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Experimental study of the influence of the damping coefficient of a semi-active suspension on vehicle acceleration during starting

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Annotation. Problem. *The influence of the damping coefficient of a semi-active suspension on vehicle acceleration during starting can be determined experimentally. The experimental research method is the most accurate for obtaining real data, as it accounts for vehicle parameters and the specific operation of the suspension system. This study conducted an experimental investigation of the acceleration process of a vehicle equipped with a semi-active suspension. The effect of the suspension damping coefficient on vehicle acceleration was determined for the first and second gears. The vehicle selected for the study was a Land Rover Evoque equipped with a CVSA suspension system from Tenneco. Speed, acceleration, and distance parameters of the vehicle were measured under conditions of low and high suspension damping. For a clear representation of the research results, graphical dependencies of speed, acceleration, and distance on time were constructed using MATLAB software. The results were analyzed, and corresponding conclusions were drawn.* ***Goal.*** *The purpose of the study is to validate the theoretical research on the influence of the damping coefficient of a semi-active suspension on vehicle acceleration during starting under road conditions.* ***Methodology.*** *The approaches adopted in this study to achieve the objective are based on the principles of vehicle theory.* ***Results****. It has been established that a vehicle with a high suspension damping coefficient has a greater impact on acceleration in first and second gears compared to a vehicle with a low damping coefficient. It was determined that the acceleration of a vehicle with high suspension damping during first-gear acceleration is higher than that of a vehicle with low damping. During the shift from first to second gear, the suspension settings do not affect vehicle acceleration. In second-gear acceleration, the vehicle with high suspension damping also exhibits higher acceleration than with low damping. Corresponding data were obtained showing different acceleration distances for vehicles with high and low suspension damping over the same period of time.* ***Originality****. The results of the study provided an insight into the impact of suspension on vehicle acceleration when using different gears.* ***Practical value****. The results of the experimental study enable a comparative analysis of the theoretical research on the influence of the damping coefficient on vehicle acceleration. Moreover, the obtained data can be utilized in the design of new vehicles or in the improvement of sports cars, such as dragsters.*

Key words: *damping coefficient, acceleration, vehicle, starting, semi-active suspension.*

Introduction

The design of a suspension system is influenced by numerous factors, particularly the dynamic characteristics of the vehicle, ride comfort, handling, and durability. In the global automotive industry, it is common practice to "customize" or adjust suspension parameters to make the vehicle more suitable for a different customer base and adaptable to various driving environments. Therefore, determining the influence of the suspension damping coefficient on vehicle acceleration parameters is a relevant task that requires comprehensive review and investigation.

Analysis of publications

Today, vehicle modeling is a crucial tool for various applications in the automotive industry. Models are used for the design and integration of vehicle subsystems, as well as for assessing their characteristics, such as noise, vibration, stiffness, efficiency, and fuel consumption. Road transport engineers focus on improving vehicle active safety, while motorsport engineers work on enhancing performance, particularly in vehicle dynamics and lap times [1]. Virtual models and simulations are becoming increasingly important in motorsport as well [2].

Racing cars aim to achieve optimal performance by focusing on aerodynamics and suspension settings. Parameters such as vertical suspension, rolling stiffness, and damping are essential for optimal configurations. However, research often centers on passenger comfort in road vehicles [3].

Developing new or improving existing mathematical models for suspension dynamics is vital for the advancement of automotive technology [4,5,6]. Several studies analyze different suspension models and their impact on vehicle dynamics, particularly on stability during maneuvering or driving on curved road sections [7].

There are also studies investigating the effect of suspension settings on braking distance. Certain approaches allow for a reduction in braking distance by altering the vertical dynamics of the vehicle [8].

However, there is still insufficient research examining the impact of suspension damping on vehicle acceleration. This study could help improve the accuracy of virtual models and assist engineers in more precisely tuning suspension systems to achieve better performance on the road [9].

