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RIDE COMFORT PERFORMANCE EVALUATIONS ON ELECTRIC VEHICLE CONVERSION VIA SIMULATIONS

Saiful Anuar Abu Bakar, Mohd Farid Muhamad Said and Azhar Abdul Aziz
Automotive Development Centre, Universiti Teknologi Malaysia, Skudai, Johor
E-Mail: saiful@fkm.utm.my

ABSTRACT

The paper presents a simulation study on the ride comfort performance of a passenger vehicle which is expected to be converted into an electric vehicle. The studies involved evaluations of vehicle's ride comfort, performance before and after the conversion being made using a validated simulation model. The studies used a validated 7 degrees of freedom of vehicle ride comfort model of the passenger vehicle that is expected to be converted into an electric vehicle. The model was used to evaluate the vehicle ride comfort performance when it's being converted into an electric vehicle. It is done by varying the weight distribution load at the front and rear axles. The vehicle's vertical acceleration, displacement, pitch rate and pitch angle are the responses observed in this study. It was found that the EV conversion's ride comfort was not significantly affected from the modifications.

Keywords: electric vehicle, electric vehicle conversion, ride comfort.

INTRODUCTION

The development of electric vehicle (EV) from the commercially available vehicle model is becoming a trend nowadays due to the global concerns in reducing the green house effect which one of its contributing factors came from the pollution of vehicle [1-3]. An electric vehicle that is being converted from a normal production vehicle model usually known as electric vehicle conversion or EV conversion. Electric vehicle is driven by electric motor. It is either uses only two or four electric motors to move the vehicle. Other common component that can be seen in an electric conversion vehicle are batteries, AC/DC or DC/DC converters, battery management system, pedal relays and others auxiliary components such as electric power steering. Many research works were found to focus on the electric vehicle's electric and electronic systems but not many were found to focus in improving EV conversion's stability while maneuverings. The researches on EV conversion's stability are mainly related to the yaw stability control and traction system. In yaw stability control on electric vehicle [4-6] it focuses in controlling yaw motion of the electric vehicle by controlling the operation of the drive motor. The drive motor, either two or four are basically controlled in terms of its torque generation. While in traction control system [7, 8] the generation of electric motor torque is controlled to ensure the wheel does not skid while accelerating ensuring full control over the vehicle. This is done by controlling the slip ratio of the wheel.

However, it is not clear how the modifications towards an EV conversion affect the vehicle's ride comfort performance; the level of isolations of passenger compartment from being affected by harsh road profile. Typically, any conversion of internal combustion engine vehicle to electric vehicle involves some weight addition (or weight reduction). This is due to the installations of the electric vehicle systems i.e. battery system and converters. Any weight addition or weight reduction on the chassis will cause the vehicle's weight distribution to change and this compromised the vehicle's ride comfort performance, as current suspension system tuning was not being designed specifically for the new weight and load distribution at front and rear axles. This paper is dedicated to investigate the effects of weight distribution changes on EV conversion's ride comfort performance.

RIDE COMFORT MODEL OF EV CONVERSION

A vehicle's ride model of an EV conversion is derived based on the work done in [9, 10]. The ride model consists of seven degrees of freedom namely roll, pitch, bounce and vertical motion of each four wheels. Figure-1 show the vehicle' ride model.

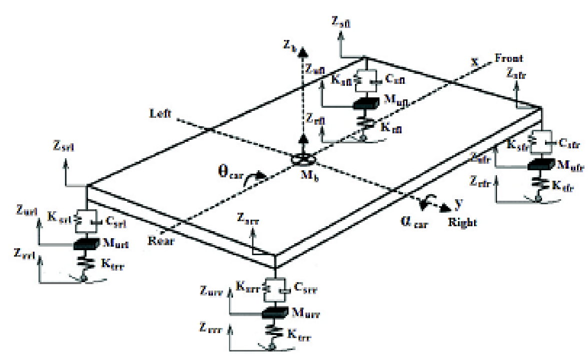

Figure-1. Seven degree of freedom of vehicle ride model.

