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Study of Vehicle Characteristics of Quarter Car Model In MATLAB/Simulink

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Abstract: The automotive industry has been growing as the world largest economic sector by revenue for a long time. A vehicle for people has been increasing ever since the automotive industry exploits the technology for their uses. One of the most important systems in the automotive industry is the suspension system. There have been various models and designs produced and used for vehicles ever since the first vehicle was made. As the suspension system getting sophisticated, comfortable ride comfort and smooth ride performance are the key to consumers. The factual information on passive suspension systems is lacking, and research needs to be done to obtain the data on passive suspension system used in earlier day's suspension systems. This study mainly focuses on the simulation of a quarter car on MATLAB/Simulink to obtain the graphical data based on the performance of the suspension system. One way of conducting a simulation for a vehicle is by constructing a mathematical model and form an equation of motion. The speeds used for the simulation research was 20 km/h, 30 km/h and 40 km/h. The bump on the road also considered as a single bump on the road with the height of 0.1 m. The method used to obtain the data from the quarter car is from the sprung and unsprung mass. The data collected from graphs was later analyzed and discussed. Data collected and block diagram used in this simulation can be used for further detailed research purpose. The research proven that when a vehicle is moving at a slower speed, the suspension system works most effectively and providing ride comfort and ride performance.

Keywords: Suspension System, Degree of Freedom, Sprung Mass, Unsprung Mass

1. Introduction

The automotive industry involves many companies and organizations involved in automotive vehicle design, production, manufacturing, marketing, and sales. It is one of the most important and rapidly growing sectors where it is one of the world's largest economic sector by revenue. The word automotive comes from the Greek autos (self), and Latin *motivus* (of motion), referring to any form of

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self-powered vehicle. This term, as proposed by Elmer Sperry (1860- 1930), first came into use with reference to automobiles in 1898 [1][2]. Vehicle dynamics refers to the directional performance and dynamics of road vehicles, and typically vehicle dynamics is based on classical mechanics. The vehicle dynamic consists of the vehicle body (sprung mass), the suspension component (spring and damper) and tire (unsprung mass) as essential parts of the system. The vehicle dynamic performance can be divided into three aspects according to the force direction which are lateral dynamic i.e. handling, longitudinal dynamic i.e. acceleration and vertical dynamic performance i.e. ride and pitch performance [3]. A vehicle development most likely commences with a mathematical model in order to optimize its dynamic and seating responses before a prototype is constructed. Furthermore, the model is used as an evaluation method that considers the sensitivity of human body to different frequencies, directions, and durations of vibration, and to obtain subjective evaluations that can contribute to design improvement [4].

1.1 Suspension System

The suspension system consists of tires, the air in the tires, springs, shock absorbers, struts, arms, bars, linkages, bushings, and joints. The suspension system components are located between the frame of the vehicle and the road. Basically, there are three types of car suspension system; passive, semi-active and active suspension system. A passive suspension system includes the conventional springs and shock absorbers. Such system has an ability to store energy via spring and to dissipate in via damper. A semi-active suspension system provides controlled real-time dissipation of energy. A mechanical device called active damper is fixed in parallel with a conventional spring. It does not provide any energy to the system. Active suspension system has an ability to store, dissipate and to introduce energy to the system. The active suspension is equipped with sensors, which are linked to a powerful computer system, which has information about the vehicle and its response to different road conditions. [5]

1.2 Quarter Car Model

The suspension system consists of tires, the air in the tires, springs, shock absorbers, struts, arms, bars, linkages, bushings, and joints. The suspension system components are located between the frame of the vehicle and the road. Basically, there are three types of car suspension system; passive, semi-active and active suspension system. A passive suspension system includes the conventional springs and shock absorbers. Such system has an ability to store energy via spring and to dissipate in via damper. A semi-active suspension system provides controlled real-time dissipation of energy. A mechanical device called active damper is fixed in parallel with a conventional spring. It does not provide any energy to the system. Active suspension system has an ability to store, dissipate and to introduce energy to the system. The active suspension is equipped with sensors, which are linked to a powerful computer system, which has information about the vehicle and its response to different road conditions. [3]

2. Materials and Methods

2.1 Mathematical Model

Tire and suspensions are considered in two degrees of freedom of quarter car model as shown in Figure 1. This model is based on the bouncing motion of the vehicle due to random road surfaces. In this model only 1/4th of the vehicle is taken in to consideration for the vibration analysis. The model is two dimensional. Basically this model is consisting of one wheel which is specified by the spring and a damper in the diagram and sprung mass.

