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A Dynamic Analysis and Evaluation of a Car Suspension System with Different Parameters

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تحليل وتقييم ديناميكي لنظام تعليق السيارة عند متغيرات مختلفة

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Abstract
The suspension system in the car is responsible for stability and balance in both the car's body and the driving room and maintains the stability of the car on the roads and turns to ensure the comfort of the passengers, as it absorbs the shocks resulting from the unevenness of the road and prevents them from reaching the driving room. The system works by means of helical springs and vibration dampers that allow the tire to rise slowly when one of the tires encounters an obstacle on the road, and the suspension system prevents it from reaching the driving room, which contributes to maintaining the stability of the car. The main objective of this paper is to study and evaluate the performance of the suspension system in cars. To evaluate the performance of the system, it was necessary to derive a mathematical model for the system using a certain model called the Quarter car model, after which the system is simulated by MATLAB Software. Also, in this paper, some variables such as the spring constant and the damping coefficient were studied to evaluate the performance of the system, in addition to the effect of the mass of the electric motors that are installed in the wheels when manufacturing electric cars.

Keywords: Suspension System, Quarter Car Model, Spring Stiffness, Damping Coefficient, In-Wheel Motor.

الملخص
نظام التعليق في السيارة هو المسؤول عن الثبات والتوازن في كل من هيكل السيارة وغرفة القيادة والمحافظ على ثبات السيارة على الطرقات والمنعطفات لتأمين راحة الركاب حيث يقوم بامتصاص الصدمات الناتجة عن عدم استواء الطريق ويمنع وصولها إلى غرفة القيادة. يعمل النظام عن طريق نوابض حلزونية ومخامد اهتزازات تسمح للإطار بالارتفاع بشكل بطيء حينما يواجه أحد الاطارات عائقاً على الطريق فيقوم نظام التعليق بمنعها من الوصول إلى غرفة القيادة الأمر الذي يساهم في المحافظة على ثبات السيارة. الهدف الرئيسي من هذه الورقة هو دراسة وتقييم أداء نظام التعليق في السيارات، ولمعرفة أداء النظام كان لزاماً العمل على إنشاء نموذج رياضي للنظام باستخدام نموذج يسمى Quarter car model، وبعدها يتم محاكاة النظام عن طريق برنامج MATLAB. أيضًا تم في هذه الورقة دراسة تأثير بعض المتغيرات مثل قيم ثابت النابض وقيم ثابت مخمد الاهتزاز على أداء النظام، بالإضافة لتأثير كتلة المحركات الكهربية التي يتم تركيبها في العجلات عند صناعة السيارات الكهربية.

الكلمات المفتاحية: نظام التعليق، نموذج ربع سيارة، ثلبت النابض، معامل التخميد، محرك العجلة المحوري.

Introduction

The contemporary automobile has advanced significantly since the time when "just being self-propelled" was sufficient for car owners. Tiding comfort and driving safety have greatly benefited from advancements in suspension, greater component strength & durability, and tire design & construction.
Basically, suspension refers to the use of front and rear springs to suspend a vehicles frame, body, engine and power train above the wheels. These relatively heavy assemblies constitute what is known as Sprung

weight. Unsprang weight, on the other hand, includes wheels and tire, break assemblies and other structural members not supported by the springs.
The springs used in today's cars and trucks are engineered in a wide variety of types, shapes, sizes, rates and capacities. Types include leaf springs, coil springs, air springs and torsion bars.
These are used in sets of four per vehicle, or they are paired off in various combinations and are attached to the vehicle by a number of different mounting techniques.
The automobile frame and body are mounted on the front and rear axle not directly but through the springs and shock absorbent. The assembly of parts, which perform the isolation of parts from the road shocks, may be in the forms of bounce, pitch and roll is called suspension system.
Suspension system of an automobile separates the wheel and axle assembly of the automobile from its body. Main function of the suspension system is to isolate the body of the vehicle from shocks and vibrations generated due to irregularities on the surface of roads. Shock absorbers are provided in the vehicles for this purpose. It is in the form of spring and damper. The suspension system is provided both on front end and rear end of the vehicle.
A suspension system also maintains the stability of the vehicle in pitching or rolling when vehicle is in motion.
The primary functions of the suspension system are as follows:1. It protects the vehicle's body and frame from road shocks. 2. It improves the vehicle's stability.3. It protects people and cargo from road shocks. 4. It provides excellent road holding when driving, cornering, and braking. 5. It provides comfort. It is a source of comfort.
The Requirements of suspension system are:1. There should be minimum deflection. 2. It should be of low initial cost. 3. It should be of minimum weight.
4. It should have low maintenance and low operating cost. 5. It should have minimum tire wear.

