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Measuring the Quality of Driving Characteristics of a Passenger Car with Passive Shock Absorbers

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The article deals with the quality of the driving characteristics of a passenger car with passive shock absorbers depending on the tire pressure. The work was solved using experimental methods using the AHS test bench. The main goal of the work was to assess the vehicle suspension system using acceleration sensors and pressures between the wheel and the road using shock absorber test benches using the EUSAMA and CAP methodology. The results of the work demonstrated the possibilities of using the measurement of acceleration values in selected places in the vehicle. The obtained results were also verified for the possibilities of further development in the area of reducing the dynamic load when driving a passenger car on the road.

Keywords: car, experiment, driving characteristics, acceleration, driving comfort, measurement

1 Introduction

The influence of the vehicle's suspension system must be assessed comprehensively from the point of view of achieving all the goals we set for the suspension system. In practice, this primarily means achieving the optimal ratio of setting the suspension stiffness, choosing between a stiffer suspension (higher driving safety) and a softer suspension (better driving comfort). From a technical point of view, it is also necessary to assess the space required for building the system, energy requirements and reliability. From an economic point of view, the price of the system, the price of maintenance and the service life are essential.

When the vehicle crosses a bump, a quick reaction of the damping system is required and a change in the characteristics of the dampers from soft – beneficial for the comfort of the crew to hard – beneficial for faster damping by suppressing disadvantageous forms of oscillations. [1]

By driving comfort, we mean from a physical point of view the acceleration of the superstructure, which affects the car's crew and especially the driver. Driving safety is mainly the dynamic forces between the wheel and the road, manifested by the pressure of the tires on the road / rebound of the tires from the road/, when it is necessary to ensure constant contact of the wheel with the road, even when the vehicle passes over bumps. Driving safety and driving comfort cannot be assessed separately, driving safety must always be ensured with respect to acceptable driving comfort. [2]

The issue of damping and determining the required properties of shock absorbers and springs in passenger cars is directly related to the efforts of motor vehicle designers to increase crew comfort, crew safety and road safety. The effort is also to reduce the negative impact of vibration transmission on other parts of the vehicle, thereby increasing wear and reducing their service life. An example can be tire wear, where up to a 10% increase in wear is reported when driving 9000 km with shock absorbers of 65% efficiency. [3]

The impact on the environment is, on the one hand, a reduction in fuel, i.e. the emission of harmful gases (improvement of tire contact with the road when driving on uneven roads) and a significant reduction in the noise caused by the car on the surroundings and the vehicle's crew. A non-negligible need is also to reduce the impact of vibrations on the crew and thereby protect their health (economic and social aspect), especially for drivers who drive tens of thousands of kilometers per year (truck drivers, transport companies, etc.). [4, 5]

The effect of inappropriate vibrations on the health of the crew is serious. Many studies mention that exposing the body to long-term vibrations causes an adverse response in the human body, which can lead to irreversible health damage. We are exposed to such vibrations, for example, when driving in vehicles, and it is also known that vibrations cause changes in the organism at almost all levels, i.e. the subcellular level, the cellular level, the tissue level, the level of organs and their systems, and the level of the whole body. However, the exact description of these changes is very complex and still unresolved, as the influence of vibrations on other organ systems than those on which the experiments are aimed is often unknown. [6-8]

The poor technical condition of shock absorbers results in a number of facts, such as a reduction in the effectiveness of the brakes and ABS, ESP systems, or a reduction in controllability. As stated by Vlk, I quote [9]: "If shock absorbers are such an important structural element and in bad condition can negatively affect the driving characteristics of the vehicle and thus the overall safety of road traffic, it is necessary to be able to test them." Vlk further states that shock absorbers are tested either separately after disassembly from the vehicle on test machines (development and research tests) or directly on the vehicle (checking the technical condition of shock absorbers). An example of the negative impact of shock absorber wear on safety is the reduction of the braking distance at a speed of 80 km/h on a flat road by 2.6 m, while reducing the effectiveness of the shock absorber by half compared to a new shock absorber. There is an even greater extension of the braking distance on an uneven road, where the distance at a speed of 70 km/h is extended by 11.3 m at half the effectiveness of the shock absorber. The values given apply to a dry road. In poor road conditions, for example in the rain, the increase in braking distance with shock absorbers can be half as effective as 23%, and aquaplaning can occur at speeds lower than would be the case with a new shock absorber.

