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Experimental Research on Shock Absorbers of Light Vehicles

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Abstract. Zero fatalities in road transport and overall traffic safety is one of the most important common goals of the society, industry and academia. To achieve this goal, various researches in different fields, from the analysis of the materials and designs to the development of autonomous ground vehicles, are being done. Respectively, vehicle suspension and shock absorbers are essential elements, which significantly contribute to the oscillations of sprung and unsprung masses, also to the handling and braking characteristics of a vehicle, i.e. they affect the safety of the vehicle. Due to this reason, in this work, an experimental research on the condition of the shock absorbers of light vehicles, when applying the original research methodology, is presented. The performed experimental research is based on two stages. Firstly, the condition of the shock absorbers of the researched vehicles was determined by using a shock absorber test stand. Secondly, equipment was installed in the test vehicles, which measures the vertical acceleration values of the vehicle body, when it drives over an obstacle at low velocities. Based on the performed analysis of the experimental results, vertical acceleration values of the sprung masses of vehicles were indicated, which allows to simply and effectively evaluate the condition of the vehicle shock absorber, without a complex investigation of the shock absorber.

Keywords: Traffic safety · Light vehicle · Shock absorber · Vertical acceleration

1 Introduction and Literature Review

Currently many vehicle manufacturers focus on increasing the safety, comfort and control of the vehicles. These properties are majorly influenced by the suspension of the vehicle and one of its main components – shock absorbers. The suspension connects the frame or the body of the vehicle with the wheels, reduces the impact from road irregularities, and dampens the vibrations. This way the traffic safety and the comfort of driving are increased, the passengers and the vehicle are protected from unnecessary overload that can appear during oscillations. That is why, it is essential to continually improve the optimal performance parameters of the vehicle suspensions, considering the condition of one of the most important elements – shock absorbers.

Shock absorbers that are well designed and have proper damping efficiency should minimize the vibrations of the vehicle bodywork and ensure the appropriate road

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surface grip of the wheels [1]. It is clear that shock absorbers, which do not meet these essential requirements, directly endanger traffic safety by negatively affecting the driver of the vehicle and the performance of different vehicle components. A number of research works can be found, which analyse the relation and interaction between the shock absorbers, other vehicle components, the driver and traffic safety. For example, the authors in [2] investigated the rattling noise of shock absorbers, which substantially affects the psychological and physiological perceptions of the driver. The influence of a shock absorber wearing on the vehicle braking performance was analysed in [3]. The authors noted that the shock absorber wearing status has no influence on the brake performance of the vehicle when the car is on a smooth road profile, however, in the case of a rough road profile, the shock absorber status has a significant negative influence on the stopping distance. The influence of worn shock absorbers on anti-lock brake systems was also investigated in [4]. The authors in [5] considered the influence of the shock absorber on the steerability of the vehicle motion. The results of their investigation showed that the damaged shock absorber actually causes the change of the profile steerability of the vehicle and increases vehicle understeering. The change of the vehicle ride comfort and road holding characteristics due to a change of shock absorber temperature was examined in [6]. In their research, the authors remarked that the decrease in temperature does influence the ride comfort of vehicles, expressed in growth in spectral density of vertical acceleration. Other researches, which similarly to [6], are based on the influence analysis of the specific parameters of the shock absorbers on ride comfort /safety, like [7, 8], also can be found. In [7] the authors considered the influence of shock absorber friction on vehicle ride comfort and, in [8], the influence of shock absorber installation angle on vehicle handling and ride quality was studied. Based on the above mentioned research works it can be stated that the influence of shock absorbers on traffic safety and proper evaluation of the shock absorber condition is a relevant problem. Respectively, different propositions for evaluating the technical condition of shock absorbers can be found in literature. A review work on most common experimental diagnostic assessments of the technical condition of the shock absorbers is given in [9]. The authors pointed out three basic experimental diagnostic approaches: testing the shock absorbers using the free vibration method, testing the shock absorbers using the forced vibration method and the damping coefficient measurement. However, in their work, the authors do not discuss in detail the advantages and disadvantages of the mentioned approaches. The authors in [10] used an assessment of the technical condition of the vehicle shock absorbers built into the vehicle on the basis of the signals recorded during the vibration test. Based on their research, the authors also proved that a change of oil leak in the shock absorber causes a negative effect and increases the vertical accelerations amplitude of the wheel. An attempt to diagnose the damage of the shock absorbers of a light vehicle during road operation with the use of a vibration response measurement has been described in [11]. In the work it is indicated that the described method allows to find not only the fact that there is a problem with a shock absorber, but even which particular shock absorber is faulty. A novel approach for monitoring the condition of shock absorbers was proposed in [12]. In the novel approach the authors suggested that instead of monitoring the change in dynamic performance of a suspension system, the age and condition of a shock absorber can be estimated by measuring the cumulative work done using a calorimetry method involving temperature sensors. In [13] it is stated that due to the non-linear dynamics of shock absorbers and the strong influence of the disturbances such as the road profile, fault detection of a semi-active shock absorber is a challenge. Thus, in [13], two model-based fault algorithms for a semi-active shock absorber were proposed and compared: an observer-based approach and a parameter identification approach. While taking into consideration the researches described in different sources, it can be seen that shock absorbers are one of the most important vehicle subassemblies that significantly affect such parameters as braking effectiveness, stability, road holding and ride comfort characteristics, etc. Thus, diagnostics of such elements is a major factor which can ensure better traffic safety. However, as can be noted from the literature review, the diagnostic process of the shock absorbers itself can be very complex and requires specific knowledge. Due to these reasons, the aim of this work is to propose a simpler and effective methodology based on the evaluation of average values of the vertical acceleration a_y of the sprung masses, which would allow to indicate the performance and condition of the shock absorber without a complex investigation.

