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Study on Characteristic of Motorcycle Suspension

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Abstract: Generally, the motorcycle has the same system as a vehicle. Its main function of the suspension system is to provide good driving comfort, better handling, isolating the noise, bump and vibration from the road condition. The passenger of motorcycle also experienced the different effect such as handling and ride comfort from different velocity of the motorcycle. The main objective of this study is to develop the simulation of a motorcycle passive suspension system and to investigates the effect of ride comfort of the motorcycle by apply different speed using vehicle model analysis. All the simulations were carried using Matlab\Simulink software and the simulation model were conducted by applying different of speed which is 20 km/h, 30 km/h and 40 km/h when hit the bump. The finding of the result from the simulation progress showed that the effect of both the distribution of spring-damping supported mass. The finding results also showed that the half-car model for passive suspension system of a vehicle can be used on a motorcycle by using the appropriate suspension component and bump dimension parameter to be simulated in the Matlab\Simulink software.

Keywords: Motorcycle half - car, passive suspension system, simulink

1. Introduction

Motorcycle can be categorized as a common transportation after a vehicle in Malaysia. This is due to their affordable price and how the motorcycle can effortlessly be used especially in the road where heavy traffic mostly occurred. A motorcycle has the same suspension system like vehicle does, where its function was to absorb the bump in the road and to ensure that the tyres are in contact with the road [1]. In vehicle, the safety and comfort of the vehicle are affected from the main component which is the suspension system [2] Unlike vehicle, a motorcycle has a quite small component of suspension which consist of front and rear suspension and are also known as shock absorber. The shock absorber in the suspension also dissipates Kinetic energy when shock impulses are damped [3]. An uneven road will generate vibration of a vehicle on its wheel and will be transmitted to the axles. The suspension role is used to reduce as much vibration and shock during on the road. A good suspension should achieve the ride comfort when interacted with uneven road profile [4-5]. The vertical force which transmitted to the rider comfort should be reduced by the suspension. This can be achieved by minimizing the acceleration of the body. An optimal contact with road surface with the wheel is also needed in any driving condition in order to maximize safety [6-7].

In this study, the equation of motion for passive suspension system will be developed in Matlab/Simulink software. The motorcycle hits a bumpy road as the road input with different speed. A rider will be affected by the road profile whereby when the motorcycle travel on a bumpy road with certain speed, a bump road will affect the driving comfort of rider. This study aims to analyze the motorcycle suspension system by developing the half-car model and running in Matlab environment. There are two scope considered to this study which are the motorcycle speed is set to 20km/h, 30km/h and 40km/h and with only a single bump as road input considered.

2. Motorcycle Suspension System

The front suspension of a motorcycle is the most important component of a suspension system. It is the main system that supports the front load of a motorcycle. The main function of a motorcycle front suspension system is to

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give a guide to the front wheel of the motorcycle, to spring, to provide good steer, to dampen and to give support under braking [8]. The similar vital component like the rear suspension of a motorcycle today is also considered to be important component of motorcycle suspension system. Almost every modern motorcycle today has a rear suspension constructed in a motorcycle, which include the main component like the swing-arms, shock absorber and spring [9].

2.1 Passive Suspension System

Mostly of vehicle in modern days uses the passive suspension system types due to its cost-effective reasons. The passive suspension system comprises of spring tensions and damper rate to be able to have control the reaction of a suspension [10]. The passive suspension system restricts the motion of the body and wheel by limiting their relative velocities to a rate that provides the ride comfort requirement. This is achieved by the use of damping element device that is placed between the body and the wheels of the vehicle this device is called the hydraulic shock absorber. However, the conventional shock absorbers do not give an energy to the suspension system and control only the displacement of the vehicle body and wheel by restricting the sprung and unsprung velocity according to the rate determined by the engineers [11].

Beside passive suspension, three kinds of fundamental damping of the suspension system which are, passive, semi-active and active suspension. The passive suspension is the simplest and has more advantages. However, the downside of the passive suspension is the limitation to overcome unwanted vibration that occurs because of the road surfaces [12]. On a normal parameter, the passive suspension performance is limited due to the fix spring and damper. The efficiency depends on the fixed standard of certain vehicle parameters. Quarter car model for passive suspension system is shown in Figure 1 below to show the passive suspension.

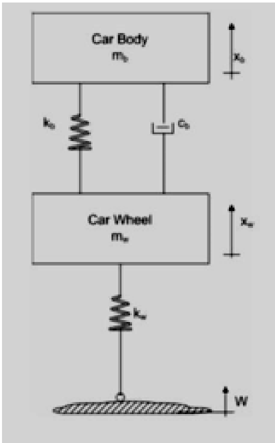

Fig. 1 - Quarter car model for passive suspension system [13]

3. Mathematical Model

The terms mathematical modelling represents the system behaviour in mathematically speaking. The main function of the mathematical modelling can be used for scientific understanding development, the test effect of changes in a system, and also aiding the decision making [14]. In a mathematical modelling, the process of modelling concerns with expressing a real-life situation into a term of mathematical. The model usually consists of conveying real-life problem into a mathematical problem [15-16].