Despite the importance of the shock absorbers being in good condition, the shock absorbers are not measured during mandatory regular MOT inspections. The decree of the Ministry of Transport and Communications on technical inspections and emissions measurement prescribes only a visual inspection of the steering and clearance of the steering condition in the list of control actions. Only the steering gears, steering gear mounting, condition of the steering lever mechanism, function of the steering lever mechanism, steering column / fork and steering clearance are visually inspected. The adhesion of the wheels to the road is not measured at the MOT.

The time-consuming disassembly method of shock absorber testing makes the operation considerably more expensive. The time required for disassembly and reassembly of all four shock absorbers must be added to the time required for testing on the test machine. In car repair practice, therefore, we only encounter shock absorbers without disassembly. In this method, not only the condition of the dampers is assessed, but the condition of the entire damping system with the influence of other parts such as tires, suspension and the mass and structure of the vehicle itself. As stated by Vlk, I quote [9]: "The fact that not only the hydraulic system of the shock absorber is tested, but the entire suspension of the wheel, can become a disadvantage when trying to locate the cause of the unsatisfactory state of the axle."

The authors of the articles [10-18] dealt with the issue of vehicle dynamics, and their knowledge was used to prepare this work.

In the presented article, a solution to the adhesion of tires to the road with passive shock absorbers is described. The measurement was carried out using the EUSAMA methodology on chassis testers. During the measurement, the vertical acceleration was measured in different parts of the vehicle.

2 Performed experimental measurements

The measurement was performed experimentally on the AHS Prüftechnik PKW test bench (see Fig. 1). The chassis tester measured:

- Adhesion of the tires of the front and rear axles of the unloaded and loaded vehicle;
- Acceleration on the steering wheel and the seat grip of the unloaded and loaded vehicle;

Fig. 1 *Chassis tester AHS Prüftechnik PKW*

A Renault Talisman Intens vehicle, dCi160 EDC, year of manufacture 2016, on Michelin Primacy 3 tires, 245/45 R18, was chosen for measuring passive shock absorbers. The vehicle was equipped with passive shock absorbers and coil springs, these components were connected on the front axle to a McPherson suspension unit. The rear axle was semi-rigid with anti-roll bars integrated into the beam, a separate coil spring and a 45° rake shock absorber. The sensors were placed on the measured vehicle on the handle of the seat and the steering wheel (Fig. 2).

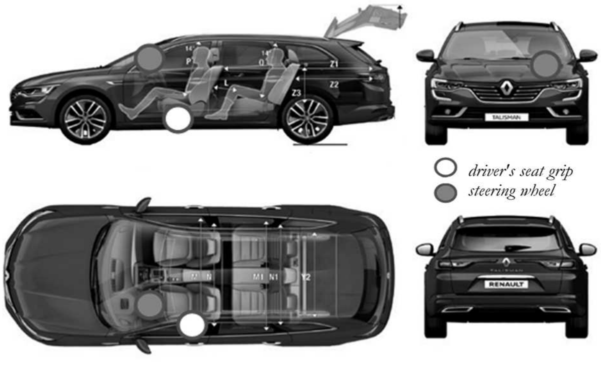

Fig. 2 *Location of acceleration sensors on the Talisman vehicle*

In this measurement, weighing the vehicle and measuring the shock absorbers of the rear and front axle were also important in order to determine the dependence of suspension, damping and vibrations on the vehicle load. The manufacturer's values for the mentioned model (equipment and engine) were:

- Operating weight 1598 kg
- Maximum payload 529 kg
- Maximum permitted total weight 2118 kg

The maximum payload was 529 kg. With an even distribution of weight between the five seats and the luggage compartment, the weight per item comes out to 88.17 kg. First, the vehicle was measured without a driver, then with the vehicle weighed down to the maximum payload level. The load weighing 529 kg was distributed over all five seats and in the luggage compartment according to Fig. 3.

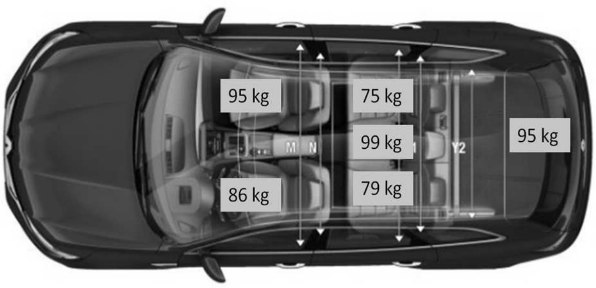

Fig. 3 *Load distribution (maximum payload) in the vehicle*

The measurement was carried out with the tires inflated to the prescribed pressure and with no load on the driver's seat (according to the regulation for testing the vehicle on the tester). Acceleration sensors were attached to the steering wheel and the driver's seat handle. For proper testing, it was necessary to follow the instructions on the tester's monitor. First, the tester recorded the static load of the vehicle on each wheel of the front axle, then the rear axle. After that, the measurement took place automatically in two phases. First, the tester vibrated and the shock absorbers were heated for three seconds. After that, the measurement itself took place for five seconds. It was important to compare the wheels parallel to the vehicle and the correct location of the wheels on the vibrating pads (Fig. 4).