The remainder of this work is organised as follows. In Sect. 2, the experimental procedure is described. Section 3 provides the results and discussion of the experimental procedure. The final section presents the conclusions of the work.

2 Experimental Research

To achieve the aim of the work, an experimental research, during which the technical condition of the front and rear axle shock absorbers of the test vehicles was determined, was performed. The experimental research was performed in two stages. Firstly, the technical condition of the shock absorbers of the test vehicles was determined under laboratory conditions using a shock absorbers test stand. Secondly, to imitate real life vehicle exploitation conditions, the experimental research was performed in an open public road, while the test vehicles were moving over a speed bump. In total, the experimental researches were performed with 10 test vehicles.

2.1 Research Under Laboratory Conditions

During the first stage, the experimental research was performed in order to estimate which test vehicles will be used in further experimental tests. This stage of the experimental research is important in order to precisely indicate vertical acceleration values which will allow to evaluate the condition of the vehicle shock absorbers, i.e., to eliminate the vehicles that have shock absorbers with poor damping efficiency, which would have an impact on the formation of errors. In this case, testing of the shock absorbers, while applying the forced vibration method, was performed.

As already noted, the experimental research was performed using a *SAFELANE 400/800* shock absorbers diagnostics stand, designed to diagnose the shock absorbers damping efficiency indicators. In general, the used diagnostics stand consists of two measuring plates which consistently transfer to each other oscillations of variable frequency and constant amplitude. The stand measures the vertical force that is transferred from the wheel to the measuring plate. During the measuring, it is sought to determine the *Eusama* value, which shows the ability of the suspension elements to ensure the road surface grip of the wheels under unfavourable traffic conditions, and in this way to check the shock absorbers damping efficiency. For proper understanding of the shock absorbers damping efficiency evaluation process, it must be pointed out that the *Eusama* value is the minimal vertical resonant force to the wheels, which is expressed as a percentage of the wheel static mass. The evaluated *Eusama* value can change from 0 to 100% and respectively, the determined values can be divided into: from 0 to 20% – poor damping efficiency, 21 to 40% – sufficient damping efficiency, 41 to 60% – good damping efficiency, above 60% – excellent damping efficiency. An example of the experimental research results is given in Fig. 1.

