IJDIAS International Journal of Discoveries and Innovations in Applied Sciences

| e-ISSN: 2792-3983 | www.openaccessjournals.eu | Volume: 1 Issue: 8

The Effect of Tire Mass, Damping Coefficient, and Spring Stiffness on the Car Suspension Performance and Vibrations

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Abstract:

The primary elements of the conventional suspension systems, which called passive suspension system, are the wheels with tires, the wheel carrier systems, damper and spring elements, the brakes and steering. The dynamic behavior and performance of passive suspension systems is primarily determined by choice of spring stiffness and the damping coefficient. In this paper, the performance of a passive suspension system is evaluated using a quarter-car model, where the proposed system is evaluated at different parameters of the system parts by choosing three values for each parameter of the spring stiffness, the damping coefficient, and the car tire mass. The two main factors that should be taken into consideration that represent the performance of the suspension are the acceleration of the car body and the tire deflection, where the first factor denotes ride or passenger comfort, while the second factor refers to road holding. The mathematical model of the passive suspension system is performed; this model is used to construct the Simulink model of the system. This study showed that there is a slight effect of the values of the spring stiffness, damping coefficient, and tire mass on the performance of the suspension system.

Keywords: Passive suspension system, spring stiffness, damping coefficient, tire mass, Simulink model.

1. Introduction:

The twin purpose of an automobile's suspension system is to give passengers with a comfortable ride by isolating them from road irregularities, bumps, and potholes, and to improve the vehicle's road holding capacity, hence enhancing safety. Vehicle suspension systems are not a novel concept. In reality, they have been used since automobiles were horse-drawn carriages [1]. Nonetheless, there has been an abundance of study into the creation of new and improved suspension systems. This is mostly due to the fact that the suspension is intended to provide both ride comfort and handling, which are in contradiction with one another. Figure 1 illustrates the contradictory nature of various suspension parameters in terms of the RMS acceleration of the chassis (comfort) and the RMS dynamic tire force (handling and safety) under a variety of road and driving circumstances. It can be seen that a softer suspension (low K and b) is required for improved ride comfort (like in a limousine), but this results in higher tire forces and, consequently, reduced safety. Alternatively, for improved handling (like in a sports car), a stiffer suspension (high K and b) is required, although this reduces ride comfort. A fixed point represents a traditional suspension with a passive spring and damper on this conflict diagram.

