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Представлено 15.05.2024

УДК 629.03

ВЛИЯНИЯ ИЗМЕНЕНИЯ ЖЕСТКОСТИ ШИН ПРИ ИЗМЕНЕНИИ НАГРУЗКИ НА КОЛЕБАНИЯ ЛЕГКОВЫХ АВТОМОБИЛЕЙ

EVALUATING THE IMPACT OF TIRE STIFFNESS VARIATION DUE TO LOAD CHANGES ON PASSENGER CAR OSCILLATIONS

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Tires are the components that make contact with the road surface, and their condition is one of the factors affecting the smoothness of the vehicle. This paper investigates the influence of tire stiffness variation on the performance of the suspension system. The study employs a combination of experimental and simulation methods to examine how changes in pressure and load lead to changes in tire stiffness, thereby affecting vehicle body oscillation. Experiments were conducted to determine tire stiffness, and the experimental results were incorporated into a quarter-car suspension system simulation model for further investigation. The *simulation results about relations of tire stiffness, load changes and vehicle body oscillation were presented.*

Шины являются компонентами, которые контактируют с дорожным покрытием, и их состояние является одним из факторов, влияющих на плавность хода автомобиля. В данной статье исследуется влияние изменения жесткости шин на работу системы подвески. В исследовании используется сочетание экспериментальных и имитационных методов для оценки изменения давления и нагрузки шин к изменениям жесткости шин, и тем самым влияя на колебания кузова транспортного средства. Были проведены эксперименты по определению жесткости шин, и результаты экспериментов были включены в имитационную 1/4 модель системы подвески автомобиля для дальнейшего исследования. Показаны результаты моделирования о связи между жесткостью шин, нагрузкой и колебанием кузова автомобиля.

Keywords: *tire stiffness, tire pressure, vehicle vibration, quarter-car model.*

Ключевые слова: *жесткость шин, давление в шинах, вибрация автомобиля, 1/4 модель подвески автомобиля.*

INTRODUCTION

One of the criteria for evaluating the quality of an automobile is the ride comfort of the vehicle on the road [1, 2]. Among these, tire stiffness is a major factor influencing the ride comfort of the vehicle. Changes in tire stiffness led to body oscillation, affecting the sensation of the occupants. The paper [3] pointed out that tire stiffness has a significant impact on the performance of the suspension system. Rostami et al. [4] investigated the influence of tire stiffness on the suspension system. However, these studies have not clearly elucidated the importance of tire characteristics to the performance of the suspension system.

This paper assesses the influence of tire characteristics (changes in pressure and load applied to the wheel) on the performance of the suspension system. The experimental method combined with simulation demonstrates that the parameters used to evaluate the suspension system, such as vertical body oscillation, acceleration, and damping time, are affected by tire characteristics. The experiment helps determine the tire stiffness dependent on specific values of pressure and load, which are then incorporated into the simulation model. The simulation results help evaluate the impact of tire and load characteristics on the vehicle's suspension system operation.

METHODOLOGY

To evaluate the oscillations of the vehicle body, a full-car suspension model is typically required. However, constructing a full-car model is quite complex. Therefore, this study employs a quarter-car suspension model for the analysis. Based on [1], the paper derives the equations (1) and (2):

$$m_a \cdot \ddot{z} = C \cdot (z_1 - z) + K \cdot (\dot{z}_1 - \dot{z}); \tag{1}$$

$$m \cdot \ddot{z}_1 = CL \cdot (h - z_1) + KL \cdot (\dot{h} - \dot{z}_1) - C \cdot (z_1 - z) - K \cdot (\dot{z}_1 - \dot{z}). \tag{2}$$

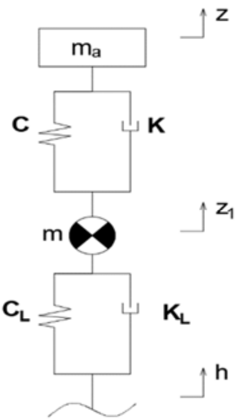

Figure 1 – Quarter-car suspension model

Tire stiffness at various pressures and loads was collected through experimentation. The experimental equipment included: a suspension test bench, height measuring devices, a 2014 Toyota Vios, load measurement devices, and tire pressure measurement devices.

The experimental procedure began by placing the rear axle of the Vios on the load measurement device. A tire pressure gauge was used to determine the pressure in the tires, after which the vehicle was loaded with four different loads (load values displayed on the device) to measure tire deformation. The recorded measurements were documented. Finally, the process was repeated for four different tire pressures.

Following the experiment, the paper constructs trendline graphs based on the collected data. From this, the equation of the trend line is described by (3):

$$y = 755,63 \cdot x^2 - 2466,8 \cdot x + 4029,9\,. \quad (3)$$

To evaluate the vehicle body oscillations, the paper simulates the wheel passing over a step bump. The step bump describes a scenario where the wheel, initially at a height of h = 0,175 m, drops to the road surface. By using a set of differential equations, the oscillation graph of the unsprung mass over time is obtained.

RESULTS & DISCUSSION

Figure 2 illustrates the relationship between vehicle body oscillations over time in two scenarios: low pressure under unloaded conditions and high pressure under fully loaded conditions.