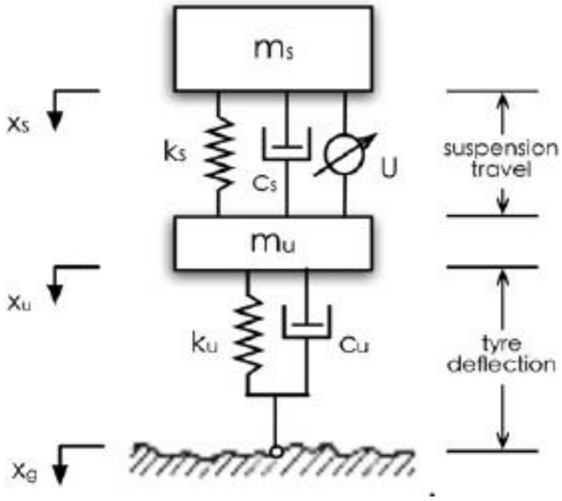

Figure 1: Quarter car model of a suspension system

2.2 Mathematical Equation

Modeling of automotive suspension is of great interest for automotive and vibration engineers. Vehicles ride quality is prime concern for the engineers when a vehicle passes over the speed bump. For our analysis 2 DOF quarter car model (Figure 1) has been developed with following assumptions [7]:

- Vehicle is rigid body with the suspension
- Suspension consist of suspension spring, absorber, sprung, un-sprung mass of the body
- Tire stiffness and tire absorptivity is considered separately

Parameters used for mathematical modeling are as follows:

m_s = Sprung Mass

m_u= Un-sprung Mass

x_s = Vehicle body motion,

x_u = Wheel body motion,

x_r = Road velocity,

k_s , k_t = Suspension & Tire spring rates respectively,

c_s , c_t = Suspension & Tire damping respectively

The equation of motion for sprung and unsprung mass of the model considering it moving over a speed bump will become [8][9]:

$$m_s\ddot{x}_s - c_s(\dot{x}_s - \dot{x}_u) + k_s(x_s - x_u) = 0 \qquad \textit{Eq.1}$$

$$m_u\ddot{x}_u - c_s(\dot{x}_s - \dot{x}_u) - k_s(x_s - x_u) - k_t(x_u - x_r) = 0 \qquad \textit{Eq.2}$$

Figure 2: Methodology flowchart of quarter car model

3. Results and Discussion

The mathematical model in Figure 3 below shows the model that had been constructed for a quarter car model. The mathematical model begins from the formation of mathematical equation of the mathematical model. The speeds used to run this simulation was 20 km/h, 30 km/h and 40 km/h. The three speed for this simulation was choose due to the driving conditions and average speed each driver passes through a bump.