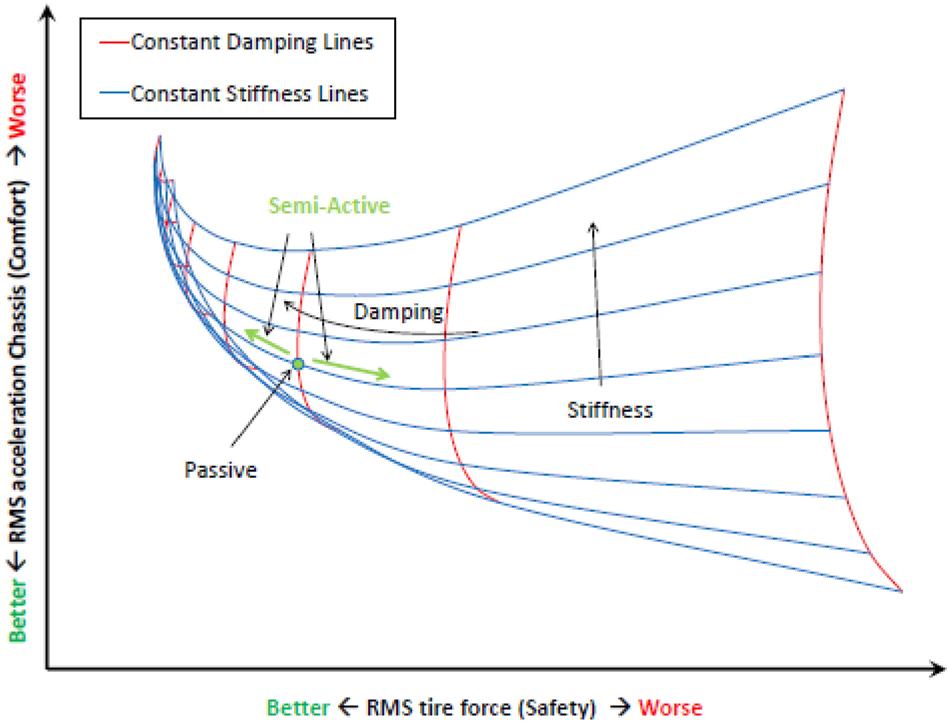

Figure 1. Contradictory safety and ride comfort (for some particular road and driving conditions)

Automobile suspension methods have traditionally been a compromise between three opposing criteria: road holding, rattling space needs, and passenger ride comfort. The suspension system must account for vehicle handling factors as the vehicle is traversing a terrain and be accountable for effectively isolating passengers from road disturbances (2). Although a passive suspension system is capable of collecting energy with a spring and releasing it with a shock absorber, its variables are often fixed. By selecting alternative stiffness and damping values, these fixed parameters help achieve a specific compromise between road holding and ride comfort (2). The difficulty with passive suspension is that if its design is overly damped or the suspension is excessively stiff, it will either transfer a great deal of road input or throw the vehicle on road imperfections (3). The ride comfort is enhanced by minimizing the acceleration of the vehicle's body caused by irregular road disturbances (4). Analyzing and optimizing the performance of passive suspension for a specific road reaction has been the subject of previous research using several techniques, including state space modeling in MATLAB and physical modeling (5).

2. Passive suspension system mathematical model

The model of vehicle considered in this study is a quarter automobile. Figure 2 depicts the quarter vehicle model suspension system, which comprises one-fourth of the body mass, suspension components, and one wheel for a passive suspension system. The following are the assumptions of the quarter car modeling:

a. The tire is treated as a spring with linear properties and no dampening.

b. There is no rotation in both the wheel and the frame.

c. The performance parameters of the spring and damper remain linear.

d. The road wheel is in continuous touch with the lane surface, and the consequence of resistance is disregarded, thus residual essential damping is not accounted for in vehicle modeling.

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Figure 2 depicts a two-degree-of-freedom system depicting the quarter-car model. The model includes the sprung mass *Ms* and the unsprung mass *Mu*. Modeling the tire as a linear spring of stiffness K_2. The suspension system consists of a passive spring K_1 and a damper b_1.

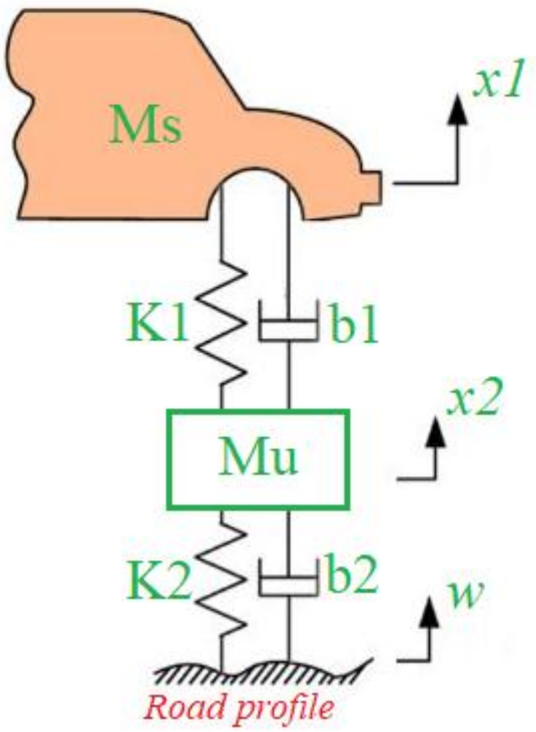

Figure 2. Quarter car model of passive suspension system

Based on the second Newton law, it can easy to derive the mathematical equations of the motion for passive suspension system, which given as following:

$$M_s\ddot{x}_1 = -K_1(x_1 - x_2) - b_1(\dot{x}_1 - \dot{x}_2)$$

$$M_u\ddot{x}_2 = K_1(x_1 - x_2) + b_1(\dot{x}_1 - \dot{x}_2) - K_2(x_2 - w) + b_2(\dot{x}_2 - \dot{w})$$

Where:

w is the road profile.

x_1 is the displacement of the car body.

x_2 is the displacement of the un-sprung mass.

b_1 is the damping constant of the system = (1000, 1400, and 1800) N.m/s.

b_2 is the damping constant of the wheel =0 N.m/s.