Fig. 4 *Tester screen and vibration pad with wheel correctly positioned*

The measurement of tire grip and acceleration acting on the steering wheel and the driver's seat grip was supplemented by a measurement of the damping range - shock absorber stroke. Shock absorber travel was measured indirectly, by measuring the length from the center of the wheel to the edge of the fender. This measurement was carried out on the wheels suspended, and on the vehicle standing on the wheels without load. The front axle was measured after descending from a concrete sleeper with a height of 150 mm. The maximum compression of the rear axle was determined by the length of the stop, which is 70 mm.

The difference between the sprung and unsprung wheel was 100 mm for all four wheels. The front wheel was pressed against the stationary vehicle by 20 mm after going down the concrete sleeper with a height of 150 mm (the maximum space between the tire tread and the wheel arch is 80 mm). The maximum compression of the rear shock absorber is limited by the 70 mm spring stop, and the spring in the unsprung state has a length of 140 mm. From the mentioned measurement, it follows that the front damping system has a maximum stroke range of approximately 120 mm and the rear damping system 170 mm. The deflection of the vibrating plate during testing is 6 mm.

3 Measurement results

The results of the adhesion measurement were supplemented by the amplitude measurement with the AHS Prüftechnik tester (Fig. 5-8). The measurement results were evaluated as unsatisfactory if the difference between the left and right side tested was greater than 30%, both for grip and for amplitude. Furthermore, the measurements were unsatisfactory if the damper amplitude exceeded more than three times the deflection value of the test plate, or the adhesion of the wheel to the pad was less than 21% (according to the EUSAMA methodology).