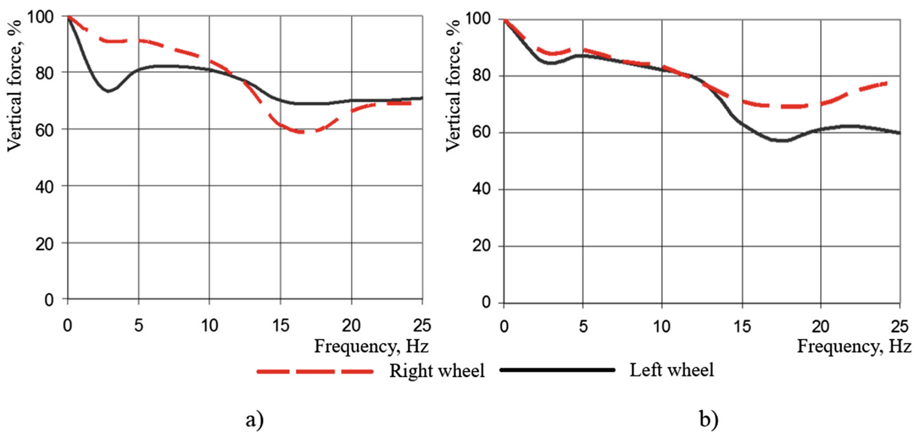


Fig. 1. The influence of the oscillations frequency of the front and rear axles on the value of the vertical forces affecting the wheels: (a) – front axle of test vehicle No. 1; (b) – rear axle of test vehicle No. 1 (Source: by the authors).

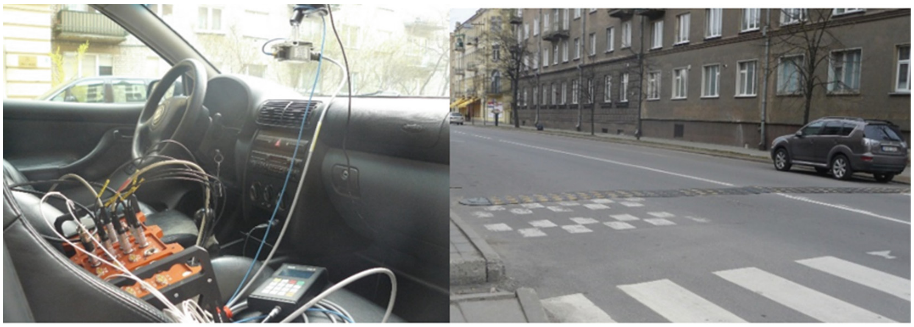
In the presented results in Fig. 1, the horizontal coordinate shows the vibration frequency of the measuring plates of the used stand, the range of which is from 0 to 25 Hz. The vertical coordinate, respectively, shows the relative value of the vertical force, which is affecting the wheel and is transferred to the measuring plates. It also must be remarked that, in Fig. 1, the curves show the minimal vertical force relative value of the vibrating wheel that is transferred to the measuring plates at different vibration frequency. Thus, the higher the curve, the smaller the change in the vertical force, the better the shock absorbers damping efficiency. As a result of this stage of the experimental research, it is important to note that the *Eusama* values of all the tested vehicles were within the value ranges corresponding to good and excellent damping of the shock absorber, i.e., these values of all the vehicles were within 41–60% and above 61%.

While taking into consideration the goal of the first stage of the experimental research, based on the results, after testing the shock absorbers damping efficiency of all the test vehicles using the diagnostics stand it can be stated that all of these vehicles can be used in further research, while moving in an open public road and imitating real life vehicle exploitation conditions.