Suspension model

The most types of suspension systems are passive suspension system and active suspension system. In this paper, we selected to study the passive suspension system.
Figure 1 shows the passive suspension system structure; in passive suspension, system has an ability to store energy via spring and to dissipate in via damper.

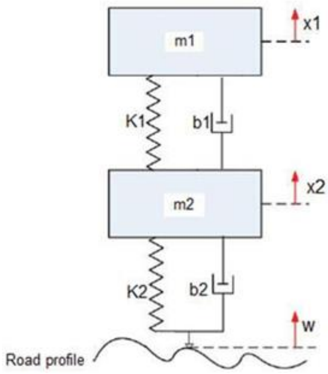

Figure 1: passive suspension system **(Quarter car model)**

Designing a suspension system is an interesting and challenging control problem. Also, Suspension system modeling serves two purposes: understanding system dynamics and developing control strategies. Models are simplified representations of physical systems, allowing focus on important system dynamics.
When the suspension system is designed, a quarter car model (one of the four wheels) is used to simplify the problem to a 1D multiple spring-damper system (Figure 1).

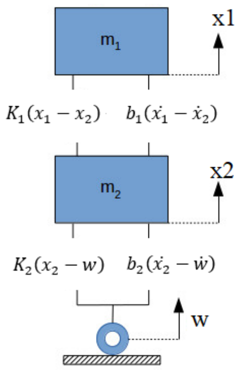

Figure 2: Free body diagram of the passive suspension system.

Based on Newtonian mechanics the equations of the motion and the free body diagram (Figure 2) for passive suspension system are given as following:

$$m_1 \ddot{x}_1 = -K_1(x_1 - x_2) - b_1(\dot{x}_1 - \dot{x}_2) \quad (1)$$

$$m_2\ddot{x}_2 = K_1(x_1 - x_2) + b_1(\dot{x}_1 - \dot{x}_2) - K_2(x_2 - w) - b_2(\dot{x}_2 - \dot{w}) \quad (2)$$

System parameters

(w) Road displacement or road profile
(x_1) car body displacement
(x_2) Un-sprung mass displacement
(b_1) damping constant of suspension system
(b_2) damping constant of wheel and tire
(K_1) spring stiffness constant
(K_2) Tire stiffness constant
(m_1) quarter car body mass (sprung mass)
(m_2) unsprung mass

Road profile

The selected road pump in this paper is selected as shown in figure 3. It generated used the signal builder from MATLAB Simulink library.

