Method for determining the shock absorber effectiveness in the vehicle suspension to ensure its active and operational safety

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Abstract. The article is devoted to the development of a new method for determining the shock absorber effectiveness in the vehicle's suspension on a vibration stand with vibrating plates, which has greater accuracy and functionality compared to the already known method. The use of the new method will make it possible to reduce the risk of accidents and improve road safety with its widespread introduction.

1. Introduction

Nowadays, hydraulic shock absorbers have been exclusively used on modern domestic and foreign cars. Serviceable shock absorbers provide damping for body and wheels, as well as the absence of tire separation from the road, which affect the stability and controllability of the vehicle, as well as the stopping distance during emergency braking on rough roads [1]. There are more than 50% of such roads in the Russian Federation; consequently, the shock absorbers ensure the active safety of the vehicle, it reduces the risk of road accidents. However, during operation on rough surface roads, even high-quality shock absorbers from leading manufacturers wear out quickly, their performance deteriorates, which reduces their effectiveness in operating with the suspension to ensure the active safety of the vehicle. According to GIBDD (traffic police in RF), from 13 to 18% of road accidents are caused by adverse road conditions, i. e. potted surface of roads. To ensure the active safety of vehicles, it is established in the state standard of the Russian Federation [2] that the critical threshold of the shock absorber life occurs when its efficiency decreases by 25%, after which the absorber must be replaced. However, the shock absorber is usually not replaced, and the vehicles with defective shock absorbers are still kept in use, which leads to an increase in the accident rate in the country. This is due to the fact that the current GOST R 51709-2001 standard in the Russian Federation, which establishes requirements for the technical condition and methods for testing when allowing vehicles to operate [3], has no requirements for shock absorbers and suspension elements. In the current Technical Regulations of the Customs Union (TP TC 018/2011) "On the safety of wheeled vehicles" [4] such requirements are also absent. Therefore, in the Russian Federation, drivers do not have information about the reduction in the effectiveness of shock absorbers to ensure its active and operational safety, which reduces road safety in the country.
Continued use of vehicles with defective shock absorbers leads to lower tire mileage, accelerated wear or even breakage of brake mechanisms and many other parts and components of the chassis: hub bearings, springs, suspension rack mounts, rubber-metal joints, ball joints, steering nodes, constant-velocity ball joints. This significantly increases the operating cost of vehicles in the Russian Federation.

The solution to the problem of reducing the costs associated with operating vehicles with defective shock absorbers is hampered not only by the shortcomings of the legislation, but also by the low reliability of their shock absorbers. The results of statistical studies of the development to failure of the rear shock absorbers of VAZ branded cars of the Samara family, shown in Figure 1 [5], show that the most likely life of these shock absorbers is about 70 thousand km. A similar result (mileage to a shock absorber failure of 60... 80 thousand km) was obtained as a result of research conducted by the German Technical Supervision Association (TUV) [6]. Thus, given the significant average age of vehicles used on the roads of the Russian Federation, it can be argued that more than half of them have defective shock absorbers.

![Figure 1. Distribution of the operating time before the failure of the rear shock absorbers of VAZ cars of the brand "Samara": 1 – the actual distribution; 2 – calculated distribution.](image)

### 2. Analysis of shock absorber test stands

Currently there is the problem of organizing the verification of shock absorbers during technical inspections of vehicles in the Russian Federation. Russian firms that offer technical control lines, as a rule, use foreign-made modules to check the quality of damping. The leading manufacturers of this equipment are such companies as Maha, Nussbaum, Bosch and others. However, the owners of service stations are in no hurry to purchase such equipment and create special posts to check the condition of the shock absorbers, since they do not believe that this service can be sold. Due to the absence of a ban on the operation of vehicles with defective shock absorbers, it is very difficult to convince car owners that the shock absorber is faulty. Therefore, even when it is definitely established at the stand that the quality of the damping in the vehicle's suspension does not meet safety standards, the driver, in order to save money, ignores the proposal to replace it. Car owners in the Russian Federation will replace shock absorbers only in the case when the vehicle becomes unstable in motion, and it is clear, even without any diagnostics, that shock absorbers do not function as expected. In this regard, stands and testers for controlling shock absorbers are not in demand on the Russian market and are almost not supplied.