2.2 Experimental Research While Moving in an Open Public Road

During the second stage, the experimental research was performed in order to estimate the value of the test vehicles sprung masses oscillations in the vertical direction, when the vehicle is moving over a speed bump and, based on the estimated values, to find out at which values of the vertical acceleration it can be stated that the shock absorbers in vehicles have proper damping efficiency (ensuring safe control of the vehicles). To achieve this goal, measuring equipment was installed in all of the test vehicles which is designed to evaluate the vertical acceleration a_y of the oscillations of the vehicle body as accurately as possible:

- data collection /processing device *KISTLER DAS-3* (was installed in the interior of the test vehicles (Fig. 2, part a)). The device was used to systemise and process the data measured during the experimental tests;
- dynamic angular deviation and acceleration sensor *KISTLER TANS-3215003M5* (was installed in the interior of the test vehicles (Fig. 2, part a)). The device was used to measure the oscillations and acceleration of the vehicle body;
- diagnostic equipment *BOSCH KTS570* (was installed in the interior of the test vehicles). The device was used for accurate measuring of the test vehicle velocities during experimental drives.



a) b)

Fig. 2. Second stage of the experimental research: (a) – vertical acceleration sensors with the data collection /processing system; (b) – the open public road with the speed bump where the experimental research was performed (Source: by the authors).

The tests were done on an asphalt-concrete coat in an open public road driving over a speed bump (Fig. 2, part b). The speed bump in the shape of a part of a circle in the street was set up over the entire width of the roadway. The width of the bump was 0.9 m, and the height – 0.05 m. What is more, during the second stage of the experimental research, different experimental drives were performed, i.e., the tests were done at the velocities of 10 km/h, 20 km/h and 30 km/h. During all the experimental drives, in all of the tested vehicles there were two human supervisors: the driver and the passenger.

3 Results and Discussion

In general case, the change patterns of the vertical acceleration values a_y, depending on time and the position of the test vehicle in relation to the speed bump, can be explained by the dependency presented in Fig. 3.

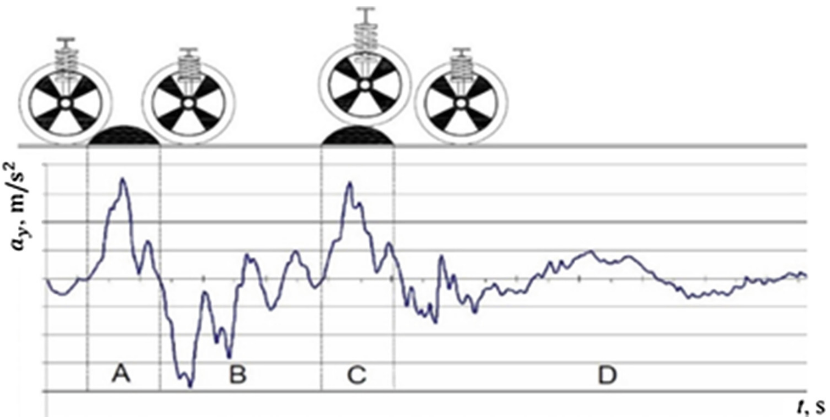


Fig. 3. The change patterns of the vertical acceleration values a_y, when the vehicle drives over a speed bump (Source: by the authors).

Figure 3 can be explained as follows: at the top of the graph portrayed is the wheel of the vehicle with a shock absorber and a spring at the moment of driving when the vehicle drives over the speed bump with the front and rear wheels. The condition of the spring (compression, rebound) and respectively, the compression and rebound of the shock absorber are portrayed, when the wheels drive on and off the speed bump. In Fig. 3, part A reflects the moment and the values of the vertical acceleration a_y, when the front wheels of the vehicle drive over the speed bump. The highest values of the appearing acceleration a_y are noticed at this moment. Part B indicates the acceleration values of the sprung masses of the vehicle, when the front wheels of the vehicle make contact with the road surface after driving off the bump. At this moment, the damping of the oscillation of the sprung masses and the high growth of the vertical acceleration values a_y can be noticed. In part C, portrayed is the moment when the vehicle drives on and off the speed bump with the rear wheels and the highest acceleration a_y values are seen. Part D indicates the vertical acceleration values of the sprung masses of the vehicle, when the rear wheels of the vehicle make contact with the road surface after driving off the bump.

