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DYNAMICS PERFORMANCES OF MALAYSIAN PASSENGER VEHICLE

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ABSTRACT

In this work, a Malaysian passenger vehicle is tested and driven on a predetermined route. The dynamic performances of the vehicles are studied based on roll moment and 3-axis vibrations. A simple data acquisition system with gyro and 3-axes accelerometer is used. The dynamic performances of the vehicles are analyzed based on road conditions such as corners, bumpers and vehicle speeds and vehicle drivability. The driving behavior of the drivers is also studied. The data from the experiment can be used for improvement in safety driving, optimum fuel consumption and vehicle maintenance prediction.

Keywords: vehicle dynamics performance, driving conditions, driving behavior, vehicle ride.

INTRODUCTION

The dynamic performances of passenger vehicles play important role in the determination of vehicle drivability, vehicle safety, passengers' comfort, fuel consumption, vehicle reliability and vehicle maintenance activities [1-3]. Currently, researches use computational approach to analyze the dynamic performances of the vehicle [4-6]. This approach is generally conventional and fairly acceptable for the purpose of theoretical validation. The vehicle and the road conditions are modeled and simulated using computer. However, most of the time, many inputs and conditions are neglected for the simplicity of the simulation and to reduce time. This practice makes the results rather nice to be presented but it is not representing the actual driving conditions. The experimental approach in studying the dynamic performances of vehicles is costly and consumes a lot of time. Preparations have to be made for the vehicle, installation of sensors, camera for the footage, and sometimes require zero traffic condition for the selected route. Extensive number of sensors is necessary; however, few sensors with only recording important data should be used. Furthermore, zero traffic means easy driving and there is no urge to consider vehicle followings and vehicle headings [7-10].

In this study, a simple data acquisition (DAQ) with 3-axis accelerometer and gyro (Figure-1) is used to measure and record the vertical, horizontal and lateral vibrations and roll moment of a passenger vehicle. The experiment is performed on an exclusive route from Universiti Teknikal Malaysia Melaka (UTeM) Industrial Campus to its Main Campus. The dynamic performances of the vehicle are discussed based on driving conditions and traffic conditions.

METHODOLOGY

A common type of passenger vehicle is used in this experiment. The vehicle is full with 4 passengers and 1 driver. Before the experiment is performed, the vehicle is weighted to determine its center of gravity (COG). This location of COG is important for the position of DAQ and sensors to be installed. The vertical, horizontal and lateral vibrations and roll moment are recorded throughout experiment. The velocity of the vehicle is recorded every 30 seconds and the video and still photos are taken during experiment for observation purposes. Road conditions such as corners, junctions, roundabout and traffic lights are observed and recorded. Figure-2 shows the type of passenger car used in this experiment.

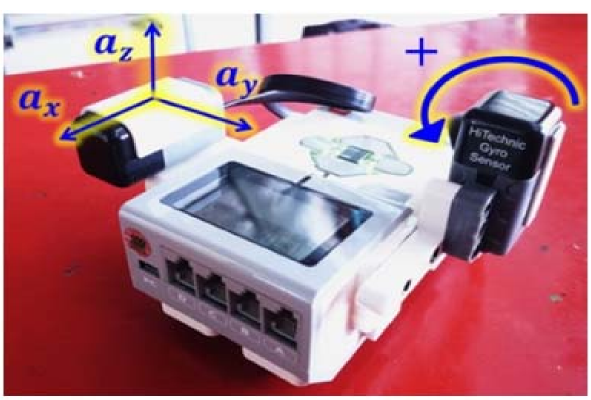

Figure-1. Lego Mindstorms EV3 DAQ.

Figure-2. Proton Saga FLX 1.3.

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Experiment

The vehicle is undergone weighting process where its weight is measured and recorded. It will be weighted on level ground and slope at few degree of angle. This procedure is important to determine its COG. Figure-3 shows the weight of each tire for selected vehicle. Figure-4 shows the location of COG. This COG is used to install the DAQ. Once everything is ready, the driving experiment is performed from UTeM Industrial Campus to UTeM Main Campus. The video and photo are taken. Vehicle velocity and road conditions are recorded.