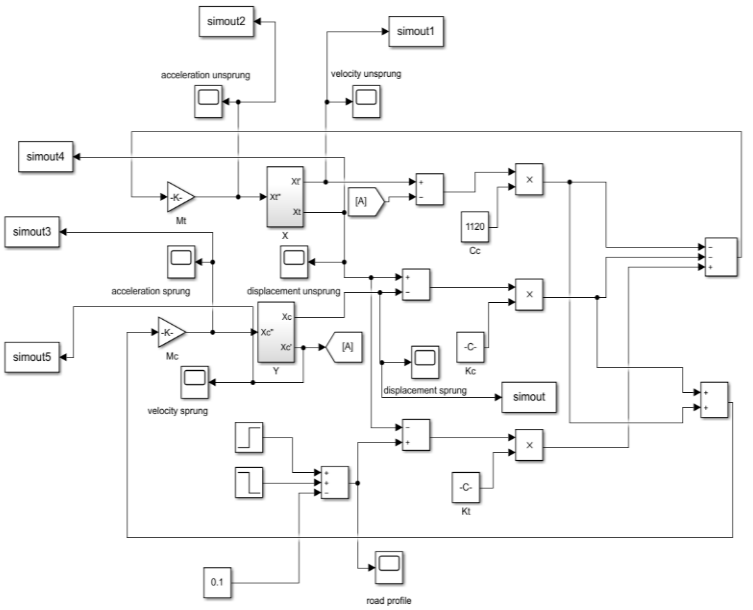

Figure 3: Mathematical model in MATLAB/Simulink software

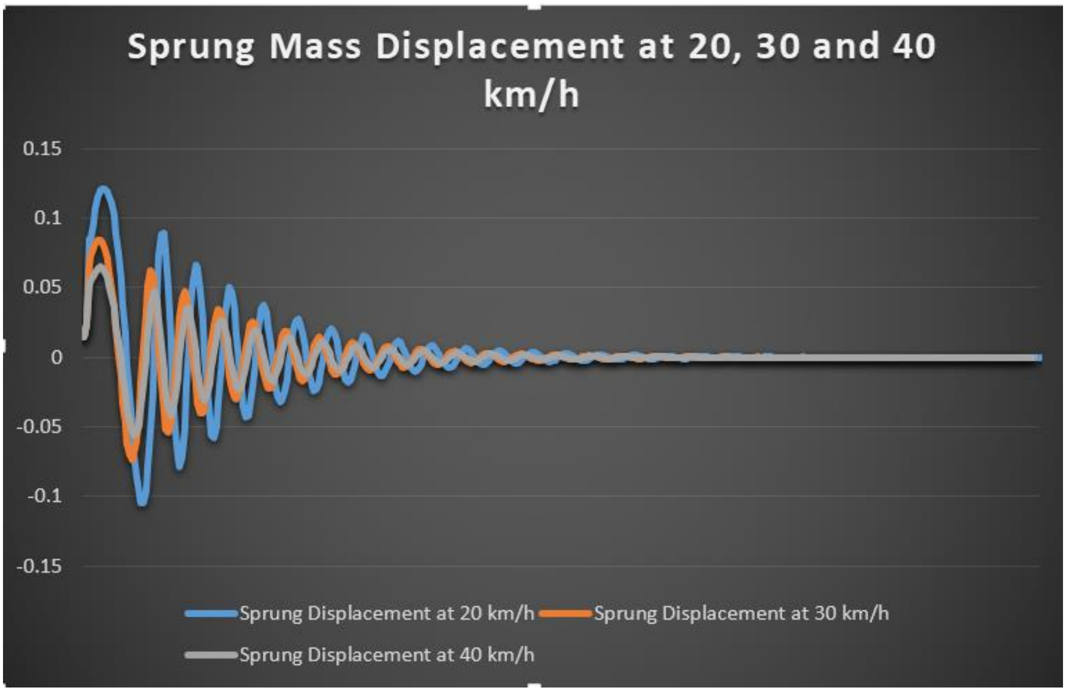

Figure 4: Sprung mass displacement at 20, 30 and 40 km/h

Graph shows the sprung mass displacement of quarter car model at speeds of 20, 30 and 40 km/h. The graph shows that the sprung mass displacement has the highest and lowest amplitude at 20 km/h and the lowest amplitude recorded is at 40 km/h. The graph dissipates to zero for all three speeds at the time of 8 second. The difference between sprung mass displacement at 20 km/h and 30 km/h is less than 20.00 % while the difference between sprung mass displacement at 20 km/h and 40 km/h is more than 60.00 %.