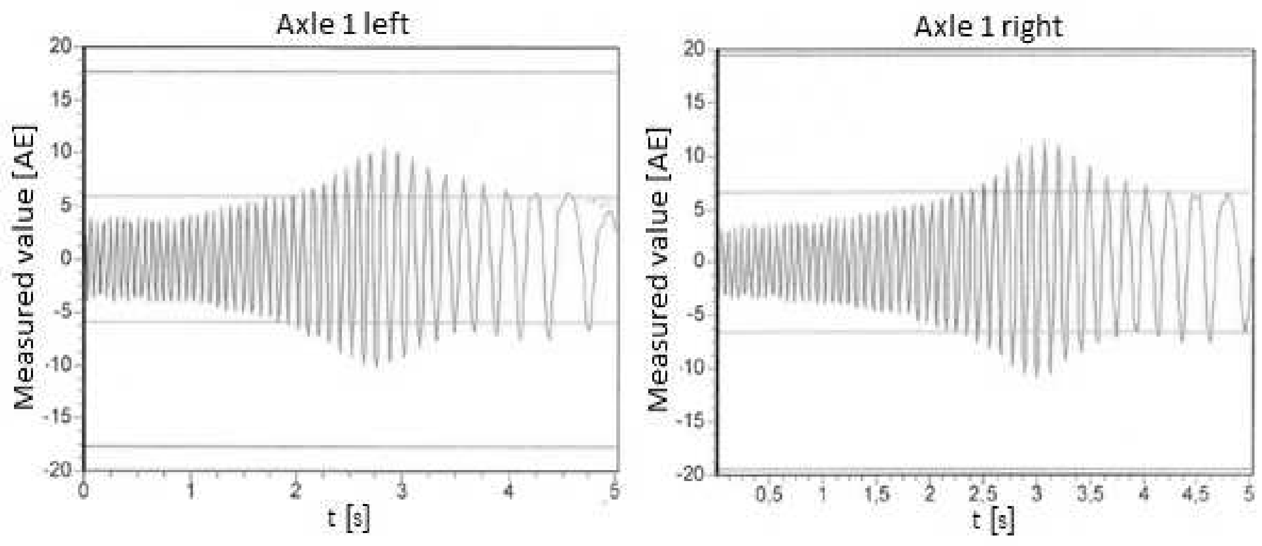

Fig. 5 *Measurement of the front axle of a fully loaded vehicle*

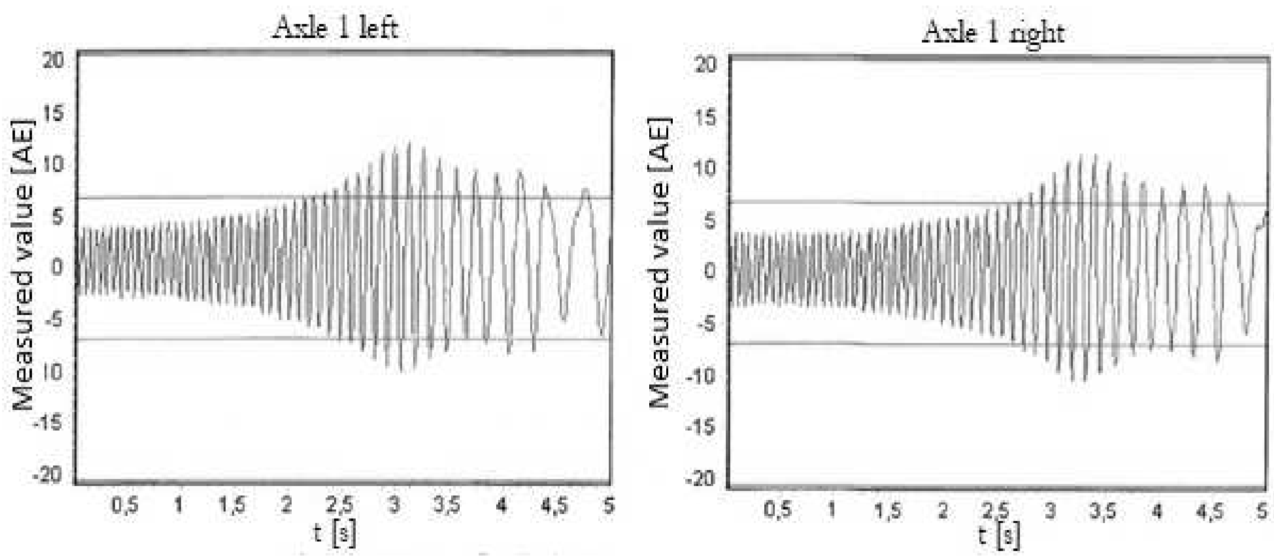

Fig. 6 *Measurement of the front axle of an unloaded vehicle*

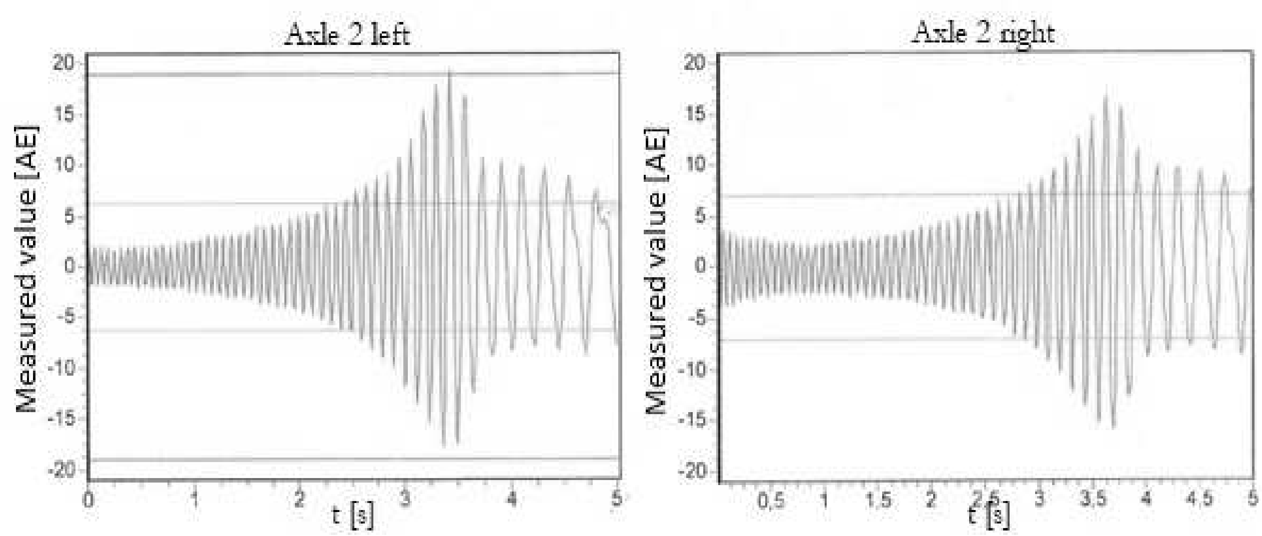

Fig. 7 *Measurement of the rear axle of a fully loaded vehicle*

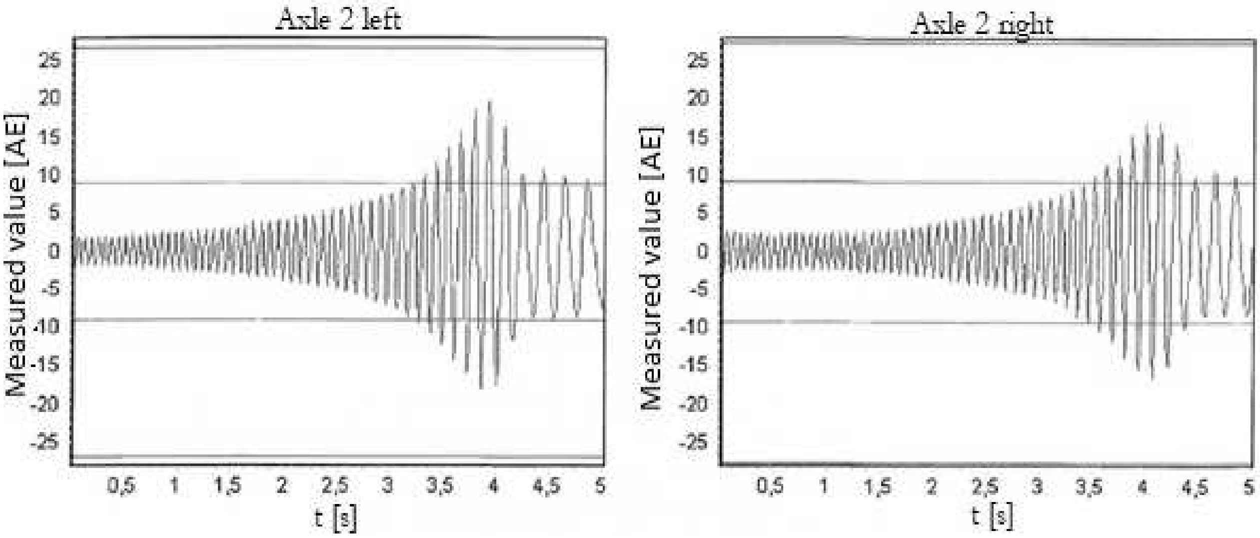

Fig. 8 *Measurement of the rear axle of an unloaded vehicle*

In Tab. 1 shows the results of all performed measurements.

Tab. 1 *Overview of adhesion measurements performed using the EUSAMA method, average of 10 measurements*

	Unloaded			Full load		
Front axle	left	right	difference	left	right	difference
Amplitude [mm]	22,1	21,8	1,2%	20,6	22,7	7,0%
Damping [%]	67,8	68,8	1,0	65,5	65,4	0,1
Weight [kg]	488	481	7	584	562	22
Rear axle	left	right	difference	left	right	difference
Amplitude [mm]	37,7	33,5	11,1%	37,1	32,6	12,1%
Damping [%]	57,0	63,1	5,1	41,0	53,0	12,0
Weight [kg]	319	309	10	505	461	44
Total weight [kg]	1597			2112		

4 Discussion

Front axle grip measurements for all model situations were found with approximately identical results. This was to be expected for a loaded vehicle, as the vehicle structure must be designed in such a way that the driving characteristics are not significantly affected if the prescribed payload is not exceeded. This applies mainly to the front axle, because it is necessary to maintain grip here, both because this axle is driven and because the front wheels turn. With low adhesion, the wheels would lose contact with the road and this would worsen both the steering and the necessary grip of the tires when crossing an obstacle or when going through a bend. The payload is 1/3 of the weight of the unloaded vehicle, i.e. at full load, the weight of the vehicle accounts for 75% of the weight and the weight of the crew and cargo 25%. For the rear axle, the difference between an unloaded and loaded vehicle is up to 16%.

It was found that with new shock absorbers, this difference may not have a major impact on driving safety, but with a worse condition of the shock absorbers, the vehicle can pass the test according to the EUSAMA methodology and, under load, reach the area of the no longer satisfactory condition of the shock absorbers. At the same time, there was a more pronounced difference between the grip of the left and right wheels on the rear axle - the left wheel had worse grip by 6% in an unladen vehicle, by 12% in a loaded vehicle.