Purpose and Tasks

The purpose of the study is to validate the theoretical research on the influence of the damping coefficient of a semi-active suspension on vehicle acceleration during start under road conditions.

To achieve this objective, it is necessary to perform an analysis of the suspension characteristics, vehicle acceleration, distance, speed, and time, and determine the effect of the suspension damping coefficient on vehicle acceleration.

Description of the equipment, methodology, and results of the experimental studies

The vehicle selected for the study was a Land Rover Evoque equipped with a CVSA suspension system from Tenneco. The overall view of the vehicle is shown in Figure 1.

The control and registration system was installed in the trunk of the vehicle, allowing for convenient and secure placement within the vehicle. This approach enables all necessary system components to be stored in one location, ensuring easy access when needed.

Fig. 1. The overall view of the installed external equipment on the experimental vehicle

Figure 2 shows the precise location of this system in the trunk, helping to understand how the space is organized and how the system components interact with each other within the vehicle. Placing the system in the trunk is an important element for ensuring the system's uninterrupted operation and for making efficient use of the available space in the vehicle.

Fig. 2. The overall view of the control and registration system

The control and registration system consists of several important components, each performing its function to ensure the effective operation of the system. The components of the system include:

1. RapidPro digital signal amplifier, which ensures stable signal transmission at a high level without quality loss.
2. dSPACE SCALEXIO AutoBox system, used for simulation and testing processes, providing the ability to connect various devices for conducting tests.
3. TELTONIKA RUTX11 router, which ensures uninterrupted communication and stable network access, crucial for data exchange.

4. Race Logic VBOX 3i data recording device, used for collecting and storing information about the vehicle's operational characteristics.

5. Lithium-ion battery, which powers all of the above components, allowing the system to operate autonomously under limited power supply conditions.

These components are shown in Figure 3, where their placement and interaction within the control and registration system are depicted.

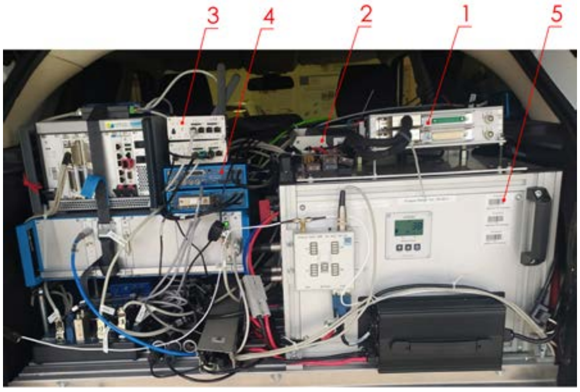

Fig. 3. The placement of devices in the control and registration system

The overall view of the location where the experimental studies were conducted is shown in Figure 4. It illustrates how the vehicle performs the acceleration run in first and second gears. This allowed for the assessment of the vehicle's acceleration dynamics under real operating conditions.

Fig. 4. Test vehicle on the test site (Range Rover EVOQUE)

The parameters studied during the experimental research were recorded using the ControlDesk dSPACE software, as shown in Figure 5.This program allows for real-time monitoring and data recording, ensuring an accurate display of all necessary indicators such as speed, acceleration, dynamic vehicle characteristics, and other important parameters during testing.

The analysis of the results of the experimental study conducted to assess the impact of suspension damping on the acceleration and braking of the vehicle revealed significant differences in the vehicle's dynamics depending on the damping level.