3.1 Half Car Model of The Motorcycle Suspension System

The model for 4-DOF system is described by the vertical displacement of the front wheel, the vertical displacement of the rear wheel, the vertical displacement of the chassis (bounce), and the rotation angle of the chassis (pitch). It requires four (4) mathematical equation to describe the model [17]. In Figure 2 below shows the four degrees-of-freedom of a half-car model. There are two motion that represented by this model which is the moment of inertia pitch θ, and heave motion Z of the body and also the vertical translational of front and rear axles component which is known as the unsprung mass and the body of the system is sprung mass. The spring stiffness and the damping rate are represented by the symbol Keq and beq. For the tyre stiffness, the symbol that represents it is K.

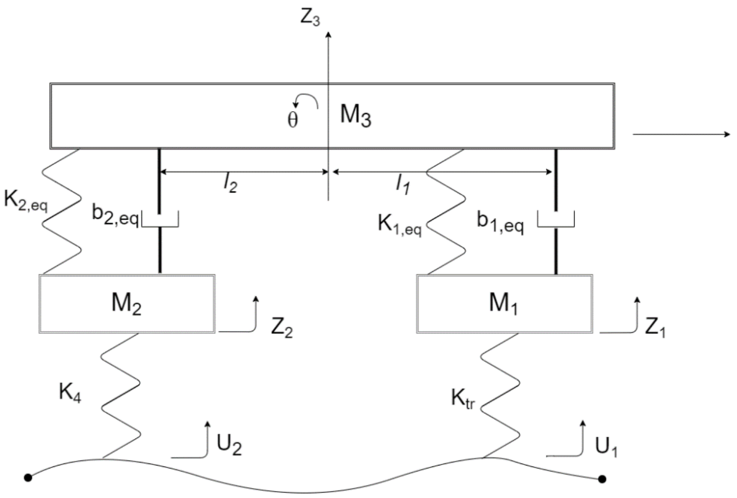

Fig. 2 - 4 – DOF Half-car model

The motorcycle equations of motion can be described by the following set of ordinary differential equations that can be written by free body diagram concept. Therefore, the equations for the 4 degrees-of-freedom system as in figure 2 (Half-car model) are as following:

$$\ddot{Z}_3 = \frac{1}{m_3}[-b_{1eq}(\dot{z}_3 + l_1\dot{\theta}_3 - \dot{Z}_1) - b_{2eq}(\dot{Z}_3 - l_2\dot{\theta}_2 - \dot{Z}_2) - K_{1eq}(Z_3 + l_1\theta_3 - Z_1) - \quad K_{2eq}(Z_3 - l_1\theta_3 - Z_2) \tag{1}$$

$$\ddot{Z}_1 = \frac{1}{m_1}[b_{1eq}(\dot{Z}_3 + l_1\dot{\theta}_3 - \dot{Z}_1) + K_{1eq}(Z_3 + l_1\theta_3 - Z_1) - K_3(Z_1 - U_1)] \tag{2}$$

$$\ddot{Z}_2 = \frac{1}{m_2}[b_{2eq}(\dot{z}_3 - l_2\dot{\theta}_3 - \dot{Z}_2) + K_{2eq}(Z_3 - l_1\theta_3 - Z_2) - K_4(Z_2 - U_2)] \tag{3}$$

$$\ddot{\theta}_3 = \frac{1}{I_s}[-b_{1eq}l_1(\dot{Z}_3 + l_1\dot{\theta}_3 - \dot{Z}_1) + b_{2eq}l_2(\dot{Z}_3 - l_2\dot{\theta}_3 - \dot{Z}_2) - K_{1eq}l_1(Z_3 + l_1\theta_3 - Z_1) + K_{2eq}l_2(Z_3 - l_2\theta_3 - Z_2)] \tag{4}$$

3.2 Parameter Input and Road Condition

For the parameter of the half-car system, the parameter value was taken from one study from Stefan Segla and Sayantan Roy (2020) [18]. The paper focuses on the dynamic in-plane simulation analysis of the motorcycle suspension with a grey-box model of a motorcycle mono-tube shock absorber as the consideration. In Table 1 below shows the parameter of the motorcycle suspension system.

Table 1 - Parameter motorcycle suspension system

Item	Parameter Name	Symbol	Variable Value	Unit
1	Sprung mass	M_s	194	Kilograms (kg)
2	Unsprung mass front	M	15	Kilograms (kg)
3	Spring stiffness front	$K_{1\,eq}$	15000	Newton-Meter (N/m)
4	Damping coefficient front	$b_{1\,eq}$	710	N.s/m
5	Tyre stiffness front	K_3	180000	Newton-Meter (N/m)
6	Unsprung mass rear	M_2	18	Kilograms (kg)
7	Spring stiffness rear	$K_{2\,eq}$	24000	Newton-Meter (N/m)
8	Damping coefficient rear	$b_{2\,eq}$	1171	Newton meter per second (N.s/m)
9	Tyre stiffness rear	K_4	180000	Newton-Meter (N/m)
10	Length 1 front	l_1	0.64	Meter (m)
11	Length 2 rear	l_2	0.7	Meter (m)
12	Pitch Axis Moment of Inertia	I_θ	38	kilogram per square metre (kg.m^2)