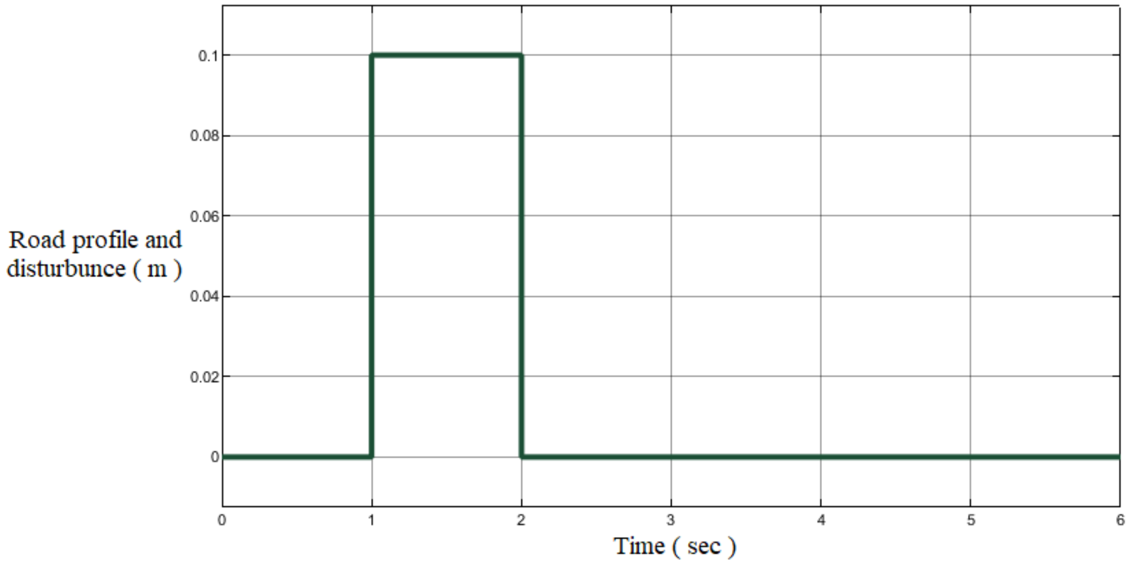

Figure 3: The selected road input signal.

Simulink Models and Results

This section contains the most important parts of the paper, including the Simulink model for the system, in addition to the most important blocks that were used in this paper, which were taken from the Simulink MATLAB library. Also, this section shows the most important results that indicate the effect of the system variables which are the spring stiffness, damper coefficient and wheel mass on the performance of the suspension system.
In this paper, three values were chosen for each of the suspension system variables, where three values were chosen for the spring stiffness (17000 N/m, 20000 N/m, and 23000 N/m) and three values for the damper coefficient (1050 N.s/m, 1250 N.s/m, and 1450 N.s/m), in addition to choosing three values for the wheel mass (55 Kg, 75 Kg, and 95 Kg), (the weight of the wheel increases due to the installation of an in-wheel motor).
When designing cars in general and suspension systems in particular, two important variables are taken into account, namely the tire deflection (w-x_2), which indicates the road holding, and the other variable is the acceleration of the sprung mass ($\ddot{x}_1$) and indicates the passenger comfort, so these two variables were chosen as an output for our system in this paper.

Simulink model

Figure 4 shows The Simulink model of the passive suspension system for quarter car model which built by using the equations 1 and 2, and figure 3 illustrates the selected road profile (Input signal).