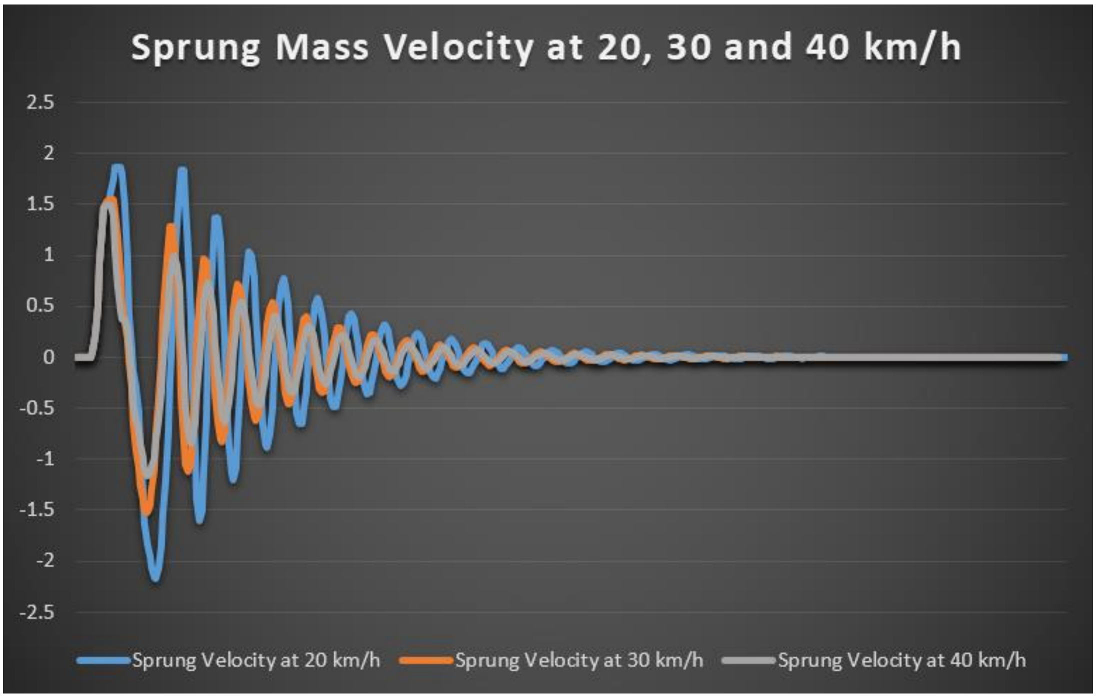

Figure 5: Sprung mass velocity at 20, 30 and 40 km/h

Graph shows the velocity of sprung mass at 20, 30 and 40 km/h. The highest and lowest amplitude recorded was at the speed of 20 km/h and the lowest followed by at the speed of 40 km/h. The graph started to settle down at 8.5 seconds for all three speeds. The difference between sprung mass velocity at 20 km/h and 30 km/h is less than 15.00 % while the difference between speeds of 20 km/h and 40 km/h is more than 30.00 %.