K_1 is the spring stiffness constant = (16000, 20000, and 24000) N/m.

K_2 is the wheel stiffness constant =170000 N/m.

Ms is the quarter car body mass or the sprung mass =255 Kg.

Mu is the unsprung mass = (35, 40, and 45) Kg.

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3. Road Profile

One form of road profile (input signal) will be employed to mimic the type of road condition in this work. It is a step input signal. This input is required to replicate the car suspension system, and it must precisely reflect the real-world road state when a vehicle travels on it. The Simulink model and the shape of the signal is shown in the figure 3 and figure 4.

Figure 3. The step input's Simulink model

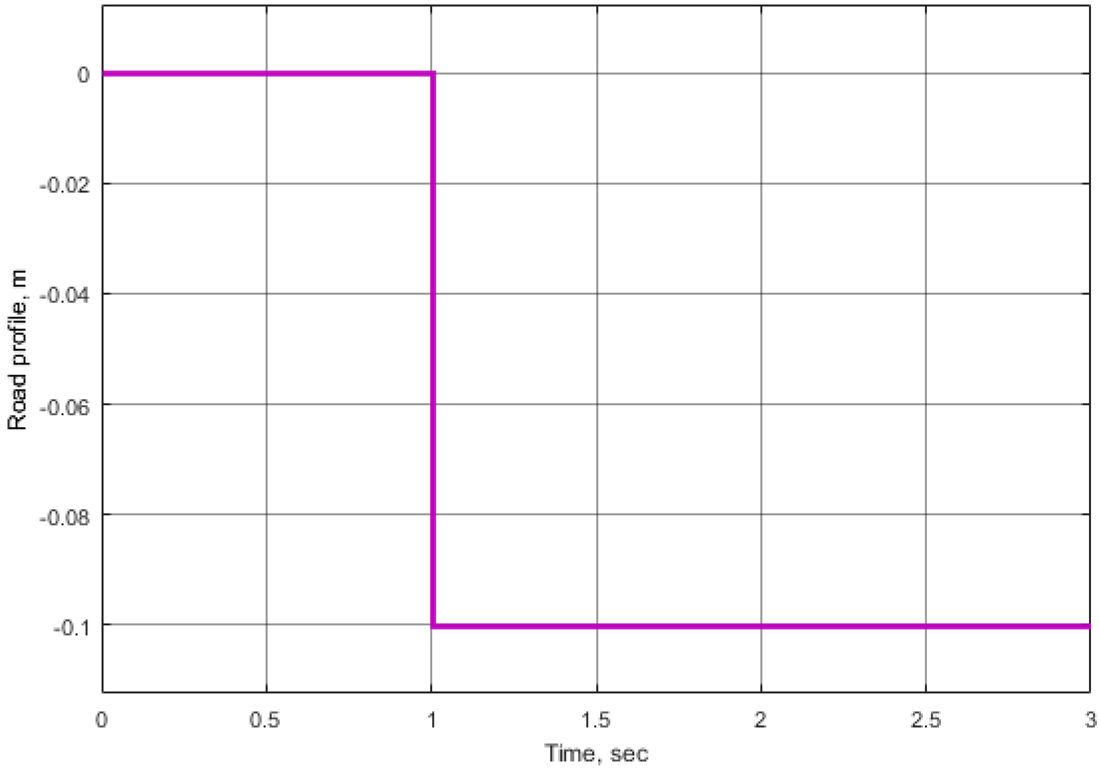

Figure 4. Road profile (Unit step road signal).