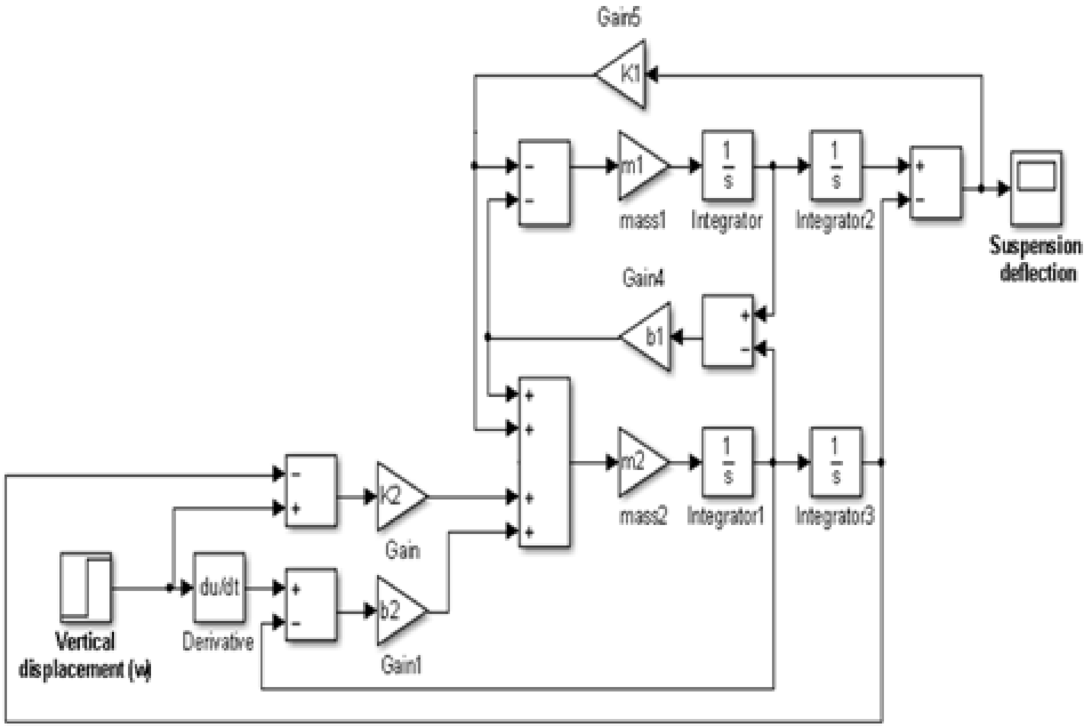

Figure 4: Simulink diagram of passive suspension system.

Simulation results

figures 5 and 6 shows the effect of the spring stiffness value on the tire deflection and acceleration of the sprung mass. Although the change is considered small in the two figures, but we can say that the higher the value of the spring stiffness increases both the deflection of the tire and the acceleration of the sprung mass.

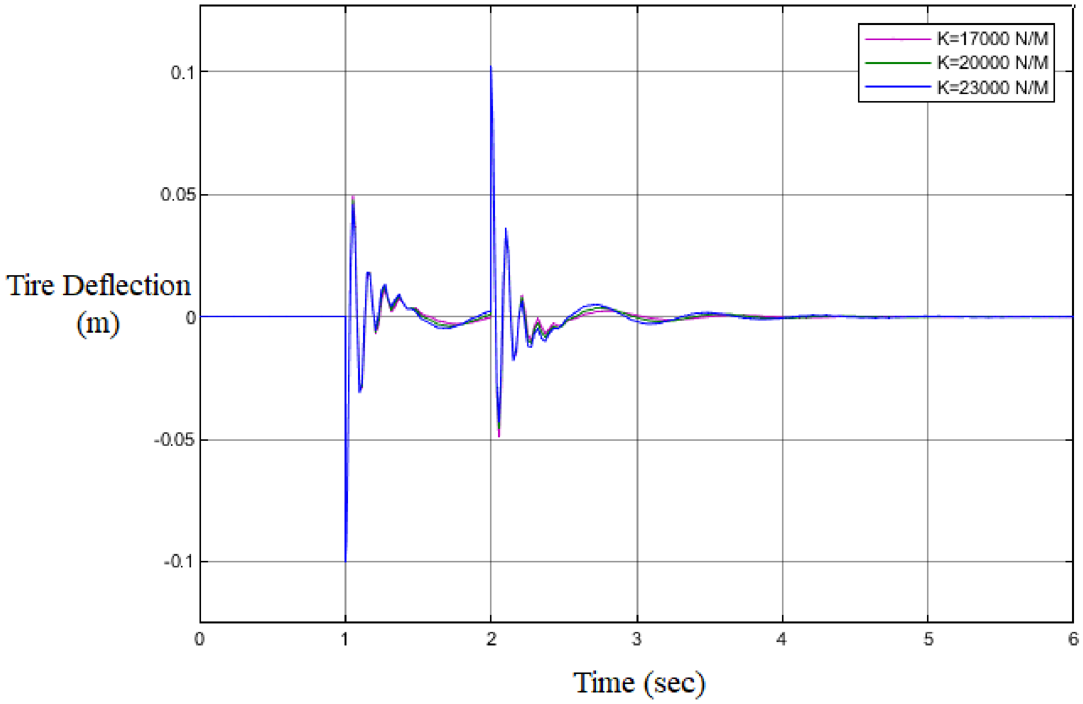

Figure 5: Effect of the stiffness constant on the Tire Deflection.