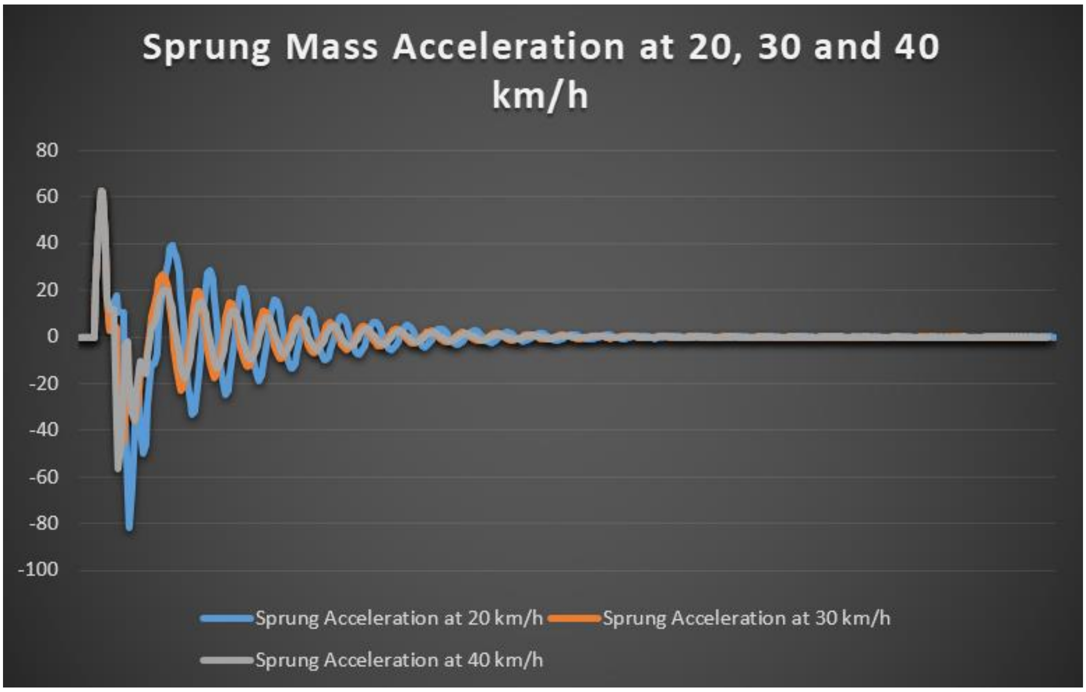

Figure 6: Sprung mass acceleration at 20, 30 and 40 km/h

Graph shows the sprung mass acceleration at speeds of 20, 30 and 40 km/h. The lowest amplitude was recorded was at speed of 20 km/h while the highest amplitude recorded was recorded was at speed of 40 km/h. The sprung mass acceleration at 30 km/h recorded the steadiest between all three speeds.

The difference of sprung mass acceleration at 20 km/h and 30 km/h is 35.00 % while the difference between 30 km/h and 40 km/h is less than 15.00 %.