Lowering the effectiveness of the left side of the rear damping system was due to a worse condition of the damper or spring. A significant difference was found when comparing the grip of the tires between the front and rear axles. It was 10% lower for the rear axle on the left side. It was even 24% lower for a loaded vehicle.

When comparing the right sides (with rear damping without reduced efficiency), the difference between front and rear adhesion for the unloaded and under-inflated vehicle was only 5%, and the difference for the loaded vehicle was found to be 12%.

The difference in adhesion between the front and rear damping shows that the rear damping system has been designed to be softer for better crew comfort and cargo security. This was clearly shown when the vehicle was loaded, where the grip was slightly reduced for comfort. Again, it can be stated that with new (functional) shock absorbers, this reduction does not affect safety and the vehicle would pass the adhesion test according to the EUSAMA methodology. If the shock absorbers are of poor quality, the vehicle may still pass during testing, but the condition may already be unsatisfactory when loaded.

Another measurement was the effect of acceleration at the driver's place, which is transmitted to the steering wheel and the driver's seat grip. The results of the measurements can be seen in Fig. 9 to 12.

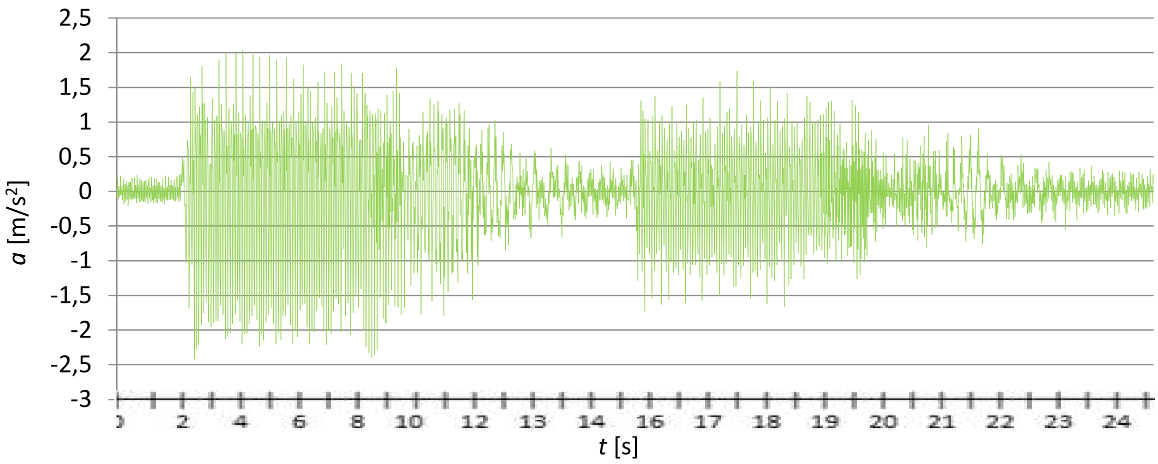

Fig. 9 *Course of accelerations acting on the steering wheel - test of the left and right wheel of the front axle of the unloaded front axle*