For the road profile, the motorcycle will travel to pass through the bump while hitting it. The bump orientation is arranged perpendicular to the direction of the motorcycle. The half car model is simulated at a constant speed 20km/h before hitting a bump. The dimension of bump is 0.075 m (height), 0.40 m (width) and 2.45 m (length). There was 2 combination of step input used as the bumper for the road profile. In Matlab/Simulink, the motorcycle will travel with a constant speed that was visualized in step input from 0 to the final value for the step input will be 0.075. For the 2nd step input, the value is set as a 0.075 to the final value of 0 in step input specification requirement. The calculation to visualized of speed to time domain into step input are shown in Table 2, the time for motorcycle traveling when it hitting the bump with 20 km/h is 0.072 s. The time domain for motorcycle travelling when it hitting the bump for speed 30 km/h and 40 km/h are 0.048 s and 0.036 s.

Table 2 - Calculation of speed to time domain into Step Input

Item	Parameter	Calculation	
1	**20km/h**	$\frac{20km/h}{1\,hr} = \frac{0.4\,m}{time\ (s)}$ $\frac{20\times10^{3}}{3600\,s} = \frac{40\times10^{-2}}{t(s)}$	$\frac{(40\times10^{-2})}{(20\times10^{3})} \times 3600s = time\ (s)$ $time\ (s) = 0.072\ s$
2	**30km/h**	$\frac{30km/h}{1\,hr} = \frac{0.4\,m}{time\ (s)}$ $\frac{30\times10^{3}}{3600\,s} = \frac{40\times10^{-2}}{t(s)}$	$\frac{(40\times10^{-2})}{(30\times10^{3})} \times 3600s = time\ (s)$ $time\ (s) = 0.048\ s$
3	**40km/h**	$\frac{40km/h}{1\,hr} = \frac{0.4\,m}{time\ (s)}$ $\frac{40\times10^{3}}{3600\,s} = \frac{40\times10^{-2}}{t(s)}$	$\frac{(40\times10^{-2})}{(40\times10^{3})} \times 3600s = time\ (s)$ $time\ (s) = 0.036\ s$

3.3 Simulink Block Diagram

Simulink is a visual tool for computational simulations which mostly used by engineer and engineering students. The friendly user enables it to drag and drop the block from the Library to make a simulation and by connecting the components using line arrow. The Simulink offers some way of solving equation numerically without using code and by using graphical user interface [19-20]. In Figure 3 below, it shows the Simulink block diagram that represents the half-car model which was developed by using the governing equation derived from the half-car model shown in Figure 2. In the block diagram, the road profile is connected in the gain block as the tyre to represent the wheel to pass through a bump. From the simulation of the block diagram, the result can be obtained for sprung mass, unsprung mass front and rear and the moment of inertia.

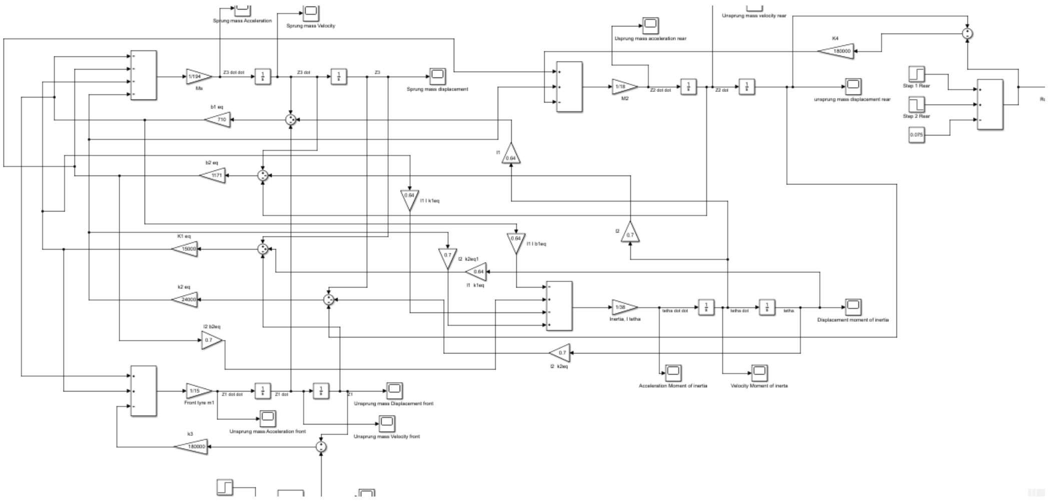

Fig. 3 - Simulink block diagram of half-car model

4. Result and Discussion

The result discussed will be the sprung mass, unsprung mass front and rear and the moment of inertia. There will be 3 linear motion results to be discussed which is the displacement, velocity and acceleration. Three speed of the motorcycle simulated is 20 km/h, 30 km/h and 40 km/h from the initial state until it hits the bump. The parameter for this speed used is referred to as the safe speed limit for the motorcycle travel test on bumpy road condition [21]. All of the results are converted into Microsoft excel to compile all data into one graph for all speed with each motion.

4.1 Sprung Mass

The result presented in this section is the comparison of variant speed of sprung mass for displacement, velocity and the acceleration. In Figure 4 shows the sprung mass displacement result followed by Figure 5, the sprung mass velocity and in Figure 6 the sprung mass acceleration result.