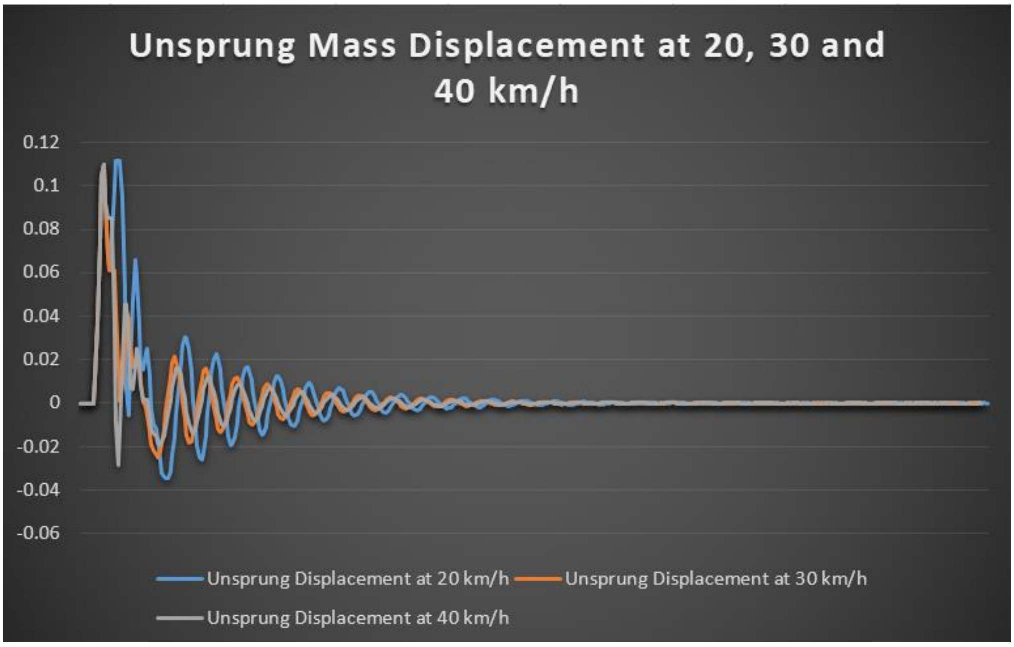

Figure 7: Unsprung mass displacement at 20, 30 and 40 km/h

Graph shows the data collected for unsprung mass displacement at speeds of 20, 30 and 40 km/h. The highest amplitude recorded was at speed of 20 km/h while the second highest amplitude was at 20 km/h. The lowest amplitude was recorded was also at speed of 20 km/h. Unsprung mass displacement of speeds of 20, 30 and 40 km/h settled down at 8 seconds. The difference between unsprung mass displacement at 20 km/h and 30 km/h is more than 40.00 % while the difference between unsprung mass displacement at 30 km/h and 40 km/h is less than 20.00 %.

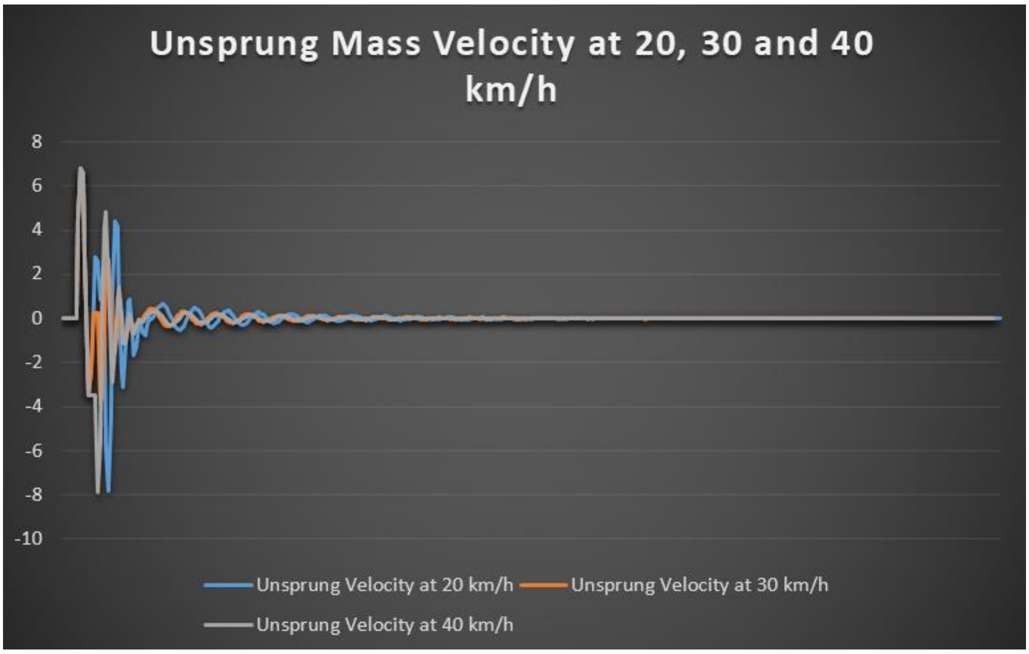

Figure 8: Unsprung mass velocity at 20, 30 and 40 km/h

Graph shows the unsprung mass velocity at 20, 30 and 40 km/h. The highest and lowest amplitude recorded of unsprung mass velocity at speed of 40 km/h. The speed of 30 km/h recorded the most average result between all three speeds. The difference between unsprung mass velocities of speed 20 km/h and 30 km/h is more than 40.00 % while the difference between speed of 20 km/h and 40 km/h is less than 30.00 %. The time taken by all three speeds to settle down was around 6.5 seconds.