Actual examples of the results of the second stage of the experimental research are respectively given in Figs. 4 and 5. It must be noted that the results of the experimental drives of all the test vehicles were similar to each other. Thus, only a few specific examples of the experimental data recorded during the experimental drives are described further.

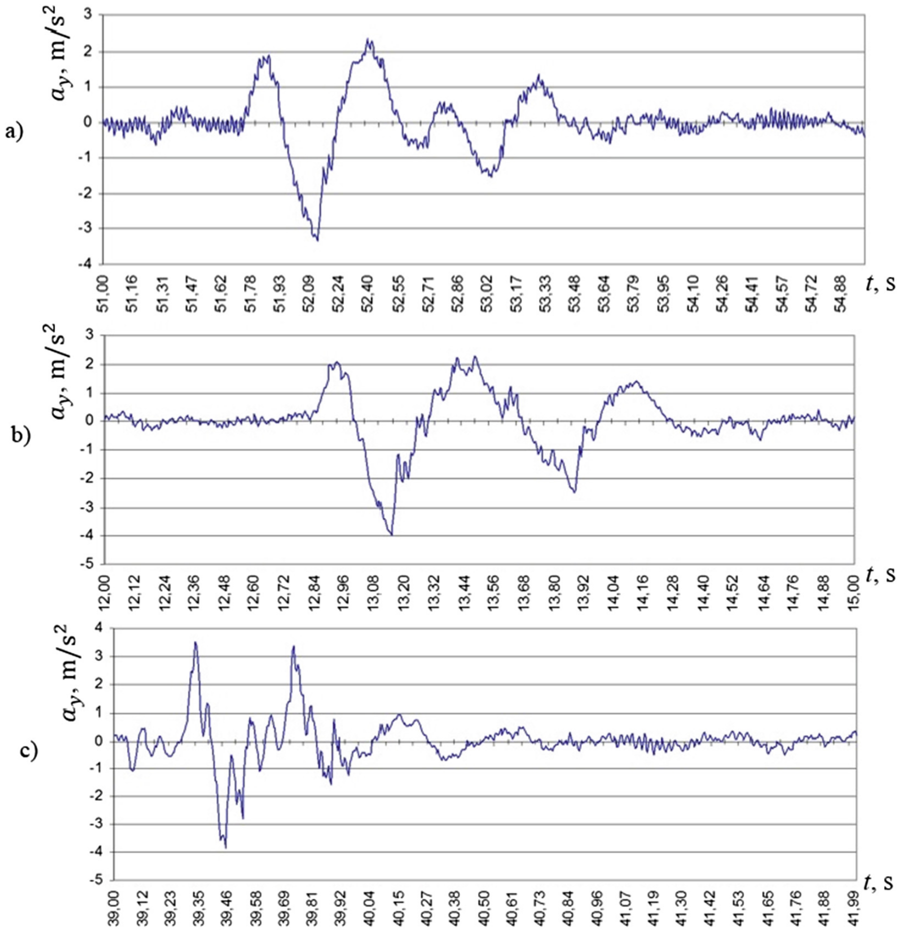


Fig. 4. The change patterns of the vertical acceleration a_y, when the test vehicle No. 1 drives over the speed bump: (a) – at the velocity of 10 km/h; (b) – at the velocity of 20 km/h; (c) – at the velocity of 30 km/h (Source: by the authors).

In Fig. 4 an example of the change pattern of the vertical acceleration a_y of test vehicle No. 1, while driving over the speed bump at different, afore mentioned, velocities, is presented. From all of the cases of Fig. 4, the damping of the vertical oscillations of the vehicle sprung masses, when the wheels of the vehicle drive off the bump, can be clearly seen. When the vehicle drives over the bump with the front wheels, the value of the acceleration in the vertical direction a_y grows exponentially and then starts to gradually decrease. When the vehicle drives over the bump with the rear wheels, the value of the acceleration a_y increases and starts to decrease equally quickly, and then settles down during smooth driving. Respectively, based on the data of all the experimental drives, it can be indicated that the highest values of the vertical acceleration a_y, when the acceleration measuring sensors are installed on the front part of the vehicle (on the front glass of the vehicle), depending on the vehicle velocity, when driving on the speed bump, varies from 0.6 m/s^2 to 5.25 m/s^2. This observation can be explained by the above given figure (Fig. 3). In Fig. 5, the test results of three test vehicles, in the figure respectively marked as 1, 2 and 3, are also presented.