Figure-3. Weight of each tyre.

Figure-4. Location of COG.

Calculation

Table-1 summarizes the weight distribution at right hand side (RHS) and left hand side (LHS) of the vehicle. From the weight distribution measured, the total weight of the vehicle, m_T (included mass of a driver) is equal to 1124.36 kg. The following vehicle specifications features are obtained from the catalog, track of wheel, l_w = 1446 mm, wheelbase, C_w = 2465 mm, height of vehicle, h = 1520 mm, ground clearance, h_c = 150 mm.

Table-1. Weight on tyres.

Weight [kg]	Rear	Front	Total
RHS	199.41	395.07	594.48
LHS	197.59	332.28	529.87
Total	397.00	727.35	1124.36

In order to obtain the location of center of gravity (CG) of the vehicle, a static condition is used, which is the moment acted on the center of gravity of vehicle is zero.

$$C_w = C_1 + C_2$$
$$C_1 = C_w - C_2$$
$$C_1 = 2465\ mm - C_2 \tag{1}$$

$$+\curvearrowright \sum M_{CG} = 0$$
$$F_{N1}C_1 - F_{N2}C_2 = 0$$
$$[727.35(9.81)N]\,C_1 = [397.0(9.81)N]\,C_2 \tag{2}$$

Substitute Equation (1) into Equation (2)

$$[727.35(9.81)N](2465mm - C_2) = [397.0(9.81)N]\,C_2$$
C_2 =1594.6mm
$$C_1 = 2465mm - 1594.6mm = 870.4mm$$

Note that the load distribution of the vehicle for left side (LHS) and right side (RHS) of the vehicle are the same although the data obtained from lab shows that the load distribution for left and right are different. This is due to the weight of the driver is included during the measurement of weight distribution at laboratory. Due to the apparatus in the laboratory is not sufficient to measure the mass distribution at inclined plane, so the height of center of gravity can't be obtained using following equations.

$$F_{N1} = \frac{1}{C_1 + C_2}(m_t g C_2 \cos\theta - h m_t g \sin\theta) \tag{3}$$

$$F_{N2} = \frac{1}{C_1 + C_2}(m_t g C_1 \cos\theta + h m_t g \sin\theta) \tag{4}$$

Therefore, the height of the center of gravity of vehicle, h_{CG} is determined by separating the total mass of vehicle into vehicle body mass and unsprung mass with their respectively height. For finding the height of center of gravity, the total mass of the vehicle is divided into the vehicle body mass, m_b (sprung mass) and the four wheels mass, m_w (unsprung mass) as shown in Table-2. (In this study, we assumed the mass of each unsprung mass, m_w= 59.0 kg. Therefore, the total unsprung mass will be 236.0 kg.

$$m_T = m_b + 4m_w$$
$$m_b = 1124.36kg - 4(59.0kg) = 888.36kg \tag{5}$$

The height of the center gravity of vehicle body, h_b is calculated from the total height of the vehicle and the clearance height of the vehicle as showed below.

$$h_b = \frac{1}{2}(h - h_c) + h_c$$
$$h_b = \frac{1}{2}(1520mm - 150mm) + 150mm = 835mm \tag{6}$$

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For the wheels, it can be assumed that the weight of unsprung mass is acted at the center of the wheel and the effective radius of the wheel is same as the radius of wheel. This indicated that the height of center of gravity for wheel is same as the radius of wheel. The diameter of the wheel for this vehicle is 16 inches or 406.4 mm. Therefore, the height of the center gravity of wheel, h_w is 203.2 mm. From the calculated mass and height, the center of gravity for whole vehicle is determined using the equation below. The location of COG where the DAQ is installed is shown in Figure-5.

Figure-5. Location of DAQ in the vehicle.

Table-2. Moment of masses.