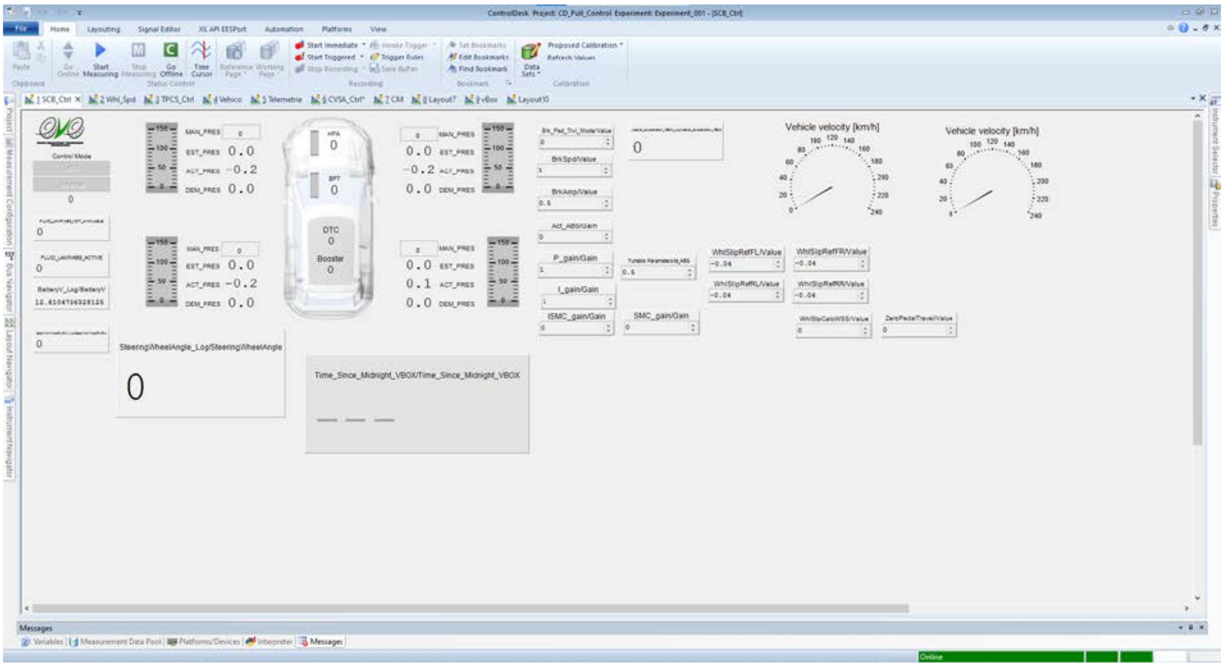

Fig. 5. The working window of the ControlDesk dSPACE software.

During the acceleration of the vehicle in the first gear, when the suspension had high damping, the vehicle reached a speed of 26.5 km/h in 5.2 seconds. This is 7.5% more than with low damping, as seen from the results shown in the graph in Figure 6. This difference in figures indicates that increased suspension damping contributes to more efficient acceleration, providing greater stability and control over the vehicle.

Further, when the vehicle shifted to second gear (5.2 – 6 seconds), coasting, the speed was also higher with high suspension damping, reaching 24.5 km/h. This indicates that the efficiency of suspension damping also positively affects the transition between gears, ensuring a smoother and quicker shifting process, as well as maintaining speed in the next phase of motion.

Moreover, when the vehicle reached a speed of 40.4 km/h at 8.5 seconds, the difference between the vehicle with high suspension damping and low suspension damping reached 8%. This shows that a high level of damping allows the vehicle to accelerate faster, which is an important factor in road performance. Such an improvement in acceleration dynamics allows the vehicle to effectively cover various sections of the track with less time spent.

In the phase when the vehicle was moving on a flat section of the road (8.6 – 11.8 seconds), with the speed stabilizing at 40.4 km/h, the vehicle with high suspension damping maintained a higher speed than the one with low damping. This is further proof that a high damping coefficient provides better stability and greater efficiency at higher speeds, which is especially important for long trips or situations where high speed is required to reach the final destination.

Finally, in the last stage, when the vehicle began the braking process (12 – 15.2 seconds), the result was even more convincing: the vehicle with high suspension damping reduced its speed 3% faster than the vehicle with soft suspension. This shows that high suspension damping not only improves acceleration and motion stability but also enhances braking efficiency, allowing the vehicle to stop faster and improving its safety on the road.