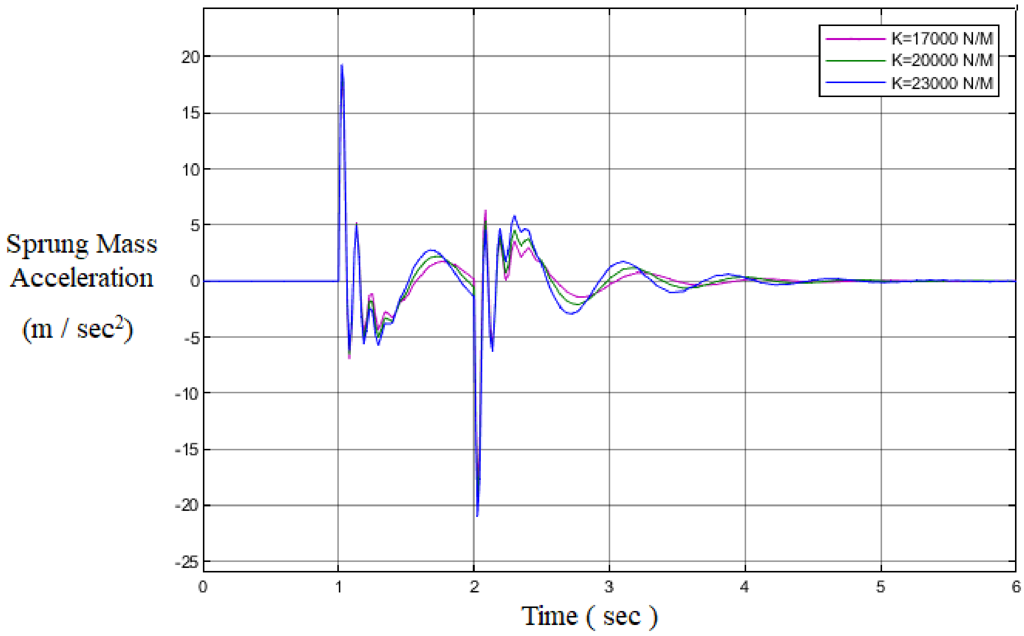

Figure 6: Effect of the stiffness constant on the Sprung Mass Acceleration.

figures 7 and 8 shows the effect of the damping coefficient value on the tire deflection and acceleration of the sprung mass. Also, in this case the change is considered small in the two figures. In both figures, the effect is not clear and it is not significant because the change in both the tire deflection and the acceleration of the sprung mass is small.

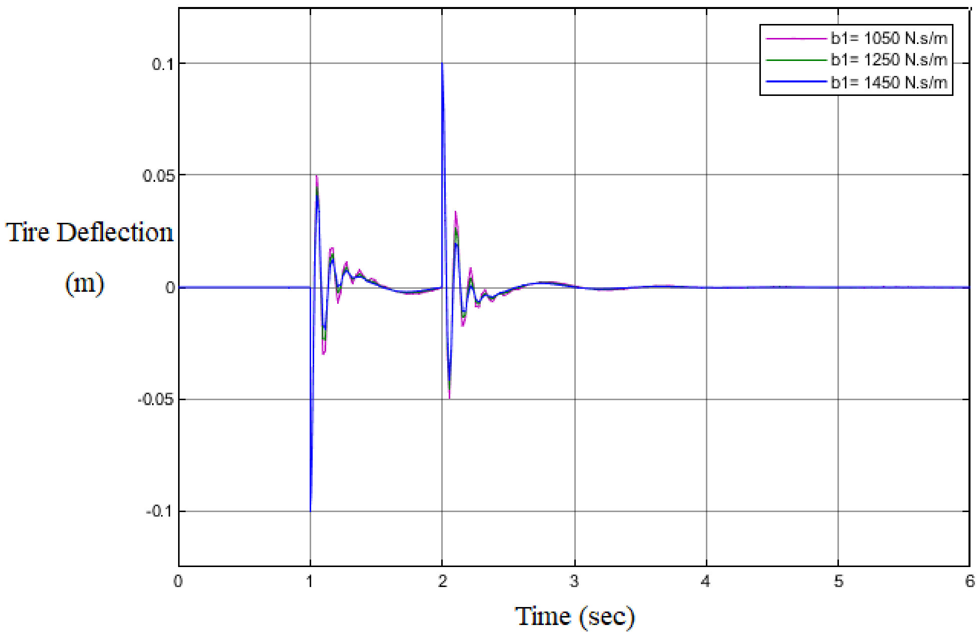

Figure 7: Effect of the damping coefficient on the Tire Deflection.

