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Performance Analysis of Half Vehicle Suspension at Different System Parameters Using MATLAB/SIMULINK

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Abstract:

Suspension system plays a significant role in automobiles to enhance and improve ride comfort and road handling. In this paper, an independent front and rear passive suspension is performed on a half car model to analyze the reaction force exerted by the front and rear wheel and simulate these forces due to bounce and pitch degrees of freedom of the car. In this suspension model, the bounce degrees of freedom is represented by the vertical displacement and the vertical velocity and the car body pitch is represented by pitch angular displacement and pitch angular velocity. To obtain essential and accurate results about the performance of the suspension system, the effect of some system parameters such as the front and rear spring stiffness, as well as the front and rear dampers coefficients were studied. Matlab Software is used for numerical simulation of this half-car suspension model.

Keywords: Suspension system, Suspension vehicle, Half vehicle model, Matlab Simulink.

Introduction

Vehicle dynamics engineers have tried for many years to find a balance between vehicle handling, ride comfort, and stability. The effects of this are evident in the automobiles that exist today. On one end of the spectrum are huge sedans and premium vehicles with superb ride quality but merely passable handling. On the opposite end of the range are sports vehicles with excellent handling and a very stiff ride. In between are a variety of variations determined by the car manufacturer and the needs of the intended market. Every suspension is designed with two objectives in mind: passenger comfort and vehicle control. The passengers' comfort is achieved by insulating them from road disturbances such as shocks and potholes. Control is achieved by preventing the vehicle's body from excessively rolling and pitching, and by maintaining tire contact with the road [1].

The vibration of the car and seat causes driver fatigue and reduces driver safety and vehicle stability. Developing an upgraded suspension system to attain a high level of ride quality is therefore one of the automobile industry's most significant ride issues. Consequently, the objective of vehicle suspension systems is to reduce the acceleration of both the vehicle body and the passenger seat. Realistically, a number of vehicle parameters are subject to uncertainty; therefore, it is crucial to deal with vehicle suspension due to uncertain parameters in engineering applications [2].

The suspension system of a vehicle varies by manufacturer, resulting in a large variety of models. Regardless of the design approach adopted, a suspension system's principal job is to ensure the safety function. Uneven roads are known to cause oscillations in vehicle wheels, which are conveyed to their axles. It is evident that the function of the suspension system that connects the axles to the car body is to decrease as many vibrations and shocks as possible. This necessitates the use of a better-quality suspension. A great suspension must accomplish good vehicle behavior and a level of comfort based on the interaction between the vehicle and an uneven road surface [3, 4].

When a vehicle is required by an uneven road profile, there should not be excessive oscillations, and if they do exist, they must be eliminated as soon as possible. The design of a vehicle's suspension necessitates a set of calculations based on the intended function. Suspension systems are commonly categorized as passive, semi-active, active, and numerous systems in between [5]. Passive systems are most prevalent. The suspension is subjected to a variety of road conditions, such as a single step road profile, brake and release maneuver, sinusoidal road profile with pitching, heaving, and mixed model excitation, broadband road profile, etc., at constant or variable speed [6]. The measuring of road surface quality is one of the most significant prospects for automobile manufacturers worldwide. The operation of measuring instruments relies heavily on displacement transducers [7]. This research analyzes the vibrational effect a vehicle experiences when subjected to varied road profiles. A vehicle model with linear and nonlinear parameters is created for this aim. For road profile testing, a 1992 Hyundai Elantra half-car model with front suspension is utilized.

Mathematical model

Automotive and vibration experts are extremely interested in suspension modeling. When a vehicle passes over a speed bump, the ride quality is the primary concern of the engineers.

In contrast to the quarter vehicle model, which analyzes only one wheel, the half car model considers two wheels, namely one front and one rear wheel. In these types of models, fifty percent of the vehicle's weight, including that of the occupants, is considered for analytical purposes. The primary advantages of models of this type are:

1. Pitch motions of a vehicle can be imitated.
2. The properties of the front and rear dampers and springs can be represented differently, just as they are on the actual car.
3. Body motions and the influence of the center of gravity can be reproduced.

This paper demonstrates how to model a basic half-car with independent front and rear vertical suspension. Additionally, the model incorporates body pitch and bounce degrees of freedom. The example describes the model to demonstrate how simulation can be used to examine ride characteristics. This model can be used in conjunction with a powertrain simulation to analyze longitudinal shuffling caused by throttle setting changes.