4. Passive suspension system Simulink model

Figure 5 obtains the Simulink model of the car passive suspension system for quarter car model which is built based on the mathematical equations shown above

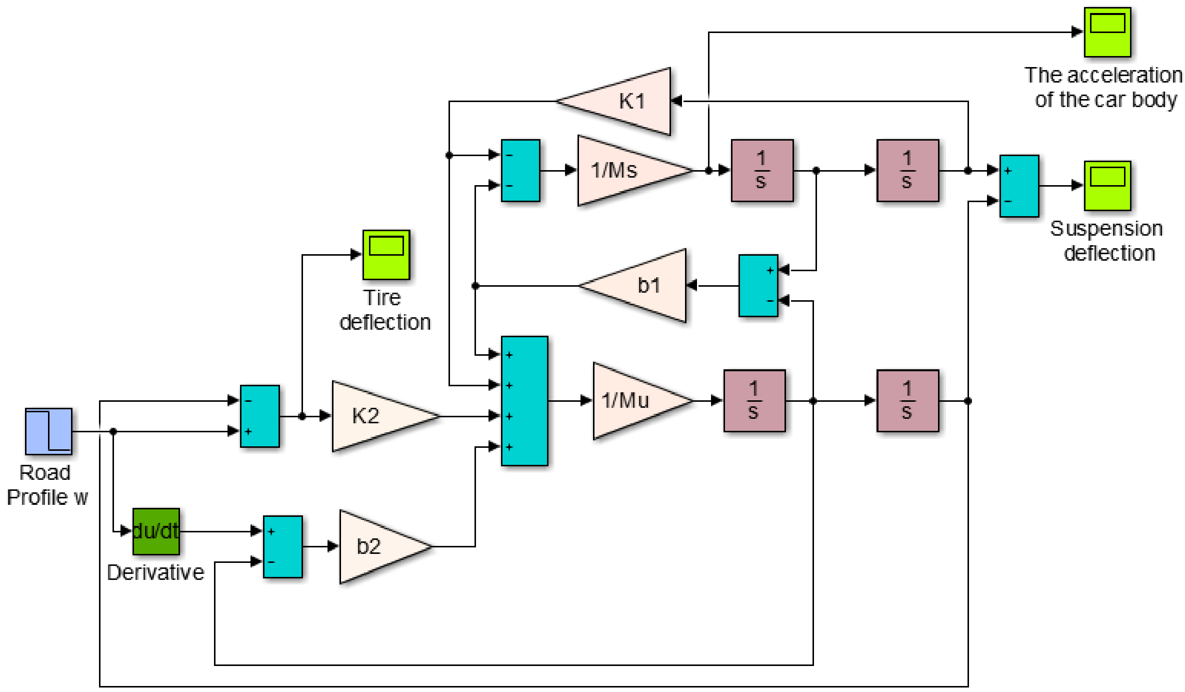

Figure 5. Simulink model diagram of passive suspension system

5. Simulation results

The two most important factors that should be taken into consideration when designing suspension systems are the acceleration of the sprung mass, which indicates or gives an impression of passenger comfort, and the second factor is the tire deflection, which shows the road holding or represents the vibration of the wheel vibration on the road. In this research and as shown in Figure 5, the two factors studied and mentioned above are the outputs of the system in this paper.

Because of the importance of the acceleration of the sprung mass and the tire deflection, each of them was compared at different variables of the spring stiffness, the damping coefficient, and the tire mass, where three values of the spring stiffness were selected, which are 16000 KN/m. 20000 KN/m, and 24000 KN/m, and three values for the damping coefficient were also selected as 1000 N.m/s, 1400 N.m/s, and 1800 N.m/s, while three values for the mass of the tire were chosen which are 35 Kg, 40 Kg, and 45 Kg.

It is noticeable in Figures 6 to 11 that changing the values of the spring stiffness, damping coefficient, and tire mass have an effect on the two factors, which represent riding comfort and road holding, although this effect is minimal, it gives us an indication that the selection of system variables is very important for designing car suspension systems.