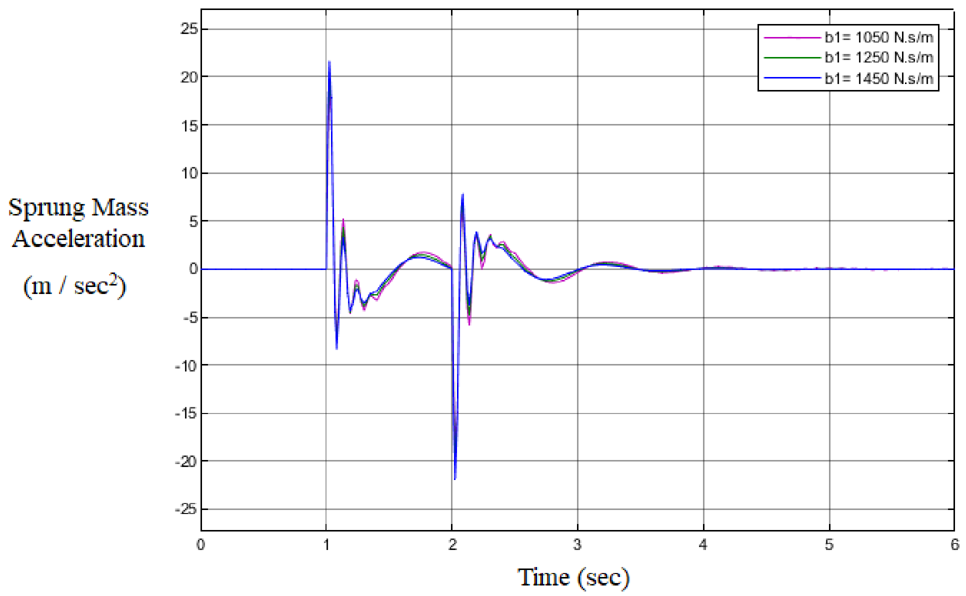

Figure 8: Effect of the damping coefficient on the sprung mass acceleration.

figures 9 and 10 shows the effect of the in-wheel motor mass value on the tire deflection and acceleration of the sprung mass. We can say that increasing the mass of the motor or tire has a negative effect on the tire deflection, even if it is small, while it has a positive effect on the comfort of the passengers.