Thus, the study demonstrated the importance of adjusting the suspension damping to achieve optimal vehicle characteristics. The research results, in the form of graphs and diagrams, are presented in Figure 6, providing a visual representation of the impact of different damping parameters on the vehicle's dynamics, confirming the effectiveness of high damping in improving acceleration, motion stability, and braking speed.

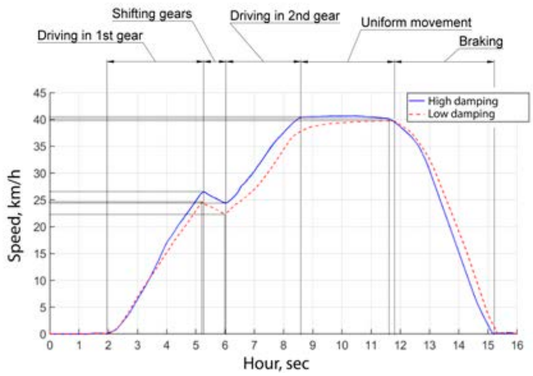

Fig. 6. The graph of the dependence of the car's speed on time with different suspension settings

The analysis of the results obtained from the experimental study showed that the acceleration of the car with high suspension damping during acceleration in first gear is significantly higher than with low damping, reaching 4 m/s². This indicates that suspension settings have a major impact on the car's acceleration, especially in first gear, when the engine operates at low revs. When shifting from first to second gear, it is important to note that the suspension settings do not have a significant impact on the car's acceleration. This could be due to the fact that during gear shifting, the main factors determining acceleration are the engine power and the gear, not the suspension characteristics. However, when accelerating in second gear, the car's acceleration with high suspension damping is again higher than with low damping, reaching 3.4 m/s². This confirms that suspension damping indeed has a significant influence on the car's dynamics, especially at higher speeds. When the car moves at a constant speed of 40.4 km/h, the car's acceleration approaches zero, as there is no significant increase or decrease in speed at such a cruising speed. At the same time, with high suspension damping, this effect is more pronounced, as the high damping reduces body oscillations and stabilizes the car's motion, leading to a lower acceleration at such a speed.

Figure 7 shows the pattern of change in the car's acceleration during its acceleration in first and second gears.

With a stiff suspension, a uniform speed is established faster than with a soft suspension. Between 8.5 to 12 seconds, the vehicle with a stiff suspension reaches a more consistent speed compared to the one with a soft suspension.

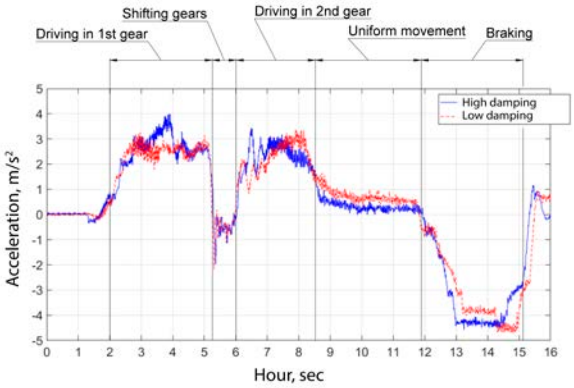

Fig. 7. The graph of the car's acceleration as a function of time with different suspension settings

This is because a stiffer suspension reduces the amount of body roll and oscillations during acceleration, allowing the tires to maintain better contact with the road surface and ensuring more efficient power transfer from the engine to the wheels. In contrast, with a soft suspension, the vehicle experiences greater body movement and less stability, which can lead to energy loss and slower establishment of a uniform speed. The difference in performance becomes evident in the time period between 8.5 and 12 seconds, where the car with a stiffer suspension maintains a more stable and higher speed than the one with a softer suspension.