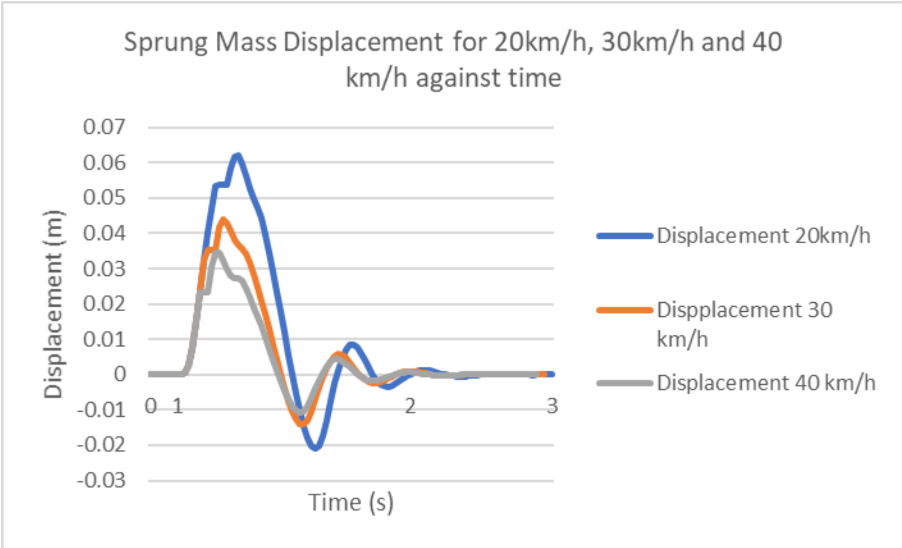

Fig. 4 - Sprung mass displacement result

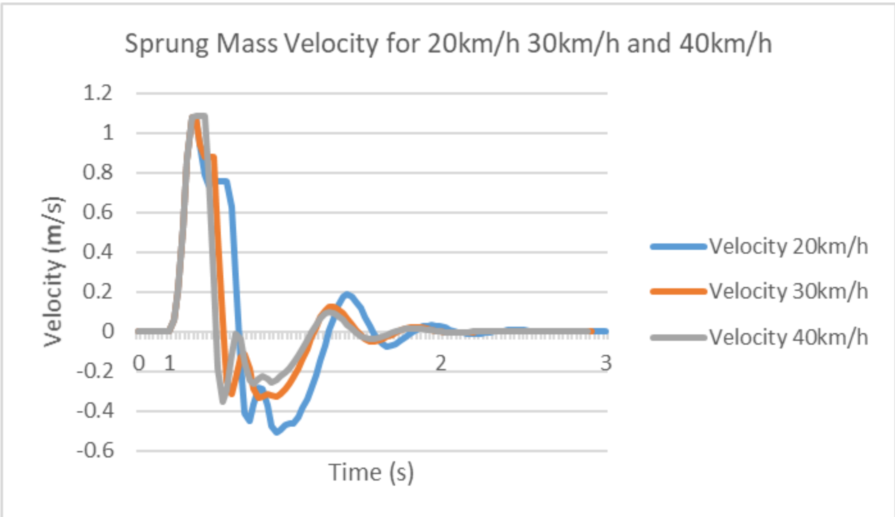

Fig. 5 - Sprung Mass velocity result

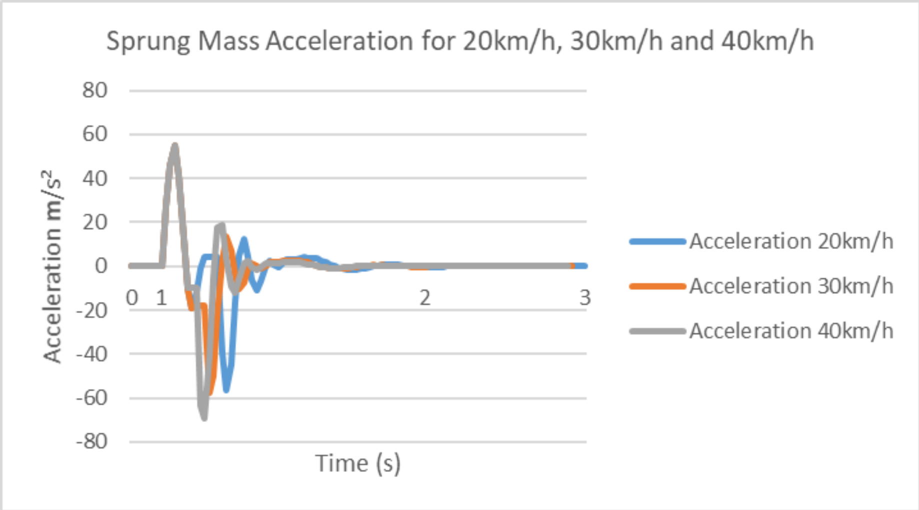

Fig. 6 - Sprung mass acceleration result

From the collected data, the reading shows that the higher the speed of the motorcycle travel, the lower the displacement of the sprung mass. The maximum reading can be seen as it starts to fluctuate at 1 s with the speed test for 20 km/h, which gives the maximum peak for the displacement of the sprung mass at 0.06 m. The reading value for the displacement of sprung mass then decreases as the speed of motorcycle increased.