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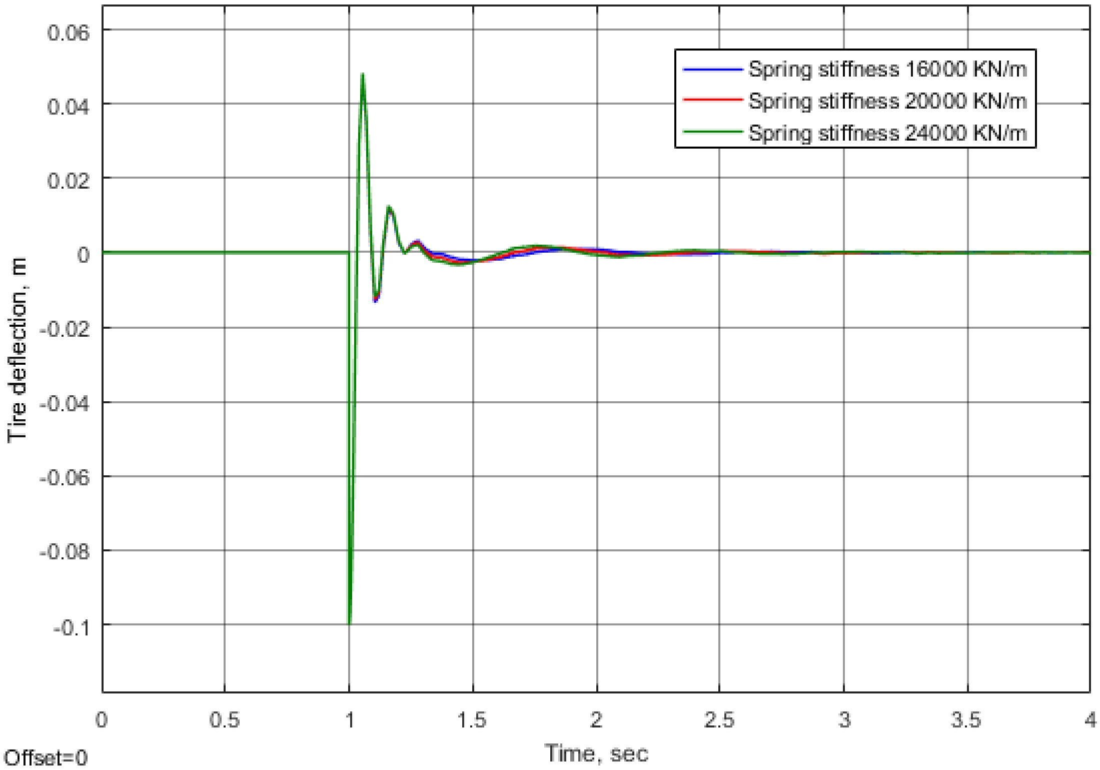