In first gear, when acceleration occurs, the wheels may start to slip because a large torque is applied to them from the engine. At this moment, the traction force is limited by the grip of the wheels on the road. If the traction force on the wheels exceeds the grip, wheel slip begins.

In second gear, the car accelerates with a lower torque on the wheels compared to first gear. Since the engine torque is limited in higher gears, acceleration in second gear is not dependent on the grip of the wheels, but instead is limited by the engine's torque.

Thus, in first gear, speed is limited by the grip of the wheels on the road, while in second gear, this limitation disappears because the engine torque becomes the main factor.

Experimental studies have also confirmed the theoretical justifications regarding the influence of suspension characteristics on the acceleration distance of a car. As seen in the graph in Figure 8, there is a noticeable difference in acceleration distance between cars with high and low suspension damping, even with the same time. This clearly demonstrates the importance of suspension damping for the overall dynamics of the vehicle, as a car with high suspension damping can achieve a higher speed over a shorter distance compared to a car with low damping.

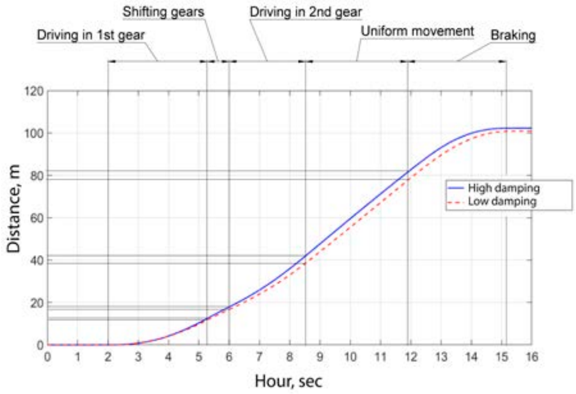

Fig. 8. The graph of the dependence of the distance traveled by the car on time with different suspension settings

High suspension damping provides better stability during motion and allows more efficient power transfer to the wheels, leading to faster acceleration and, consequently, a shorter acceleration distance. This is crucial for vehicles used in high-speed conditions or for achieving maximum performance on tracks, where a short acceleration distance is an important factor.

On the other hand, cars with low suspension damping may exhibit a greater distance to reach the same speed in the same amount of time, as they experience larger oscillations that can reduce the effectiveness of force transmission to the road. This can also lead to less stable motion and higher energy losses, which, in turn, increases the acceleration distance.

Thus, the research results clearly demonstrate that suspension damping settings are critically important for optimizing the acceleration characteristics of a vehicle and enhancing its dynamic efficiency. Therefore, it is essential to consider these factors when designing automotive systems, especially for vehicles where a short acceleration distance is vital for achieving maximum results.

In particular, when accelerating to 40 km/h in second gear at 8.5 seconds, the car with high suspension damping covers a distance of 42 meters, while the car with low suspension damping covers a shorter distance of only 38 meters. This means that the difference in acceleration distance between the two cars is 4 meters, which is 10%. This difference indicates that the car with high suspension damping is able to more effectively utilize its power for acceleration, allowing it to reach a higher speed over a shorter distance.

On the section with uniform motion, at 12 seconds, the distance traveled by the car with high suspension damping is also greater, measuring 82 meters, while the car with low suspension damping travels less – 78 meters. The difference in distance is 4 meters, which is 5% of the total distance. This difference further confirms that high damping suspension settings contribute to more stable motion and more efficient power transmission to the wheels, reducing energy losses and allowing the car to move faster in the same amount of time.

Conclusion

The work presents experimental studies on the impact of the damping coefficient of a semi-active suspension on the acceleration of a car during acceleration. The obtained results allow the following conclusions to be made:

A car with a high suspension damping coefficient has a greater impact on acceleration during movement in first and second gears compared to a car with a low damping coefficient. The difference in speed for the car in first gear is 7.5%, and in second gear — 8%.