	W [N]	$\tilde{h}$ [mm]	$W \times \tilde{h}$ [N.mm]
Sprung mass	8714.81	835.0	7276866.35
Unsprung mass	2315.16	203.2	47044.51
Total	11029.97		7747306.86

$$\bar{h}\sum W = \sum \tilde{h}W \quad (7)$$

Therefore, the COG is,

$$h_{CG}(11029.97N) = 7747306.86\ N.m$$
$$h_{CG} = 702.4\text{ mm} \quad (8)$$

RESULTS AND DISCUSSIONS

The time for the whole experiment is about 12.0 minutes and recorded up to 40412 data by both sensors. Figure-6 shows the route selected for this experiment and Figure-7 shows the velocity of the vehicle along the experiment. From the graph of velocity against time as shown in Figure-7, it can be observed that the vehicle speed is maintained around the range of 59 – 65 km/h for the whole route except at the initial driving, middle and ending. At the start of the experiment, the vehicle accelerated to 60 km/h within 30 seconds. After that the vehicle speed reduced to around 40 km/h at a time of around 360 seconds due to the vehicle taking a U-Turn near the UTeM Main Campus traffic light. After that the speed increased back to around 60 km/h and at the end of journey the speed reduced to 40 km/h when the vehicle taking a corner at the latter traffic light. The graphs of longitudinal acceleration, lateral acceleration, vertical acceleration and roll of the vehicle are plotted based on the data obtained. Figure-8 to Figure-11 show the graph of longitudinal acceleration, lateral acceleration, vertical acceleration and roll of the vehicle against time respectively [11]. The magnitude of each acceleration and roll angle are changed significantly. As seen in Figure-8, the longitudinal acceleration's data increasing dramatically within 30 seconds due to the vehicle is accelerating from rest. Figure-9 show magnitude of lateral acceleration is negative due to vehicle is turning to right at the traffic light. Note that the value for lateral acceleration is negative when the vehicle turns to right and vice versa. The vertical acceleration at the start of the experiment is change significantly since the vehicle is traveling at inclined plane and having some bounce. The roll angle of the vehicle increase when the car turn right at the start of experiment. At time 1.5 minutes (data 5065 point A2), the road surface is very rough and causes the car to vibrate vigorously.

Figure-10 and Figure-11 show significant change after the vehicle travelling about 1.5 minutes. Since the road input is like bounce sine sweep road profile, so the car body will tend to have large vertical motion. This situation also happened to the roll angle of vehicle [12]. After the vehicle travelled for 3.5 minutes (point A3), the vehicle reached highway. The Figure-9 shows that the magnitude of lateral acceleration become more negative when the vehicle has taking a left turn and lateral force is going to the right. The roll angle at that moment also has a slightly change due to the car is turning left at with big radius of curvature. However, there is no much changing in longitudinal and vertical accelerations. At duration of travelling between 4.5-5 minutes (point A4), the car reached the junction and flyover with steel connectors [13]. The steel connectors make the road profile not smooth and have a small bump. In Figure-8, the longitudinal acceleration of vehicle drops as the road has a small positive slope and the car is decelerating. While travelling through these steel connectors, the vehicle bounces twice. This can be showed in Figure-10. Similarly on the Figure-11, the car body have small angle of roll due to the vehicle is travelling on road with big radius of curvature. At 6 minutes of travelling (point A5), the vehicle has travelled half of the route and takes a U-turn at the traffic light near UTeM Main Campus. When the car near the U-turn, the car speed decreased from 60 km/h to 40 km/h and reduced to 20 km/h when doing U-turn. The reducing of speed causes the longitudinal acceleration suddenly drops until 5.423 ms^{-2} which is almost lowest value on the graph. Same result obtained for the lateral acceleration which declined sharply when the vehicle taking the U-turn. The lateral acceleration also had large negative value since the vehicle is turning right sharply. But there is no significant change on the vertical acceleration and roll angle of the vehicle [14]. The data after 6 minutes of travelling is repeated but in the opposite value. The entire graph generally has a steady fluctuation

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except for the special situation like deceleration, right and left turns, and so on. The vibration of the powertrain in the car affected the result of the graph. Vibration has no direction, so it affected longitudinal acceleration, lateral acceleration, vertical acceleration and roll moment.