For 30 km/h speed, the displacement of sprung mass has decreased which the maximum reading is at 0.04 m for 1.3 s approximately. The maximum reading displacement of the sprung mass continued to decreased as the speed increases as of 40km/h speed. Whereby, the maximum value is 0.035 m at 1 s. The same trend for the minimum reading of displacement shows the decreasing value of displacement of sprung mass. Furthermore, the velocity and the acceleration of sprung mass does not show much changes in trend for its maximum reading value. However, the acceleration minimum reading value shows an increasing trend for its value whereby for 20 km/h the minimum value is -56.76 m/s^2, 30 km/h the minimum value is 57.533 m/s^2 and for 40 km/h the minimum value is 67.81 m/s^2. The possible reason for the sprung mass reduction as the speed is increased is that, the vehicle is dependent to the dimension of the bump. whereby, higher bump dimension will give more vertical displacement of a passive suspension system. Generally, passive suspension system does not have much advance technology like active suspension and semi-active suspension. However, passive suspension can be improvised by using stiffer spring and shock absorber to reduce the vertical sprung mass displacement.

One of the reasons for the displacement reduction is by making a comparison with active suspension system whereby, the active suspension system could reduce the sprung mass vertical displacement by using the Linear-Quadratic Regulator (LQR) controller design to provide ride comfort [22].

4.2 Front and Rear Unsprung Mass

In this section, the front and rear unsprung masses are presented. The graph result shows the comparison result on different speed for each graph result. The front unsprung mass result shows the displacement result in Figure 7 followed by the front unsprung mass velocity result in Figure 8 and front unsprung mass result in Figure 9. The rear unsprung mass result for displacement also shown in Figure 19 followed by rear unsprung mass velocity result in Figure 11 and rear unsprung mass acceleration result in Figure 12.