The acceleration of a car with high suspension damping during acceleration in first gear is higher than with low damping, reaching 4 m/s². During the shift from first to second gear, suspension settings do not affect the car's acceleration. When accelerating in second gear, the acceleration of the car with high suspension damping is higher than with low damping and amounts to 3.4 m/s². When the car moves uniformly at a speed of 40.4 km/h, the acceleration of the car approaches zero, with the high damping suspension resulting in a lower value.

Cars with high and low suspension damping have different acceleration distances over the same time. When accelerating to 40 km/h in second gear at 8.5 seconds, the car with high suspension damping covers a greater distance than the car with low damping. The difference in acceleration distance is 4 meters, or 10%. On the section with uniform motion at 12 seconds, the car with high suspension damping also travels a greater distance than the car with low damping, with the difference being 4 meters (5%).

It should also be noted that the obtained research results can be used to calculate the effect of the suspension damping coefficient on the acceleration of a dragster.

Confirmation.

The work was carried out within the framework of the scientific research topics of the Department of Vehicles named after A.B. Gredeskul at the Kharkiv National Automobile and Highway University and the Department of Vehicles at the Technical University of Ilmenau, Germany.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Експериментальне дослідження впливу коефіцієнту демпфування напівактивної підвіски на прискорення автомобіля при розгоні

Анотація. Проблема. *Вплив коефіцієнту демпфування напівактивної підвіски на прискорення автомобіля при розгоні можна визначити експериментальним шляхом. Метод експериментальних досліджень є найбільш точним для отримання реальних даних, оскільки враховує показники автомобіля та специфіку роботи підвіски. В даній роботі проведено експериментальне дослідження процесу розгону автомобіля з напівактивною підвіскою. Визначено вплив коефіцієнту демпфування підвіски на розгін автомобіля на першій та другій передачах. В якості досліджуваного автомобіля було вибрано Lande Rover Evoque з встановленою підвіскою CVSA від компанії Tenneco. Визначено показники швидкості, прискорення та шляху автомобіля при низькому та високому демпфуванні підвіски. Для наглядного представлення результатів дослідження були побудовані графічні залежності швидкості, прискорення, шляху від часу за допомогою програми Matlab. Проведений їх аналіз та зроблені відповідні висновки.* ***Мета.*** *Підтвердження теоретичних досліджень впливу коефіцієнту демпфування напівактивної підвіски на прискорення автомобіля при розгоні в дорожніх умовах.* ***Методологія.*** *Підходи, прийняті в роботі для досягнення цієї мети базуються на положеннях теорії автомобіля.* ***Об'єкт:*** *процес розгону автомобіля з напівактивною підвіскою.* ***Предмет дослідження:*** *вплив коефіцієнту демпфування підвіски на показники розгону автомобіля.* ***Результати.*** *Встановлено, що автомобіль з коефіцієнтом високого демпфування підвіски під час руху на першій та другій передачах має більший вплив на розгін, чим з коефіцієнтом низького демпфування підвіски. Визначено, що прискорення автомобіля з високим демпфуванням підвіски при розгоні на 1 передачі вище, ніж з низьким демпфуванням. Під час перемикання з першої на другу передачу налаштування підвіски не впливає на прискорення автомобілю. При розгоні на 2 передачі прискорення автомобіля з високим демпфуванням підвіски вище, ніж з низьким демпфуванням. Отримано відповідні показники які показують різний шлях розгону за однаковий час автомобілю з високим демпфуванням підвіски та з низьким демпфуванням.* ***Практичне значення****. Отримані результати експериментального дослідження дають можливість провести порівняльний аналіз теоретичних досліджень впливу коефіцієнту демпфування на розгін автомобіля, а також отримані показники можуть бути використані при проектуванні нових автомобілів або при удосконаленні спортивних автомобілів типу дрегстер.*

Ключові слова: *коефіцієнт демпфування, прискорення, автомобіль, розгін, напівактивна підвіска.*

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