Figure-6. Driving route.

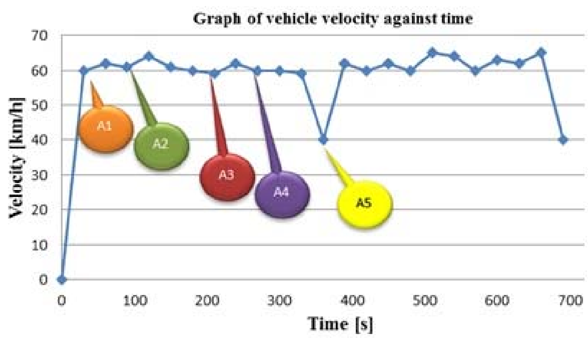

Figure-7. Velocity of vehicle.

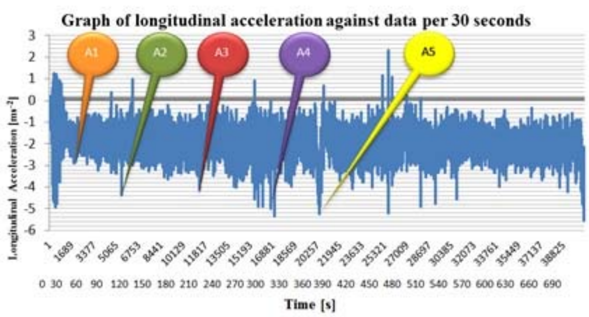

Figure-8. Longitudinal acceleration.

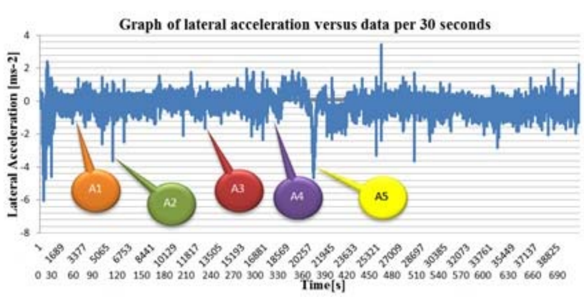

Figure-9. Lateral acceleration.

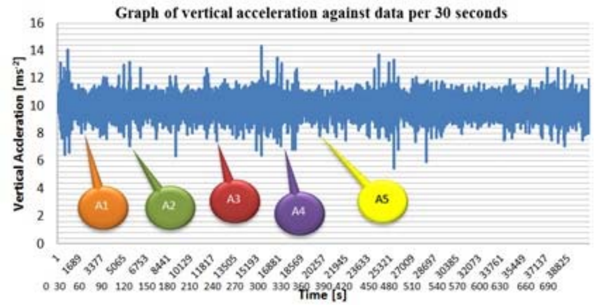

Figure-10. Vertical acceleration.

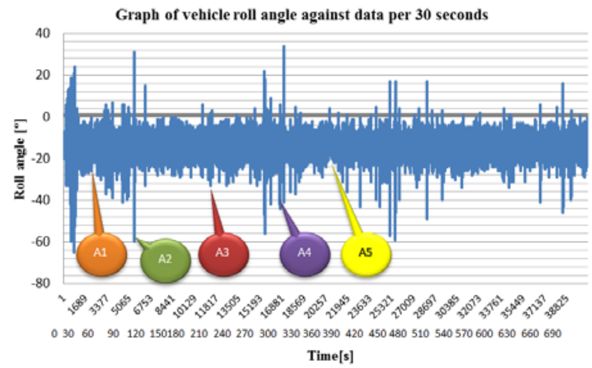

Figure-11. Roll moment.

CONCLUSIONS

In this study the dynamic performances of a passenger vehicle, Proton Saga FLX 1.3 2012 are discussed based on actual driving conditions on a selected route. The vehicle's activities such as acceleration, deceleration, cornering, and braking contribute to the longitudinal, lateral, vertical accelerations and also the roll angle of a vehicle. Irregularities or road surface roughness is another factor that leads to vibration. The results from this study can be used for further study on safety driving and driver behavior.

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