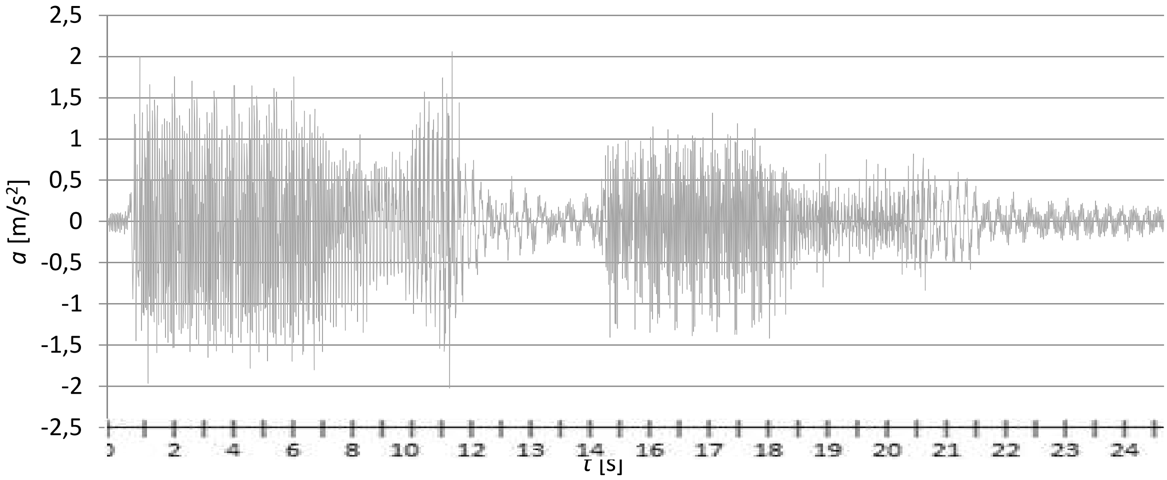

Fig. 10 *Course of acceleration acting on the steering wheel - test of the left and right wheel of the rear axle of the unloaded rear axle*

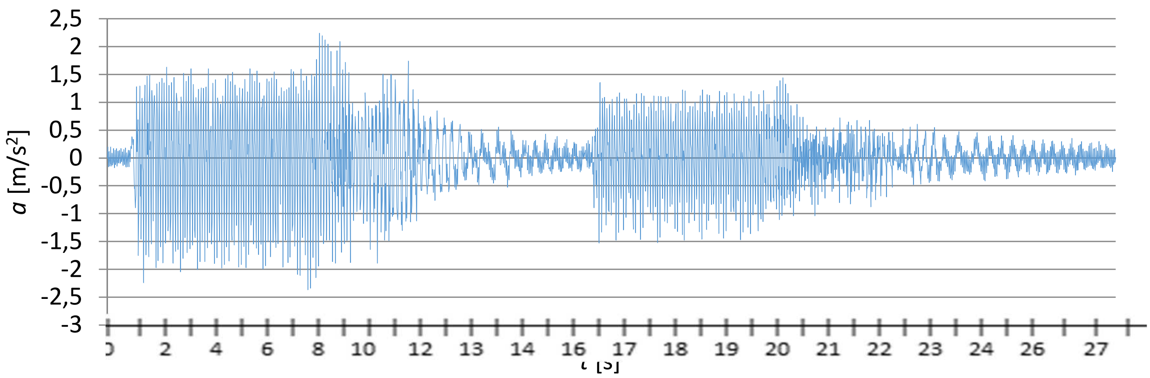

Fig. 11 *Course of acceleration acting on the steering wheel - test of the left and right wheels of the front axle under load on the front axle*

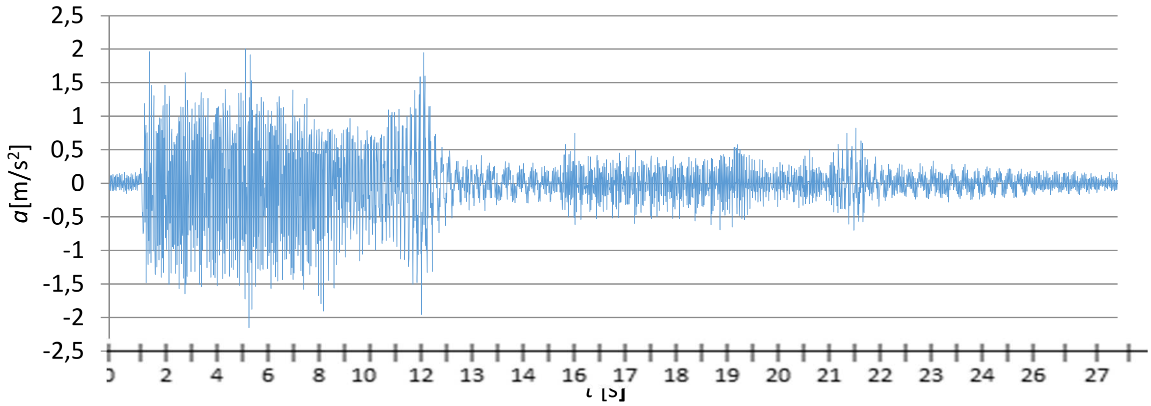

Fig. 12 *Course of acceleration acting on the steering wheel - test of the left and right wheel of the rear axle under load on the rear axle*

By comparing the acceleration curves transmitted to the steering wheel, it was found that when testing the wheels of the front axle, there is only a minimal difference in the acceleration induced by the tester plates. This acceleration ranged approximately between -2 m.s^{-2} and +1.5 m.s^{-2} from the left front wheel and -1 m.s^{-2} and +1 m.s^{-2} from the right front wheel, regardless of whether the vehicle was tested unloaded, loaded. Only for an unloaded vehicle, the acceleration is slightly greater than ± 0.5 m.s^{-2}. Even in shape, the course of the vibrations does not differ noticeably. There are bigger differences in the acceleration measured when testing the rear axle. In terms of shape, there was an anomaly in the shape of the vibrations during the damping of the left rear wheel, which, after a decrease in amplitude at the end of the test, again increased in amplitude. This anomaly is particularly noticeable in an unloaded vehicle, when the acceleration amplitude even exceeded the maximum value of the first half of the measurement.

