conduct a comprehensive study of the functional characteristics of the shock absorber and determine its optimal design and operational parameters using the method of artificial neural networks.

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