Figure 1 depicts the half-modeled car's characteristics. As spring/damper systems, the front and rear suspensions are modeled. A more comprehensive model would incorporate a tire model and nonlinear damper characteristics, such as velocity-dependent damping (with greater damping during rebound than compression). The body of the vehicle possesses pitch and bouncing degrees of freedom. Four states are used to represent them in the model: vertical displacement, vertical velocity, pitch angular displacement, and pitch angular velocity. Using vector algebra blocks, axis transformations and force/displacement/velocity computations can be performed on a model with six degrees of freedom. The first equation describes the effect of the front suspension on the vertical degree of freedom (bounce), while equations 2, 3, and 4 represent the pitch moments due to the suspension, and equations 5 and 6 represents the moments and forces result in body motion, according to Newton's Second Law:

$$P_f = 2K_f\left(L_f\theta - (z + h)\right) + 2C_f(L_f\dot{\theta} - \dot{z}) \qquad (1)$$

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$$T_f = -L_f P_f \quad (2)$$

$$P_r = -2K_r\big(L_r\theta - (z + h)\big) - 2C_r(L_r\dot{\theta} - \dot{z}) \quad (3)$$

$$T_r = L_r P_r \quad (4)$$

$$M_b\ddot{z} = P_f + P_r mg \quad (5)$$

$$I_{yy}\ddot{\theta} = T_f + T_r + T_y \quad (6)$$

Where the nomenclature can be written as:

Symbol	Description
M_b	half the mass of the vehicle
T_y	Moment of pitch generated by vehicle acceleration
T_f	Moment of pitch due to front suspension
T_r	Moment of pitch due to rear suspension
I_{yy}	The moment of inertia about the COG
P_f	Upward force on the vehicle body from the front suspension
P_r	Upward force on the vehicle body from the rear suspension
K_f	The tire coefficient at front tire
K_r	The tire coefficient at rear tire
L_f	Distance between COG and front tire
L_r	Distance between COG and rear tire
h	Road profile or road high
θ	Pitch angle
$\dot{\theta}$	Rate of change in pitch angle
z	Bounce distance
$\dot{z}$	Rate of change in the bounce distance

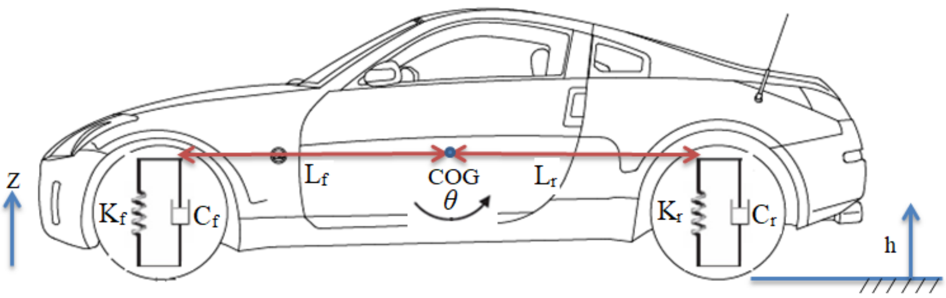

Figure 1. half suspension model of a vehicle

Road profile diagrams

In this work, two distinct road profiles are offered to stimulate the vehicle's suspension system. The initial profile input is a single 12 cm-tall bump. The second profile input is a road profile chosen at random. These two inputs for the road profile are depicted in figures 2 and 3.

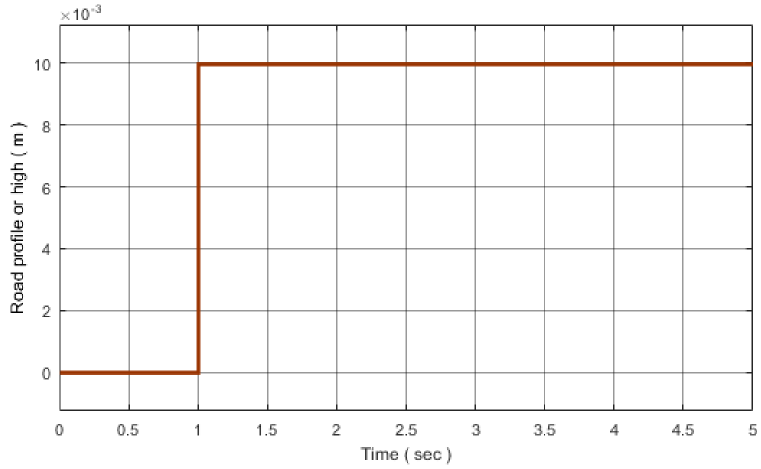

Figure 2. The first road profile: Step signal.