Figure 6. Effect of spring tire deflection

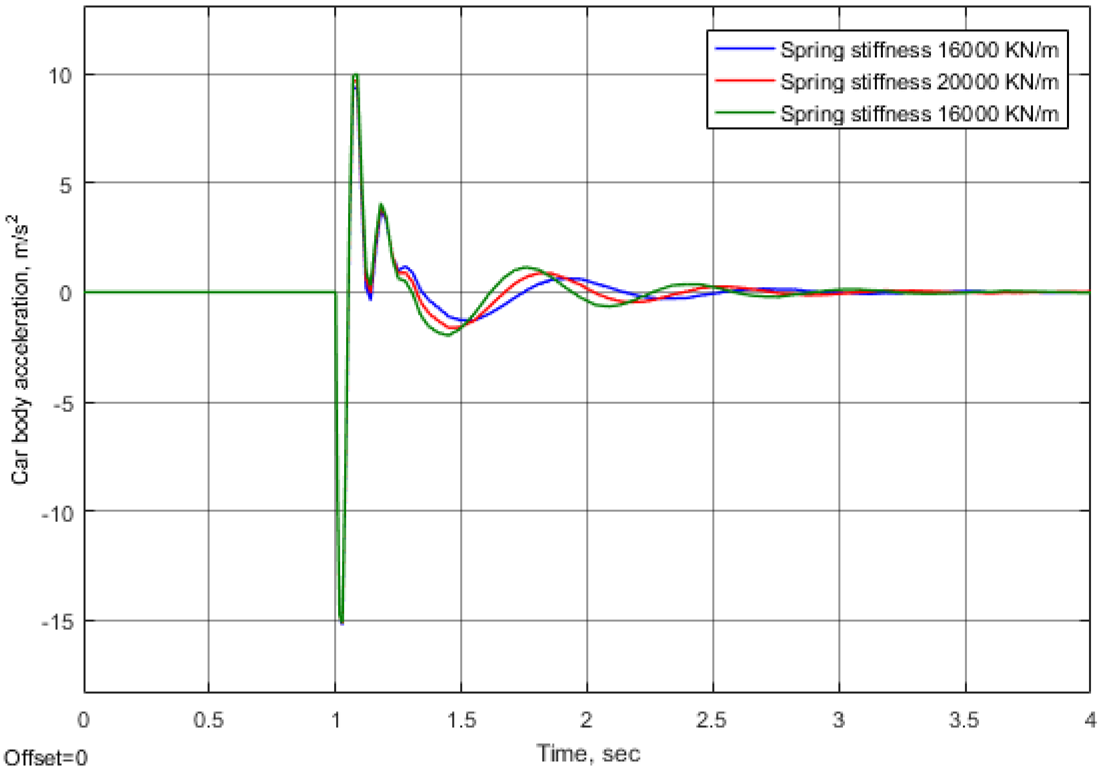

Figure 7. Effect of spring acceleration

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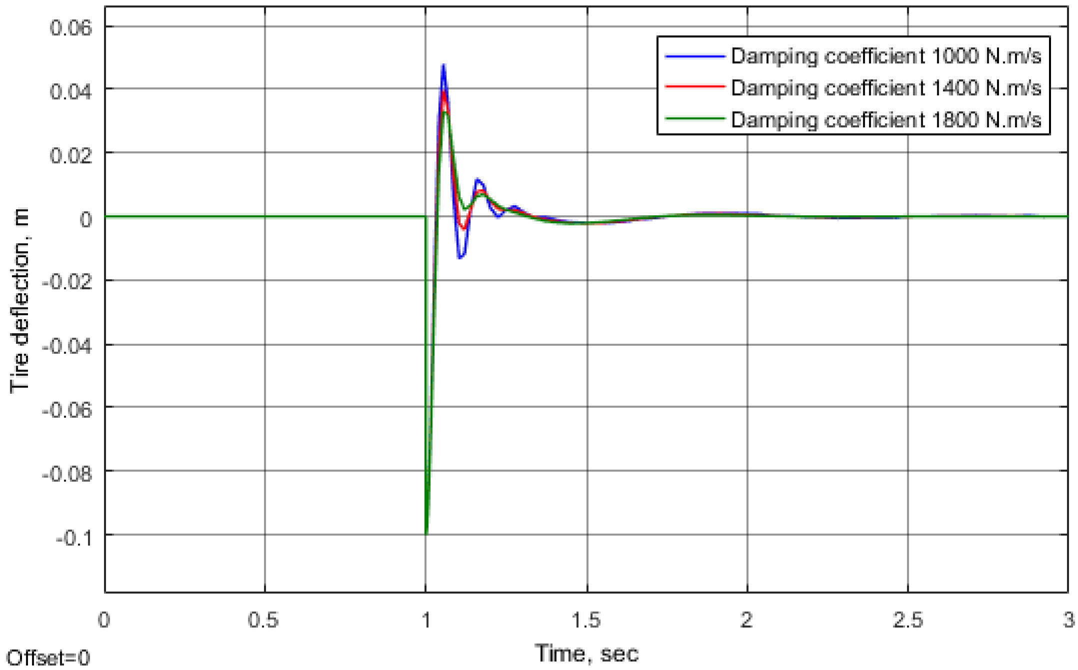