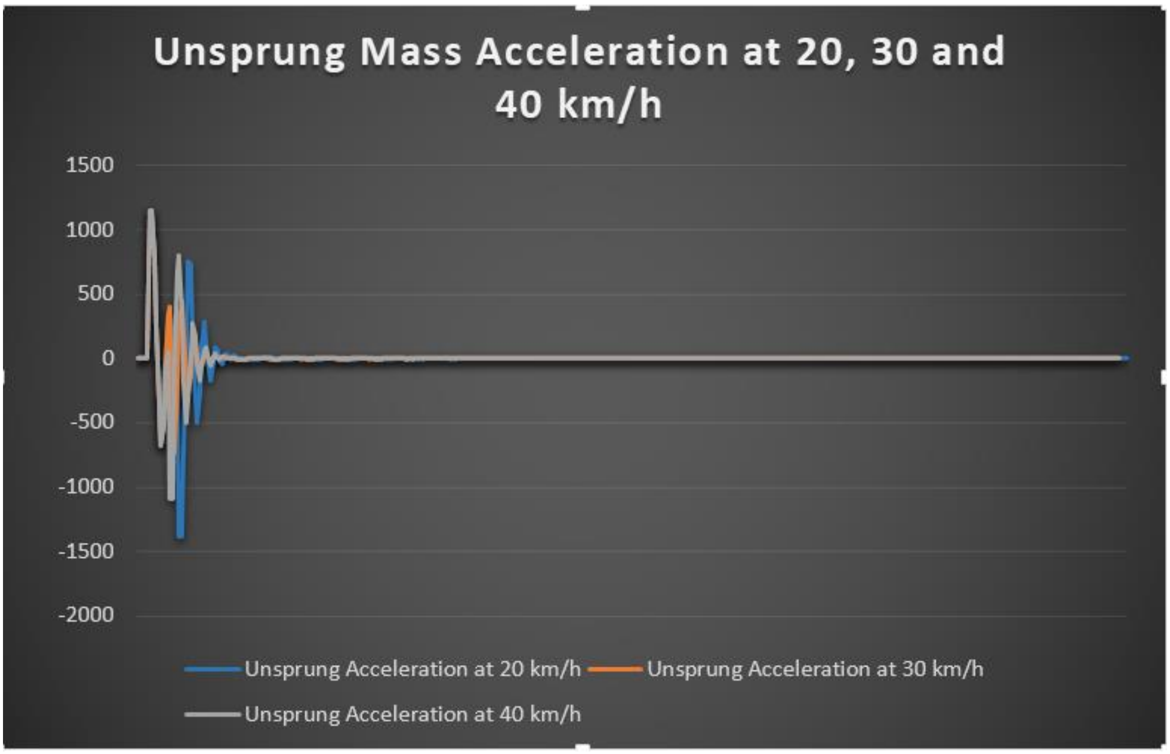

Figure 9: Unsprung mass acceleration at 20, 30 and 40 km/h

The graph shows the unsprung mass acceleration at speeds of 20, 30 and 40 km/h. The highest amplitude of unsprung mass acceleration recorded was at the speed of 40 km/h while the lowest amplitude recorded was at the speed of 20 km/h. The difference between unsprung mass acceleration at speeds of 20 km/h and 30 km/h is less than 40.00 % while the difference of unsprung mass acceleration between speeds of 30 km/h and 40 km/h is less than 20.00 %. All three speeds reached stability in graph data at the time of 6 seconds.

The graphs above shows that the ride comfort is reduced significantly when the speed is increased from 20 km/h to 40 km/h. The suspension system does not have enough time to absorb and release shock. Therefore, there is a jumping motion when passing over a bump on a high speed. The graph also shows the amplitude is controlled in the speed of 20 km/h where there is plenty of time for the suspension system to absorb and release shock. Therefore, it produces stable graph and gives better ride comfort.

4. Conclusion

Based on the simulation conducted, the objective to develop a passive suspension system using a quarter car model in MATLAB/Simulink software was able to achieve. The experiment was conducted with three different speeds of vehicle, which are 20 km/h, 30 km/h and 40 km/h to hit a bump on a road. The data that had been gathered by sprung and unsprung mass on displacement, velocity and acceleration was converted into Microsoft Excel was achieved. The results shows that the best speed of going on a bump to maintain ride comfort and ride performance is 20 km/h. the result from this study enable a further study of a quarter car model on passive suspension system of a vehicle. The vehicle speed of 20 km/h had higher amplitudes on sprung and unsprung mass displacement, velocity and acceleration. This proves that slower speeds provides better time for the suspension system to absorb and disperse shock evenly throughout the ride.

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