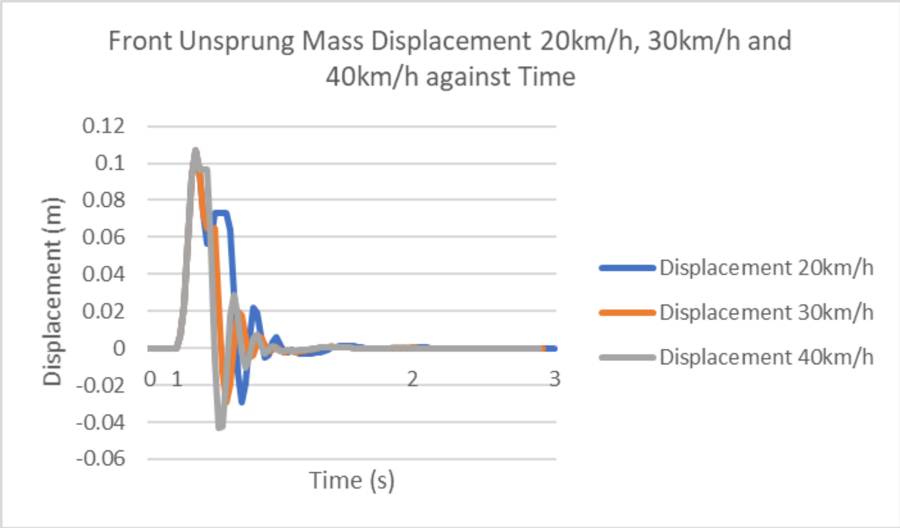

Fig. 7 - Front unsprung mass Displacement result

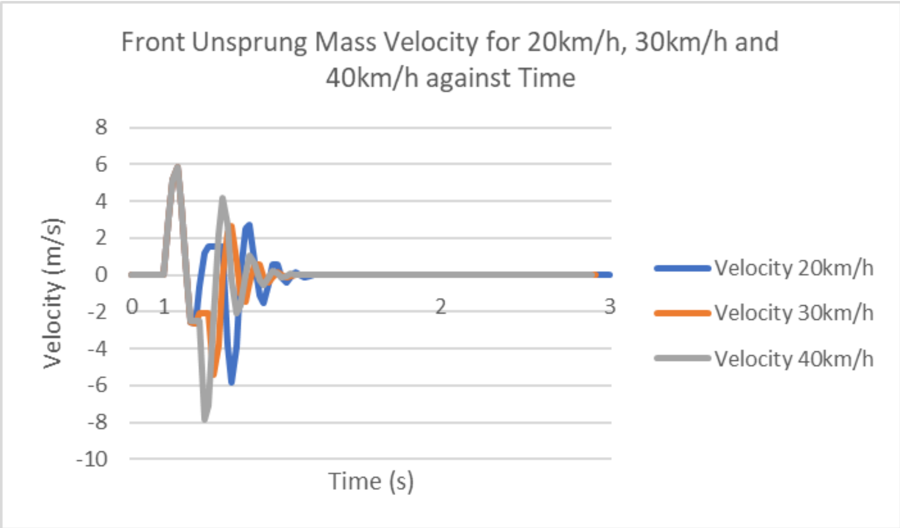

Fig. 8 - Front unsprung mass velocity result

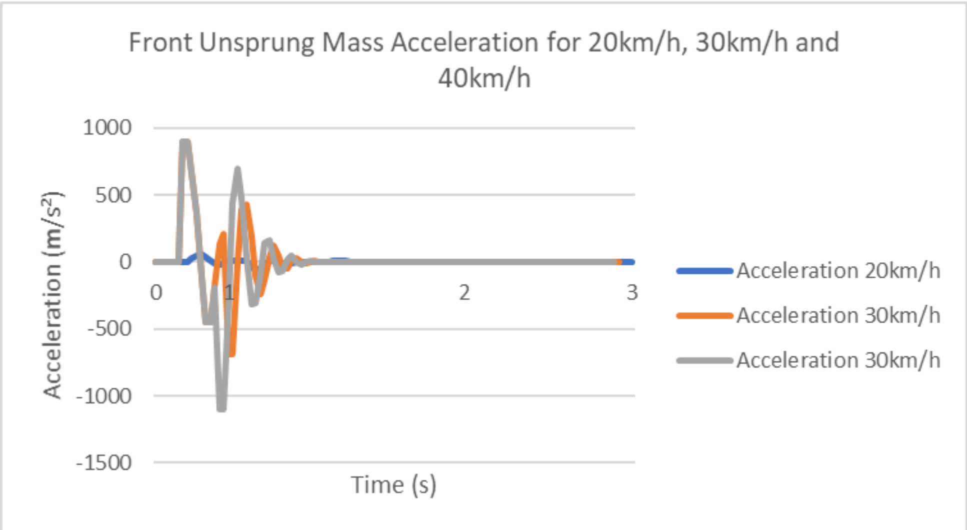

Fig. 9 - Front unsprung mass acceleration result

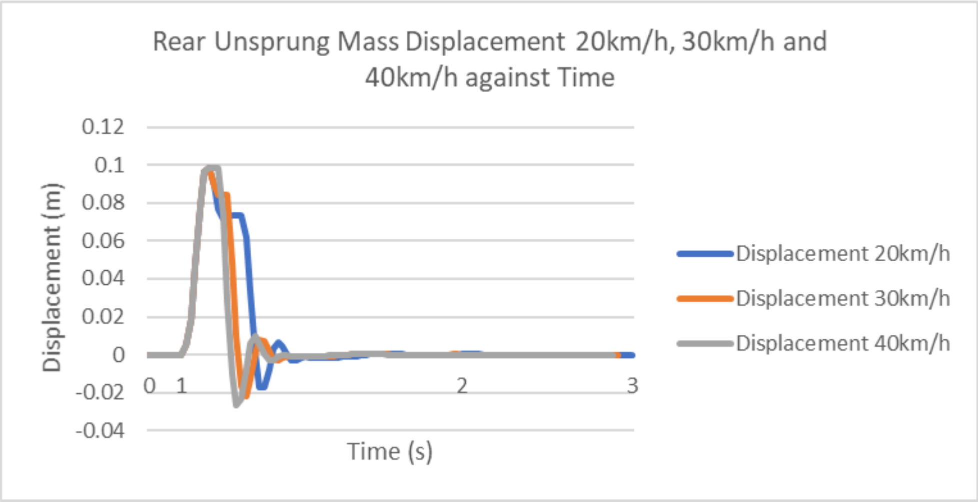

Fig. 10 - Rear unsprung mass displacement result

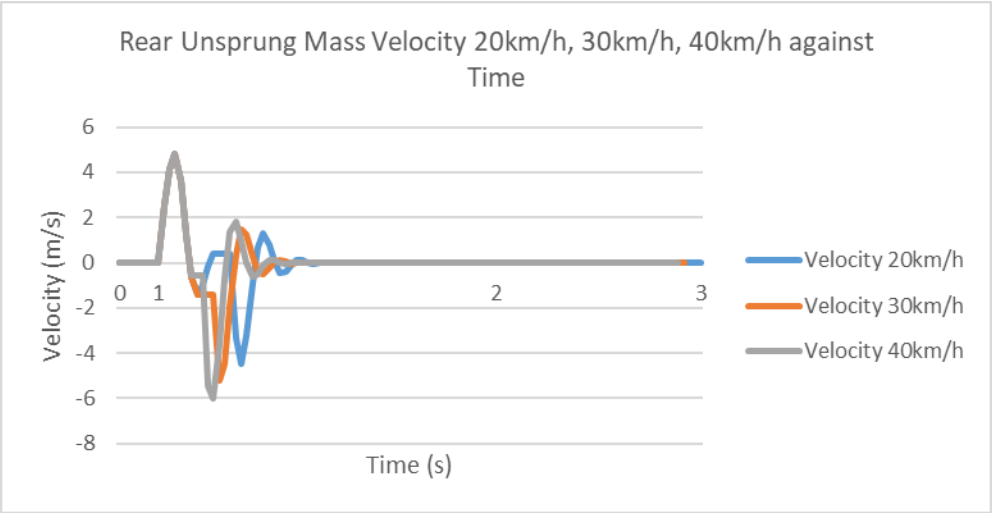

Fig. 11 - Rear unsprung mass velocity result

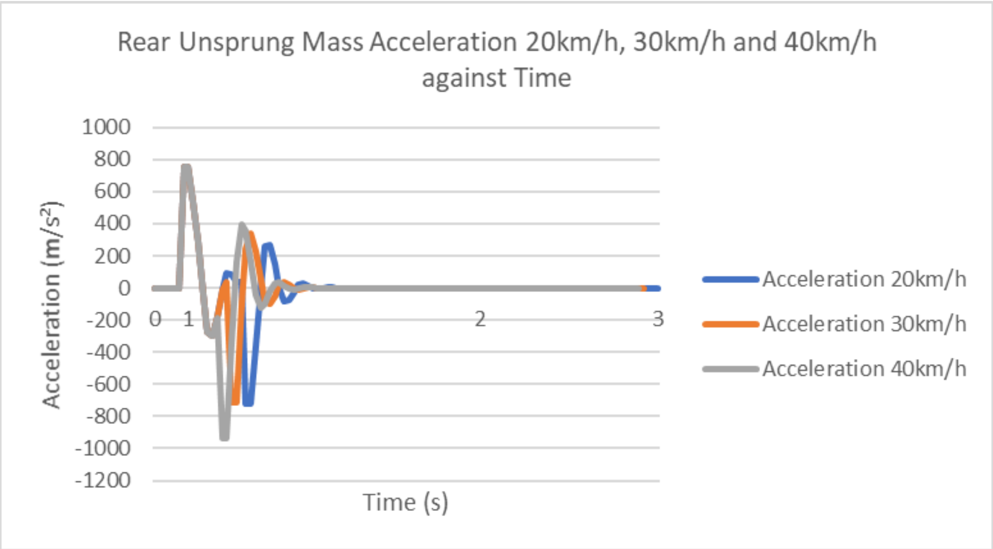

Fig. 12 - Rear unsprung mass acceleration result

According to the result for the front and rear unsprung mass, it is observed that as the speed of the motorcycle increased, the maximum reading value for the displacement, velocity and acceleration of the unsprung mass for front and rear remains the same. For the front unsprung mass displacement result, the increasing speed shows the graph to fluctuate steadily in 1 second. The velocity result shows the maximum reading is the highest at 40 km/h speed. The acceleration for the front unsprung mass shows an increasing graph trend as the speed increased. The rear unsprung mass displacement is also showing an increase steady fluctuation of graph at high speed for 1 second with the maximum reading value is at 0.1 m of displacement. The velocity shows the highest and the lowest reading at 40 km/h speed. The acceleration maximum and minimum value is increasing as the speed increases compared to the lower speed. The reason to this is because the only variable changes in this simulation are the speeds. The faster the motorcycle travel when hitting the bump road, the highest bounce occurred as the motorcycle travel hitting the bump road. This is due to the weight of the unsprung masses, which gives the ride comfort of the motorcycle, this includes the vibration isolation from the road. Another factor like the tyre stiffness also plays an important role in providing the ride comfort.

4.3 Moment of Inertia

In this section presents the moment of inertia result for the angular displacement, angular velocity and angular acceleration. In Figure 13 shows the moment of inertia angular displacement result with different speeds. The angular velocity of moment of inertia results shows in Figure 14 and in Figure 15 shows the moment inertia angular acceleration result.