Figure 8. Effect of damper tire deflection

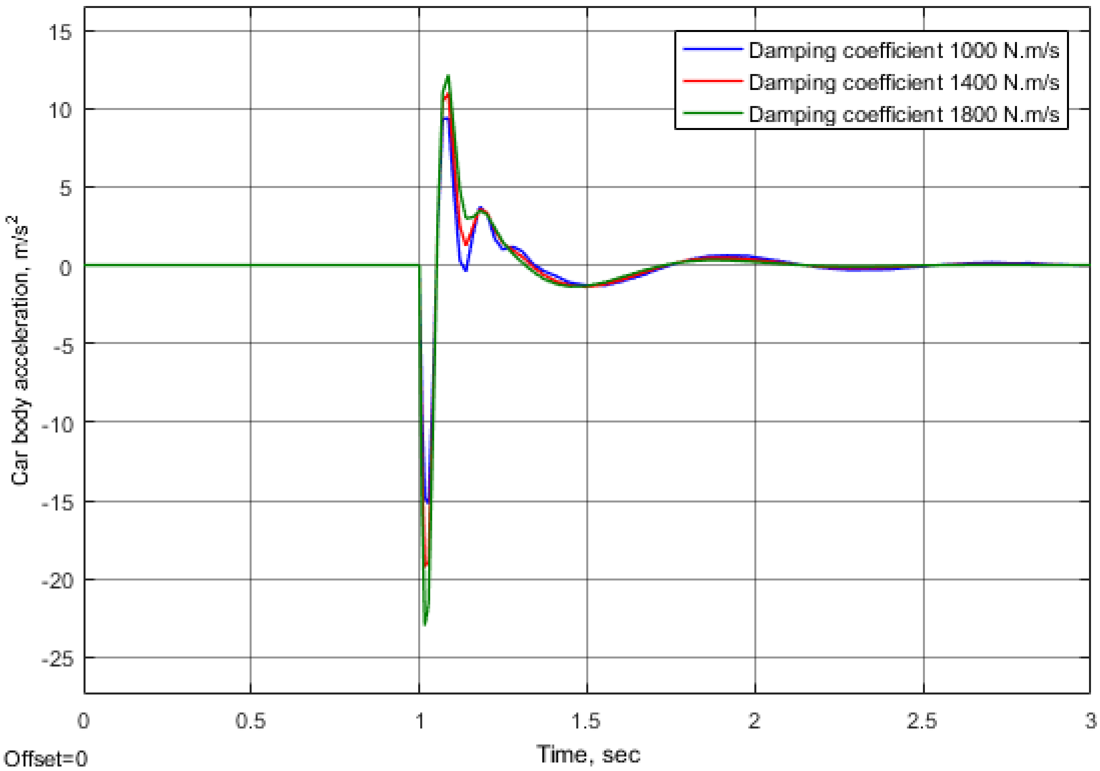

Figure 9. Effect of damper acceleration

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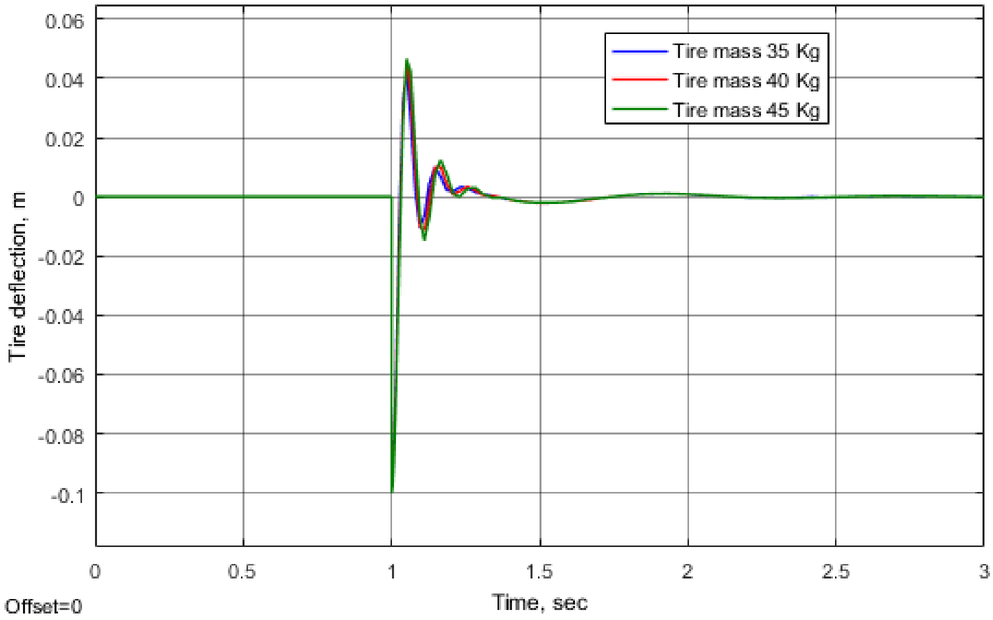