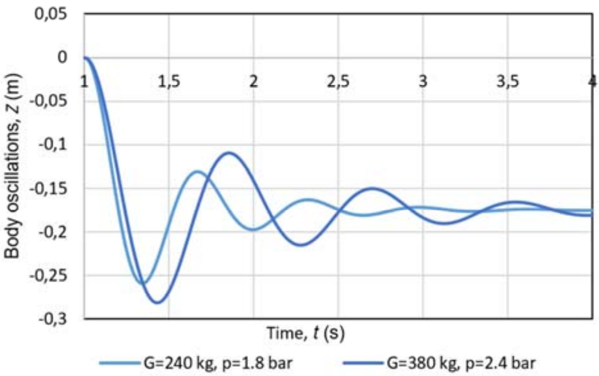

Figure 2 – Vehicle body oscillation amplitude in two cases study

Figure 2 shows a pronounced difference. When the vehicle is idling with a pressure p = 1,8 bar, two points are presented Z_{max} = 0,0847 m and Z_{min} = 0,0439 m. Meanwhile, a fully loaded vehicle traveling with a pressure of p = 2,4 bar has a score of Z_{max} = 0,1065 m and Z_{min} = 0,0661 m. The difference of two points can be evaluated, Z_{max}

and Z_{min}, in the above two cases. The amplitude of fluctuations corresponding to two points Z_{max} is 26 % and Z_{min} is 51 %. The oscillation extinguishing time of cases is also different, specifically with idle conditions p = 1,8 bar, t = 1,35 s, and with full load conditions p = 2,4 bar, t = 2,124 s. The time difference between the two cases is 58 %. With longer oscillation extinguishing times, vehicle body oscillations occur stronger, and the occupants will have a noticeable feeling of the smoothness of the vehicle in the above two cases.

Figure 3 illustrates that with two completely different conditions, an idling vehicle with a pressure of p = 1,8 bar and a fully loaded vehicle with a pressure of 2,4 bar, the acceleration between the two cases has a noticeable fluctuation. At idle with pressure p = 1,8 bar, a maximum acceleration was represented as a_{max} = 13,4 m/s^2 and a minimum acceleration of a_{min} = 9,22 m/s^2. At full load with a pressure of p = 2,4 bar, a maximum acceleration was represented as a_{max} = 8,88 m/s^2 and a minimum acceleration of a_{min} = 6,31 m/s^2. The differential acceleration in the two cases corresponds to the maximum acceleration value of 51 % and to the minimum value of 47 %.

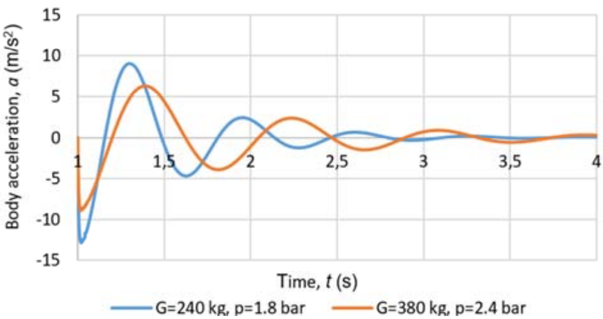

Figure 3 – Vehicle body acceleration in two cases study

According to fig. 4, in terms of quenching time, in a vehicle without a load, the extinguishing time fluctuates at 2,17 s, and in full load mode, it is 2,5 s.

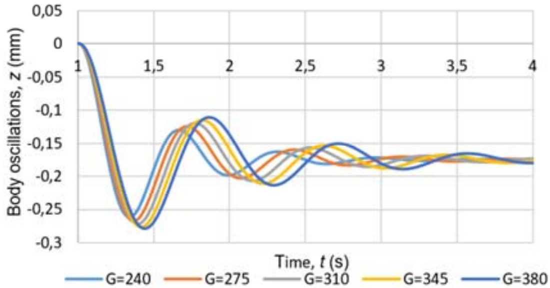

Figure 4 – Vehicle body oscillations corresponding to different loads

Figure 5 illustrates the vertical acceleration of the vehicle body under different load conditions. The damping resistance and the elastic force of the springs remain constant, as the stiffness of the C_L tires shows negligible variation. The inertial force is balanced by the damping resistance, and with the elastic force being constant, the inertial force also remains constant. Consequently, the variation in acceleration across different load conditions is primarily influenced by the mass m. As the mass increases, the acceleration decreases, resulting in a smaller acceleration amplitude compared to that of a lower mass.

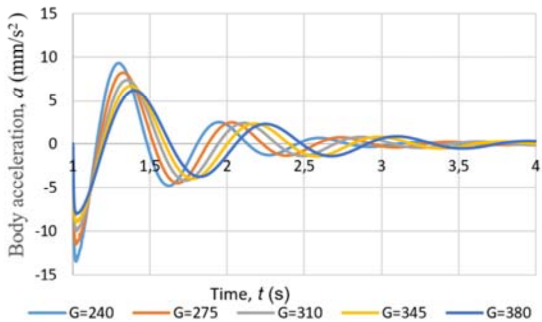

Figure 5 – Acceleration of the vehicle body corresponding to different loads

CONCLUSION

This paper evaluates the effectiveness of the automotive suspension system by determining the impact of tire stiffness. The experiment collects parameters for the simulation model by examining and assessing the suspension system under varying pressures and loads in two scenarios: the first scenario involves an unloaded condition at low tire pressure and a fully loaded condition at high tire pressure; the second scenario maintains a constant tire pressure of p = 2,2 bar while varying the load. The first scenario shows a significant difference, with vehicle body oscillation differing by 51 % and vehicle body acceleration by 58 %. The second scenario demonstrates that as the load gradually increases, the oscillation increases by approximately 12% for each load increment, and acceleration increases by 15%. In summary, riding at a low load condition provides a smoother experience for the passengers compared to a high load condition.

Funding: This research is funded by the Hanoi University of Science and Technology under project number T2023-PC-023.

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Представлено 15.05.2024