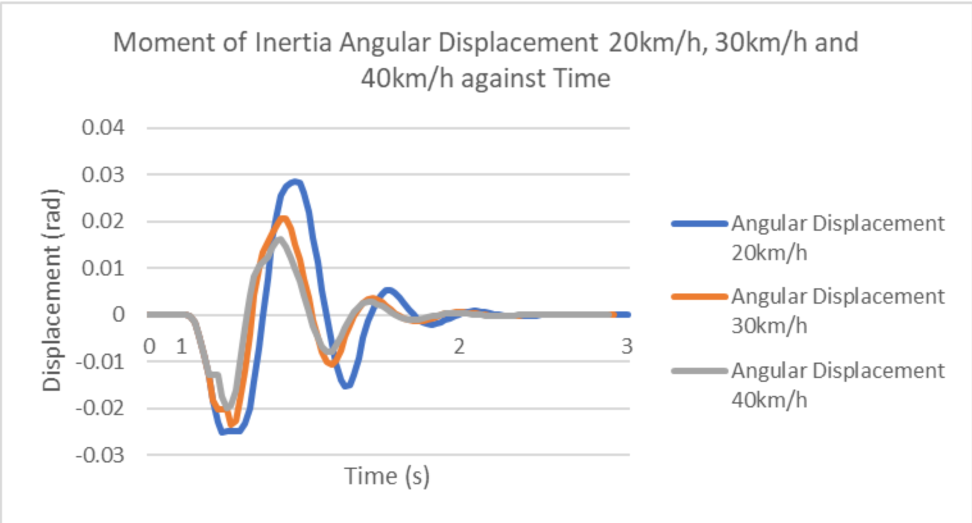

Fig. 13 - Moment of inertia angular displacement result

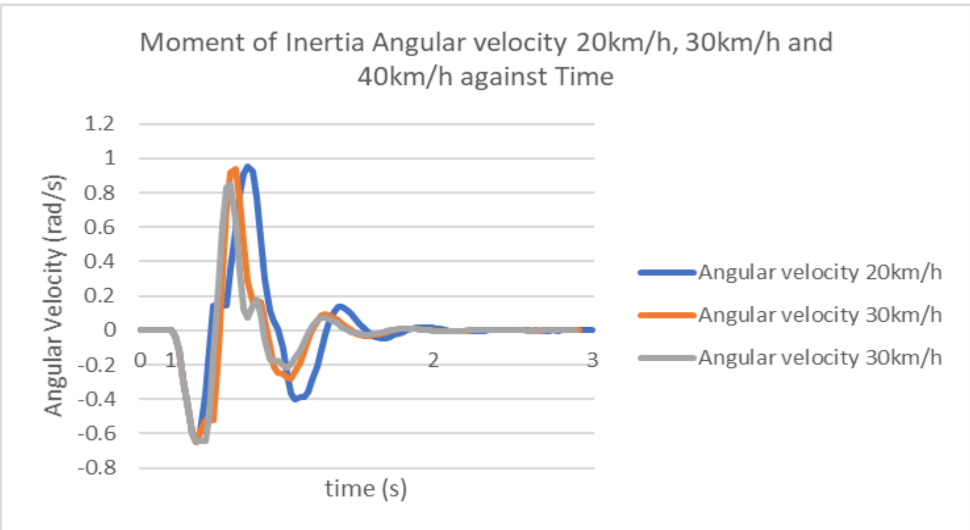

Fig. 14 - Moment of inertia angular velocity result

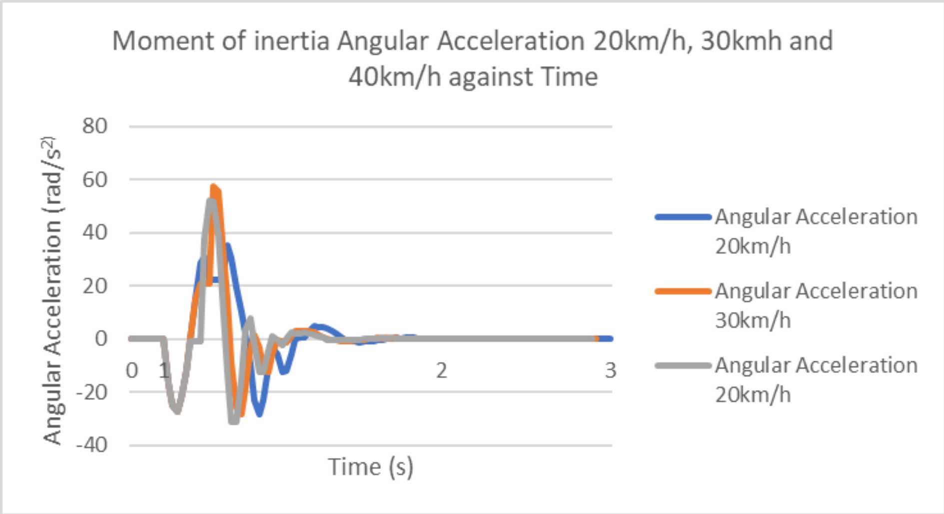

Fig. 15 - Moment of inertia angular acceleration result

According to the result in Figure 12, it is observed that as the speed increased, the maximum reading value for the angular displacement is seen to be decreasing from 20 km/h the maximum reading for angular displacement is 0.0288 rad, 30 km/h is 0.0207 rad and 40 km/h 0.0161 rad. While the minimum value is seen to increase from 20 km/h up to 40 km/h, the minimum value is - 0.0199 rad. Moreover, the angular velocity is maximum reading is increasing as the speed increased to 40 km/h and increased in minimum reading value compared to the other speeds. For the angular acceleration, the maximum reading value at highest is seen for 30 km/h speed, while the lowest value is at 20 km/h speed. However, the minimum reading value is seen at 40 km/h speed as compared to the other speeds.

The reason for the change of the result simulated is probably because of characteristic of suspension system component and the parameter value from the light weight of the suspension component, because when a motorcycle is at high speed, the chances to bounce on a bumpy road is reduced giving less bouncing effect when lighter weight of the suspension system component with high-speed travel by the motorcycle. By comparison between the active suspension system and passive suspension system, the displacement of pitch can be reduced by using a controller which is the Feedback Linearization. By reducing the pitch displacement, ride comfort can be achieved with better performance [23-25].

5. Conclusion

As a conclusion, the objective to investigate the characteristic of a passive suspension system and to develop a half-car model for a passive suspension system of a motorcycle using vehicle dynamic analysis model in the Matlab/Simulink software was able to achieve. Three main speed which is 20 km/h, 30 km/h and 40 km/h was used to conduct the experiment to hit a bump road. All the data obtained from the Simulink result was exported and converted into Microsoft Excel to produce a graph. Hence, the objective to study on characteristic of motorcycle suspension system was achieved. Therefore, this study will enable the researchers to conduct a further study on a motorcycle passive suspension system to provide a better ride performance as well as the ride comfort

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