Figure 10. Effect of mass tire deflection

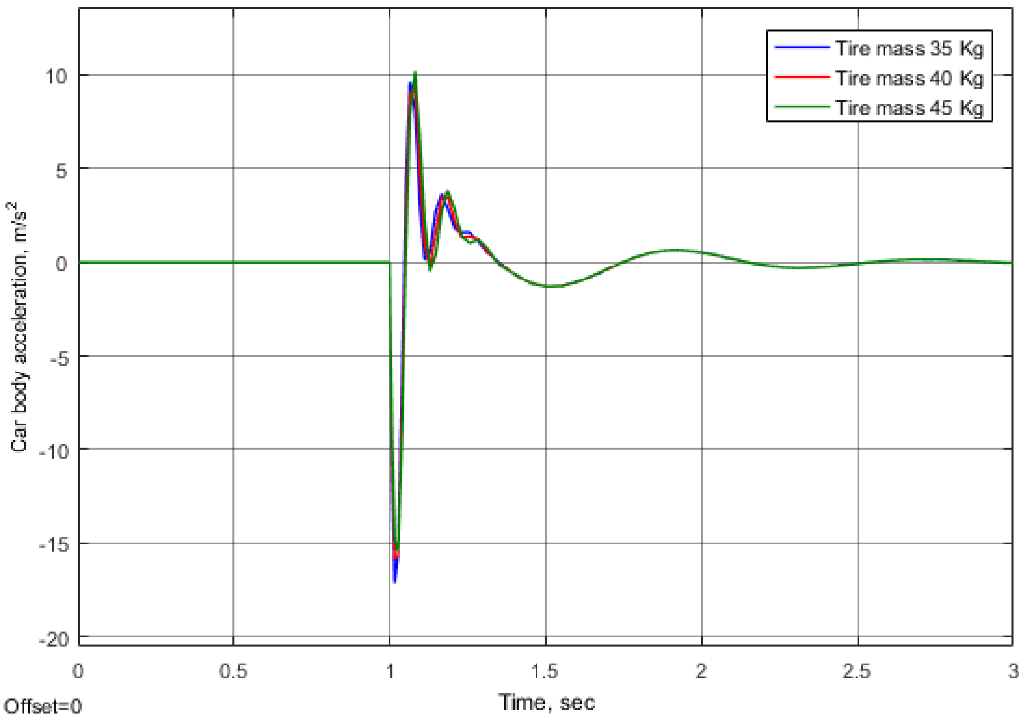

Figure 11. Effect of mass acceleration

6. Conclusion

In this paper, a suspension system was studied and evaluated using a quarter-car model, which is the most popular model in terms of use for the design of suspension systems in cars. The most prominent part of this paper was the statement of the effect of some physical variables on the suspension system, where three values were selected for each of the spring stiffness, damping coefficient, and tire mass and its effect on two important factors, namely the acceleration of the sprung mass, which represents the comfort of the passenger and the second factor is the deflection

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of the tire which gives the impression of the wheel vibrating while the car is on the road. There was a slight effect of the three variables mentioned above that may not be clear in some cases, but the study showed that it is possible to choose suitable values for the three variables to get a good design and performance of the suspension system.

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