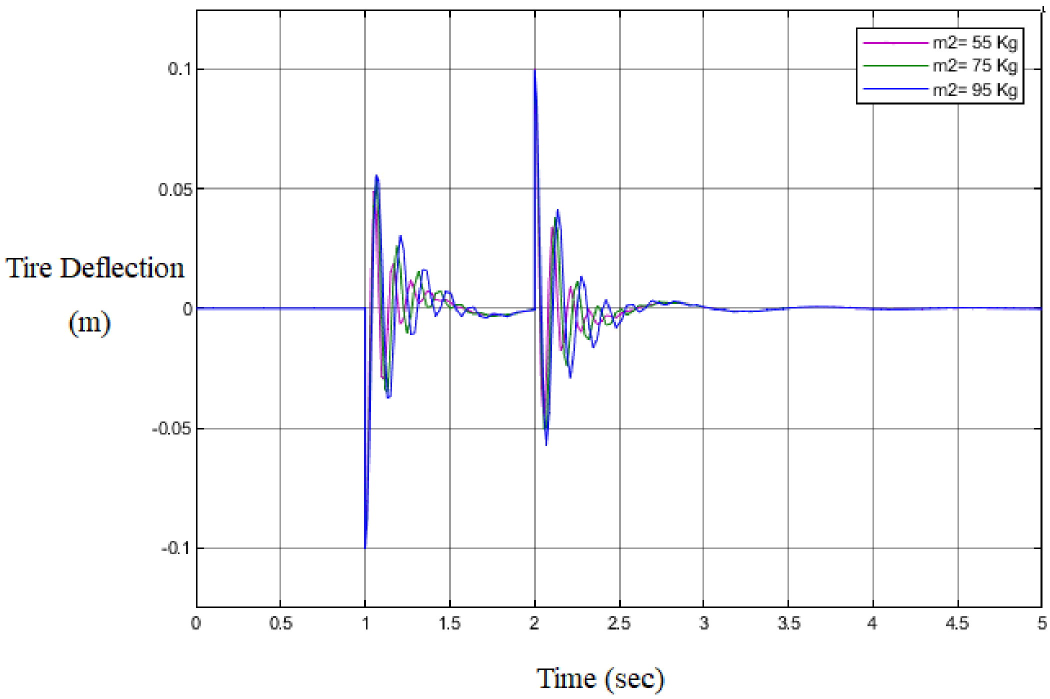

Figure 9: Effect of the In-Wheel motor mass on the tire deflection.

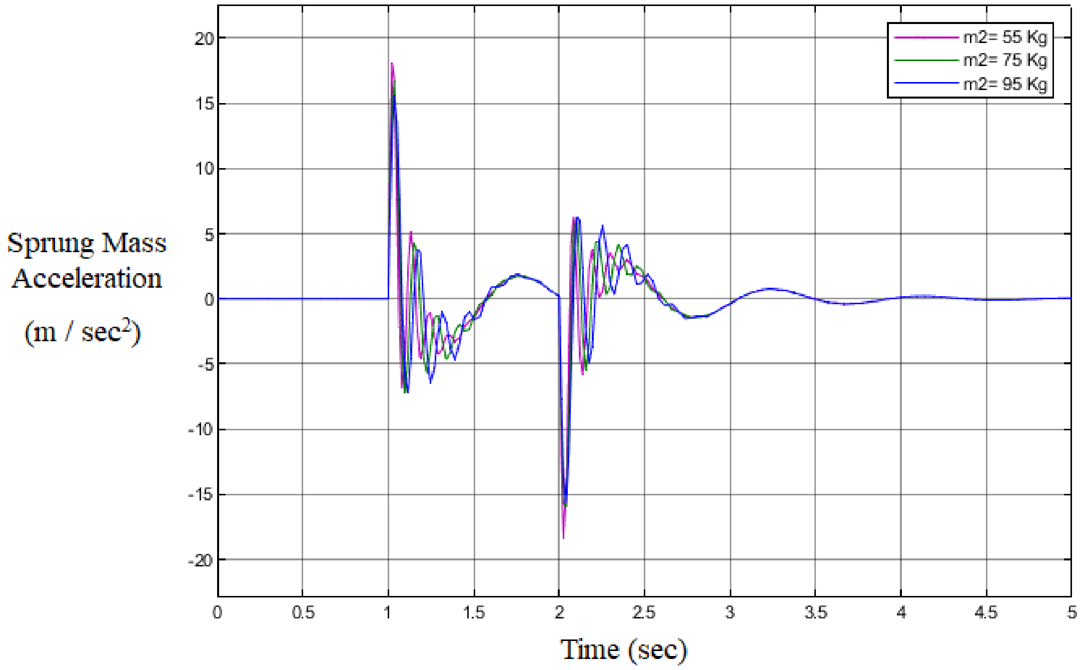

Figure 10: Effect of the In-Wheel motor mass on the sprung mass acceleration.

Conclusion

This paper presented modeling, simulation of car suspension system performed using MATLAB and the effect of three system variables which are spring stiffness, damping coefficient, and the in-wheel electric motor mass or the heavy tire on the suspension system performance. In this work, a slight effect of the three variables on the performance of the system was observed in general, but it can not be ignored because in some cases, increasing some variables has a negative impact on the performance of the system.

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