There are many types of stands, installations and methods for diagnosing shock absorbers [7-9], however, a correct check of the serviceability of a shock absorber can be performed only under professional service conditions on a specialized stand or with the help of testers. Stands for testing shock absorbers are distinguished by a kinematic chain, a load sensing system, a control unit interface, and a
method of a shock absorber performance check. Simple mechanical stands, designed on the base of the crank mechanism (Figure 2a), provide the most accurate information and are mostly common used. Tests of shock absorbers are carried out with a sinusoidal kinematic movement of its rod with different amplitudes and frequencies, providing maximum piston speeds [2]. When testing, diagrams of vertical oscillations are obtained (Figure 2b). However, stand tests of shock absorbers are not suitable for vehicle inspection stations, since they are laborious: require disassembling the suspension and removing the shock absorber, installing it on the stand, testing, and then returning the shock absorber into place.

![Mechanical stand](image1)

**Figure 2.** Mechanical stand (a), designed on the base of the crank mechanism (Precisa model manufactured by Emmetec S.r.l.) and shock absorber diagrams (b and c) obtained at the stand: $S$ – amplitude of shock absorber vertical oscillations; $F_c$ – compression force; $F_o$ – rebound force

To determine the effectiveness of the shock absorber in the vehicle suspension at the technical inspection stations, vibration stands with vibrating platforms on which the car wheels are placed are mostly suitable (Figure 3).

![Vibration stand](image2)

**Figure 3.** Vibration stand with vibrating platforms, allowing one to quickly determine the effectiveness of the shock absorber in the vehicle suspension.

3. The well-known method for determining the effectiveness of the shock absorber in the vehicle suspension on the platform vibration stand

Let us consider a known method for determining the shock absorbers effectiveness in the vehicle suspension on a platform vibration stand [10] and identify its shortcomings. The diagram of the
vibroplatform drive and measuring the load between the wheel and the platform is shown in Figure 4.

![Figure 4](image-url)

**Figure 4.** The scheme of the vibroplatform drive and measurement of the load between the wheel and the platform on the vibration stand according to the patent RU 2100792: 1 – vibroplatform with load cell; 2 – vehicle; 3 – wheel; 4 – suspension; 5 – shock absorber; 6 – strain amplifier; 7 – recorder; 8 – crank mechanism; 9 – oscillogram of the oscillation process.

The method is implemented as follows. The vehicle drives onto the vibroplatform of the stand (Figure 3). The wheel with the tire is subjected to vibrations by the platform crank mechanism in the frequency range covering the wheel resonant frequency of 0...18 Hz. The process of load oscillations between the wheel and the vibrating platform is saved on the recorder as a waveform, which determines the minimum value of the vertical dynamic loads between the wheel and the vibrating platform at the time of the steady state of forced oscillations $P_{\text{dyn}}$ (segment "b" in Figure 4) and at the time of resonance $P_{\text{res}}$ (point "c" in Figure 4) in the zone of free oscillations (segment "d" in Figure 4).

Then a dimensionless estimated index $K_{\text{eff}}$ of the shock absorber performance is obtained, according to the formula:

$$K_{\text{eff}} = \frac{P_{\text{st}} - P_{\text{dyn}}}{P_{\text{st}} - P_{\text{res}}} \cdot 100,$$

where $P_{\text{st}}$ is static load from the wheel down to the vibrating platform; $P_{\text{dyn}}$ is the minimum value of the vertical dynamic contact loads between the wheel and the platform at the time of the steady state of forced oscillations; $P_{\text{res}}$ is the minimum value of the vertical dynamic loads between the wheel and the platform at the moment of resonance.

The disadvantages of this method are low accuracy due to disregard of some influencing factors and limited functionality, which occurs due to the index $K_{\text{eff}}$ allowing not to determine the presence of wheel separation from the road and an unacceptable reduction in wheel load on the road when the wheel oscillates at resonance, taking into account the height of the road surface irregularities, while the vehicle is operated. Therefore, the method does not allow evaluating the shock absorbers performance effectiveness in the suspension to ensure the vehicle active safety.