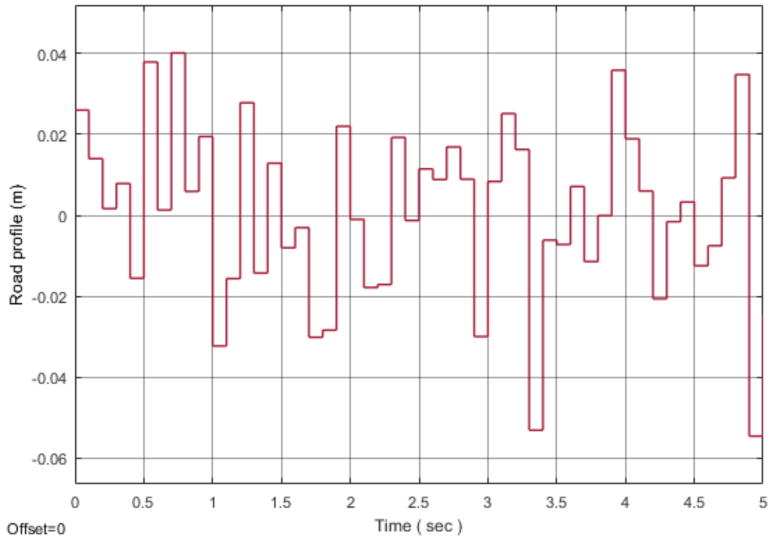

Figure 3. The second road profile: Random signal

The Simulink model of the system

Figure 4 shows The Simulink model of the suspension system for half vehicle model which built by using the previous six equations. This model is available in the Matlab library, but we made some modifications to it and changed the input signal, where it was once as a step signal and the second time was a random signal, which will lead to better analysis and evaluation of the suspension system and more understanding.

Before run the model, the system variables that were specified as follows must be entered:

Lf = 0.82 m, Lr = 1.25 m, M_b = 1190 kg, Iyy = 2100 kg m^2, K_f = 29100 N/m, Kr = 23221 N/m, C_f = 2450 N.sec/m, C_r = 2045 N.sec/m.

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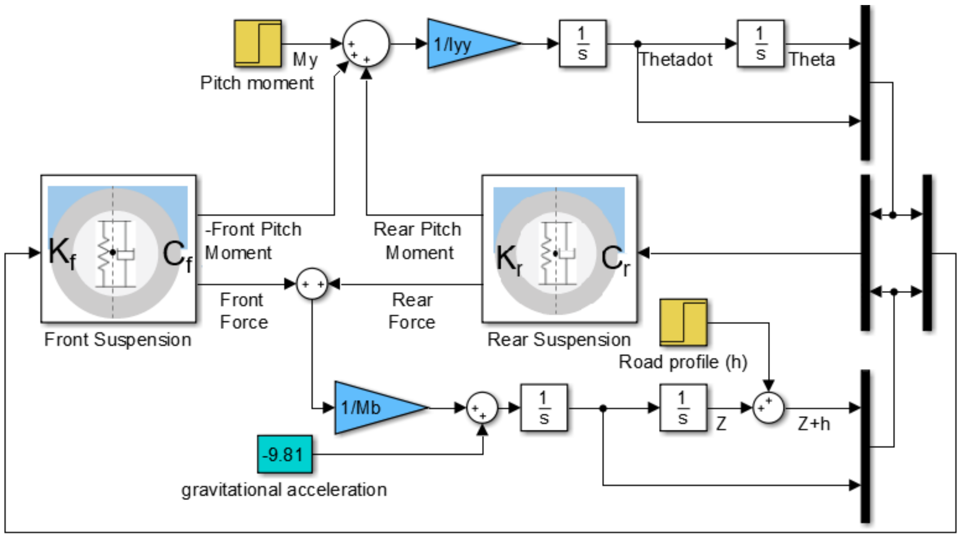
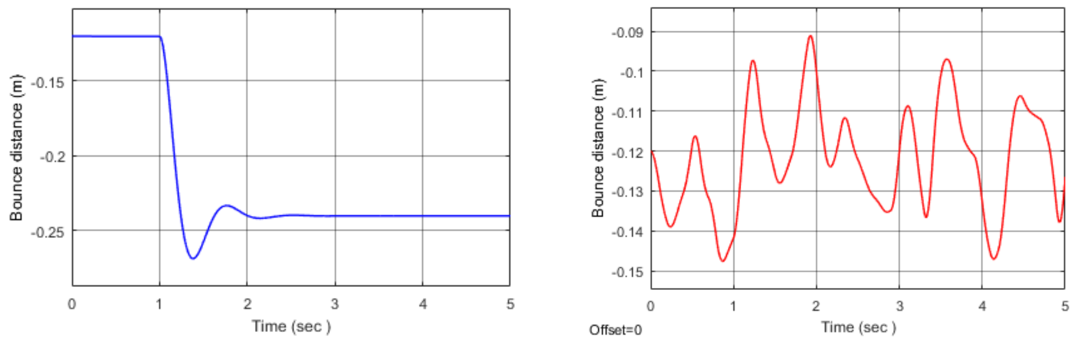