It is clear that the increase in amplitude during the transmitted acceleration from the left rear wheel is related to the low adhesion of the left rear wheel, which is up to 13% lower compared to the right rear wheel. This finding confirms the assumption that the left rear shock absorber is less efficient. The slight reduction in maximum acceleration when testing the rear axle of a loaded vehicle corresponds to the fact that the damping of the rear axle of the vehicle is dimensioned so that the driving characteristics of the vehicle are not worse when fully loaded than when unloaded. To confirm this assumption, it would be necessary to repeat the measurements on a vehicle with the same effectiveness of the rear shock absorbers and for different values of the vehicle load.

5 Conclusion

Inadequate damping is almost undetectable when driving on normal road surfaces, and yet there is no way to monitor their conditions. In contrast to tire pressure monitoring or brake pad wear monitoring, which are gradually being applied to vehicles, monitoring the effectiveness of shock absorbers is not technically resolved in any way. There is room for further development in this area. Of course, in the event of an accident, such as a broken spring, a broken spring bed or a completely non-functioning shock absorber, it is detectable by the driver (significantly reduced driving comfort, noise, etc.). In this area too, prevention and regular checks of the damping and suspension system at a professional service center are important.

The currently most widespread passive damping system certainly theoretically has many shortcomings, either in response speed or in compromise tuning that meets both comfort and safety requirements, but from the point of view of normal road traffic, it appears to be an acceptable solution. The damping effect of the system itself is acceptable, but at the same time it is a structurally simple system with an acceptable price versus performance ratio. A possible improvement is mainly in the combination of shock absorbers and coil springs with a progressive character. Due to the price and complexity of the system, adaptive dampers in passenger cars do not offer a fundamental advantage over passive dampers. Only the automatic setting of greater stiffness of the shock absorbers in a crisis situation has its justification. Sporadically used active damping systems are interesting above all from the point of view of theoretical knowledge of vibration damping issues. In practical use, this system is limited by the price, the complexity of the construction, the need for a larger installation space, the dependence on a number of other electronic systems of the vehicle and, above all, the high energy demand. Theoretically, the problem can be solved only by predicting the future state, either partially - by mapping the reactions of the front axle and, accordingly, the rear axle, or completely – by scanning the road in front of the vehicle and the reaction of the active damping system to this predicted state.

During the measurement and processing of the article, several other topics arose that would expand the assigned work with additional chapters. As an example, we can mention the measurement of damping fluid temperatures and possible changes in damping efficiency due to viscosity. Alternatively, measuring the tire pressure while driving and mapping the operating conditions in which there is a complete loss of adhesion. Furthermore, for example, the transfer of acceleration to the crew and especially to the driver through the seat, floor and steering wheel. In the case of an economic evaluation, it would be interesting to assess the probability of wear and reduction of the service life of individual vehicle parts (mainly parts of the chassis, wheel suspension and tires) due to poor vibration damping.

The draft measures can be divided into recommendations using existing technical solutions and recommendations using theoretical knowledge of solutions not yet applied. The apparently best feasible measure based on the existing situation is prevention. Prevention ensured by systematic and regular inspection at professional services. The possibility of dismantling and testing the shock absorber and spring comes at a high price, which usually exceeds the simple replacement of components with new ones. In case of suspicion of deterioration of functionality, it is advantageous to check the damping on the chassis tester. Here, it is possible and advantageous to further develop more accurate methods of non-disassembly testing with the help of optimal condition databases provided by car manufacturers. Another measure is compliance with the regulations of car manufacturers, especially the prescribed tire pressure and vehicle load. The challenge for car manufacturers is to develop such a chassis, suspension and damping system design that will minimize the vehicle's unsprung mass as a whole. It is expedient to focus primarily on structurally simpler solutions with the use of new materials and techologies, the properties of which allow, for example, the construction of springs with more complex progressive characteristics. This area is a challenge to combine the know-how of material engineering and construction. Materials based on carbon nanotubes - fullerenes and nanocomposites, which excel in an excellent combination of flexibility and strength properties, will certainly find application in damping in the future.

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