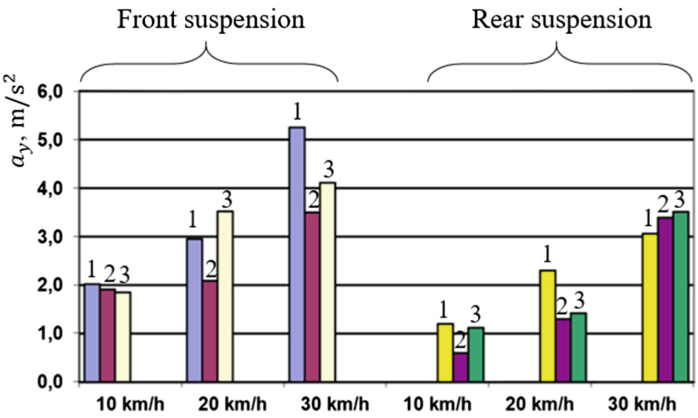


Fig. 5. Example of different test vehicles front and rear axle vertical acceleration a_y values, depending on the driving velocity (Source: by the authors).

Based on the results given in Fig. 5 it can be pointed out that, when driving over an obstacle, the average values of the vertical acceleration a_y of the sprung masses of the vehicle, when the vehicle has proper and efficient shock absorbers, are around 1.93 m/s^2 when driving with the front wheels and 0.97 m/s^2 when driving with the rear wheels. Respectively, at the velocity of 20 km/h – around 2.85 m/s^2 and 1.67 m/s^2, at the velocity of 30 km/h – around 4.30 m/s^2 and 3.32 m/s^2. It can be seen that, in all the cases of the experimental drives, the highest acceleration values were reached when driving over the speed bump with the front wheels of the vehicle. Respectively, during all the cases of the experimental drives, the highest acceleration values are reached at the highest, i.e., 30 km/h, velocity. Thus, these average values of the vertical acceleration a_y can be used as reference values seeking to evaluate whether the shock absorbers can ensure safe exploitation of the vehicle, without a detailed inspection of the shock absorbers rebound and compression performance, which requires explicit knowledge about their dynamic behaviour under various operational modes.

4 Conclusions

In this work an experimental procedure of shock absorbers condition evaluation was presented and described. The described experimental procedure is based on an approach combined of two stages: firstly, testing of the shock absorbers, while applying the forced vibration method, and secondly, an experimental research while moving in an open public road, were performed. Main contribution of this work – indicated vertical acceleration values of the vehicle sprung masses, which allows to simply and effectively evaluate the condition /fault of the vehicle shock absorbers, without a complex investigation of the shock absorber or specific explicit knowledge. The analysis of the experimental research showed that the approximate average values of the vertical acceleration of the sprung masses, at which an assumption can be made that the shock absorbers of the vehicle function properly, are: at the velocity of 10 km/h – 1.93 m/s^2 when driving with the front wheels and 0.97 m/s^2 when driving with the rear wheels, at the velocity of 20 km/h, respectively – around 2.85 m/s^2 and 1.67 m/s^2, at the velocity of 30 km/h – around 4.30 m/s^2 and 3.32 m/s^2. Respectively, practical application possibilities of the described results can be pointed out – the determined values of the vertical acceleration of the sprung masses can be used as guidelines of shock absorber and suspension condition, while performing the periodic motor vehicle inspection.

However, although the combination of the two different experimental procedure approaches increased the accuracy of the performed research, to improve the proposed assumption and values, it would be appropriate to carry out the research with a greater number of light vehicles. Due to this reason, future work by the authors is to further perform experimental research, while considering not only a greater number of test vehicles, but also a different size of obstacles and respectively, different velocities.

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