Figure 4. Simulink model of half suspension system

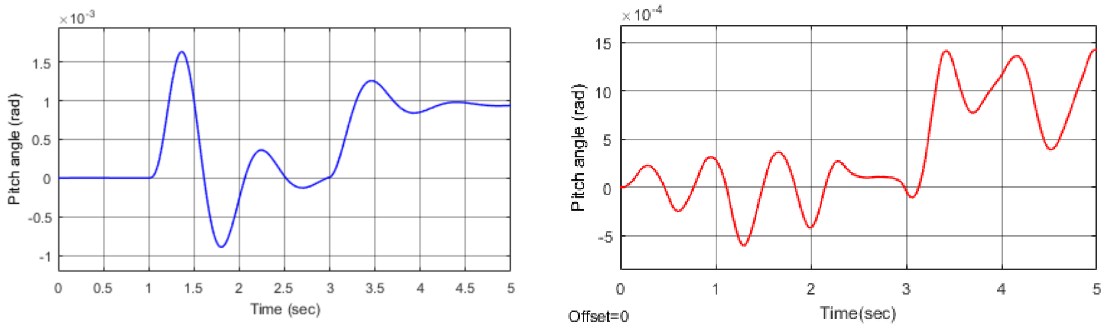
Simulation results of the system

Matlab/Simulink will be used to investigate the dynamic behavior of a half-vehicle model. Simulation in the time domain has been undertaken to test the vehicle's dynamic response with passive suspension systems. The numerical simulation was conducted under two distinct road profile types that are the step signal and the random signals.



(a) (b)

Figure 5. Bounce time response: a) at the step signal, b) at the random signal



(a) (b)

Figure 6. Pitch time response: a) at the step signal, b) at the random signal

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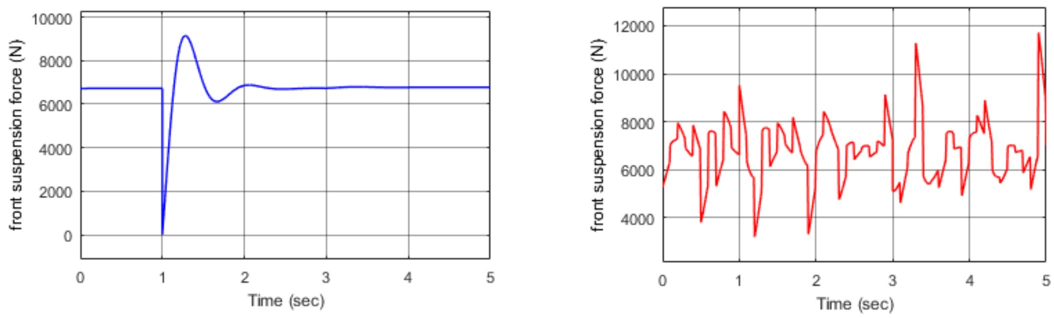
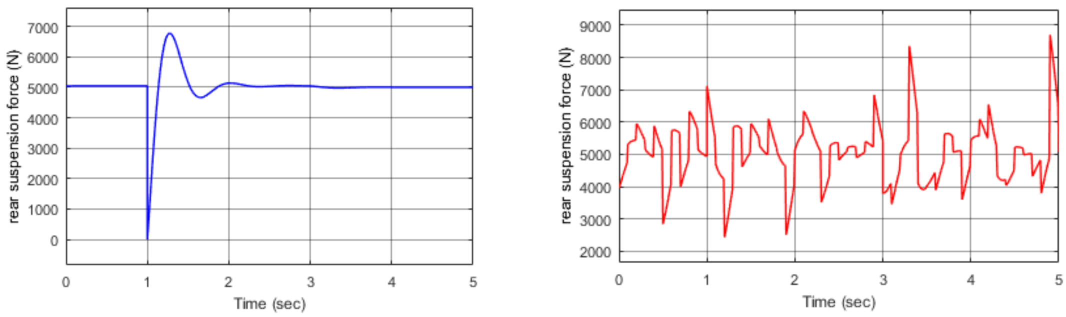


(a) (b)

Figure 7. Upward force on the vehicle body from the front suspension: a) at the step signal, b) at the random signal



(a) (b)

Figure 8. Upward force on the vehicle body from the rear suspension: a) at the step signal, b) at the random signal

Conclusion

This study showed an evaluation of car suspension system at different physical variables, as work was done to form a mathematical model of the suspension system, through which a Simulink model was created. Some important outputs of the system have been tested as the bounce time response, pitch time response, and the upward force on the vehicle body at two types of road profiles, which are step signal and random signal. According to this paper, the reader can evaluate the suspension system performance at several system variables and under different road profiles and conditions. As a future work, some of modern control techniques should be used to achieve a better performance of the proposed system.

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