4. The new method for determining the effectiveness of the shock absorber in the vehicle suspension on the platform vibration stand

In this regard, the authors of the article proposed a method for determining the shock absorber performance in the vehicle suspension on the vibration stand with vibrating platforms, which has greater accuracy and functionality. The scheme of the method implementation is shown in Figure 5.
Figure 5. The scheme of implementation of the proposed method for determining the shock absorber performance in a vehicle's suspension on a vibration stand with vibrating platforms: 1 – vibroplatform with load cell; 2 – wheel; 3 – vehicle; 4 – shock absorber; 5 – suspension; 6 – crank mechanism; 7 – strain amplifier; 8 – recorder; 9 – recorder screen; 10 – oscillogram of the oscillation process.

The method differs in that the plane of the vibroplatform coincides with the plane of the floor, which eliminates the redistribution of the load between the wheels and improves accuracy. In addition, (before the tests) the air pressure in the tire of the wheel tested is preliminary measured and brought up to the upper limit of the standard value, which improves accuracy, since with increasing pressure in the tire, its absorbing properties decrease. The amplitude of vibrations is established by vibroplatforms in accordance with the root-mean-square height of road irregularities according to the expression:

\[ A_v = 0.5 \cdot q_{rms} \cdot \sqrt{2}, \]  

(2)

where \( A_v \) is the vibration amplitude of the vibration platform; \( q_{rms} \) is the RMS height of the road irregularities. For this purpose, the spike of the crank mechanism, which can move in the radial groove on the electric motor disk, is installed and fixed at a distance \( A_v \) from the rotation axis of the electric motor. For example, if a vehicle is operated on cement concrete roads, which RMS height of 90% of irregularities is \( q_{rms} = 6-12 \) mm, then the crank of the mechanism is set at a distance from the axis of rotation \( A_v = 0.5 \cdot 12 \cdot \sqrt{2} = 8.5 \) mm. If the vehicle is operated on asphalt roads with \( q_{rms} = 18 \) mm, then the crank of the mechanism is set at a distance from the axis of rotation \( A_v = 0.5 \cdot 18 \cdot \sqrt{2} = 12.7 \) mm.

After receiving the oscillations process waveforms, the minimum value of the vertical dynamic contact loads between the wheel and the vibrating platform at the moment of resonance \( P_{res. min} \) is determined by them, and the dimensionless estimated index of the shock absorber performance \( K_{eff} \) is determined according to the formula:

\[ K_{eff} = \frac{P_{res. min}}{P_{st}} \cdot 100, \]  

(3)

where \( P_{st} \) is a static load from the wheel on the vibroplatform; \( P_{res. min} \) is the minimum value of the vertical dynamic contact loads between the wheel and the vibrating plate at the time of resonance.

This index of the shock absorber performance in the vehicle suspension has the following physical meaning: it shows how many percent of the static load on the wheel \( P_{st} \) is the minimum vertical dynamic loads \( P_{res. min} \) in the contact patch of the wheel with the vibrating platform, with resonant vibrations of the tired wheel with the platform vibrations amplitude set in accordance with the roughness of the roads, the vehicle is operated on. If \( P_{res. min} = 0 \), then \( K_{eff} = 0 \), and this means that the wheel comes off the vibrating platform, which is unacceptable, so the shock absorber should be replaced.

To assess the performance of the shock absorber in the suspension ensure active safety of vehicle, the following calculations are also performed. So that the car does not drift in a curvilinear motion, the
lateral force must be less than the strength of the wheel adhesion to the road. Analysis of normalized speeds of motion along curved sections of roads with different radii showed that the lateral force is 20-25% of the static load on the wheel. Then the condition of the side skidding absence can be determined by the expression:

\[ P_{\text{res.min.}} \geq 0.25 \cdot \frac{P_{\text{st}}}{\varphi}, \]  \hspace{1cm} (4)

with

\[ K_{\text{eff}} \geq 0.25 \cdot \frac{\varphi}{K}. \]  \hspace{1cm} (5)

To ensure the active safety of the vehicle on wet roads, which have an adhesion coefficient \( \varphi = 0.5 \), the dimensionless estimated index of the shock absorber performance \( K_{\text{eff}} \) must be at least 50%, and on a dry road with an adhesion coefficient \( \varphi = 0.8 \), at least 30%.

5. Conclusion
Using the proposed method allows with high accuracy to determine the performance of the shock absorber in the suspension of vehicle to ensure its active safety, which, with wide-spread deployment, will reduce the risk of traffic accidents and increase road safety in the country.

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