Based on the 7DOF of ride model in Figure-1, the displacements of the sprung masses are given by;

$$Z_{sij} = Z_b + \frac{a_{car}}{2}\theta_{car} - L_i\alpha_{car} \tag{1}$$

which is the total sprung mass displacement (*i* =*f* for front, *r* for rear and *j*=*l* for *le*ft, *r* for right), Z_b is the sprung mass vertical displacement at the center of gravity, is the roll angle and θ_{car} is the pitch angle. The distance of

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centre of gravity to the front axle and rear axle are given by and respectively. The forces acting at each of the suspension is the sum of the spring force and damper force. The suspension forces are given by.

$$F_{ij} = F_{sij} + F_{dij} \tag{2}$$

The spring forces, in each of the suspension system are given by;

$$F_{sij} = K_{sij}\,(Z_{uij} - Z_{sij}) \tag{3}$$

with F_{sij} is the spring stiffness of the spring, the unsprung mass vertical displacement and the sprung mass vertical displacement respectively at each side of the vehicle. The damper forces, are given by;

$$F_{dij} = C_{sij}\,(\dot{Z}_{uij} - \dot{Z}_{sij}) \tag{4}$$

with C_{sij} are the damping coefficient of the Z_{sij} dampers, the unsprung mass vertical velocity and the sprung mass vertical velocity respectively. For the vehicle tires, it is modelled as a spring and the force acting at tires is usually known as dynamic tire loads, For each tires, their dynamic tire loads are given by;

$$F_{tij} = K_{tij}\,(Z_{rij} - Z_{uij}) \tag{5}$$

where F_{tij} and K_{tij} are the tire stiffness, road input displacement and unsprung mass displacement respectively.

Using Newton's Second Law at the vehicle's sprung mass, the body vertical acceleration, $\ddot{Z}_b$ can be determined by

$$F_{fl} + F_{fr} + F_{rl} + F_{rr} = M_b \ddot{Z}_b \tag{6}$$

where M_b is the total mass of the vehicle. Angular acceleration during the roll effect, $\ddot{\theta}_{car}$ is given by;

$$(F_{fl} + F_{rl})\frac{a_{car}}{2} - (F_{fr} + F_{rr})\frac{a_{car}}{2} = I_{xx}\ddot{\theta}_{car} \tag{7}$$

where a is the vehicle's track width and I_{xx} is the moment of inertia about *x*-axis. The angular acceleration while the vehicle is in pitch effect, $\ddot{\alpha}_{car}$ it is given by;

$$(F_{rl} + F_{rr})L_r - (F_{fl} + F_{fr})L_f = I_{yy}\ddot{\alpha}_{car} \tag{8}$$

with $I_{yy}$are the vehicle's wheelbase and moment about *y*-axis respectively. Acceleration of each wheel can be calculated using

$$F_{tij} - F_{sij} - F_{dij} = M_{uij}\ddot{Z}_{uij} \tag{9}$$

with M_{uij} are the unsprung masses at each corner of the vehicle. The vehicle ride comfort model was developed using equations (1) to (9) using MATLAB/Simulink.

Validation of Vehicle Ride Model

For the purpose of validating the ride dynamics behaviors of the vehicle intended for the conversion, several types of transducers were installed and they are the three-axis accelerometer and single-axis accelerometers. The three-axis accelerometer was used to measure vehicle's vertical, longitudinal and lateral acceleration as well as the rotational motions (roll, pitch and yaw). The three-axis sensor was located approximately at the centre of gravity of the vehicle. An amount of 8 units of single axis accelerometer were installed at each corner of the vehicle, at the sprung and unsprung masses. The accelerometers were used to measure vertical acceleration of vehicle's sprung and unsprung masses when the vehicle hit the bump. A multi-channel Dewetron data acquisition system was used for the data collection.

A pitch test was performed during the experiment. In pitch test, a bump with the dimensions of 2.4 m in length, 0.4m in width and 0.075 m in height, was used and arranged perpendicularly to the vehicle's driving direction. A speed of 20 km/h was used during this test. In this pitch test, the front wheels will hit the bump followed by the rear wheels. Figure-2 shows the validation results between the experimental and simulation data. It can be seen that there is a good correlations between the simulation and experimental data; in terms of responses' trends.

Ride Comfort Evaluation of EV Conversion

The validated ride model was later used to study the effect of modifications on the passenger vehicle into an electric vehicle. It is assumed that the experimental vehicle is about to be converted into an electric vehicle. The effects of weight distribution in electric vehicle conversion (EVC) which is biased to the rear of the vehicle, due to the battery system are investigated. The evaluations were done by considering two weight distribution ratios; 60:40 and 40:60 weight distribution ratios. The 60:40 weight distribution ratio is the assumption of weight distribution before modifications while 40:60 weight distribution ratio is the assumption ratio, after modifications is done. The weight distribution used, determined the position of centre of gravity from front and rear axles, L_f and L_r respectively. Below are the relation between weight distribution and the distance of CG to front and rear axles:

$$W_f = \frac{W_t}{L} L_r \tag{10}$$

$$W_r = \frac{W_t}{L} L_f \tag{11}$$

where W_f,W_r and W_t are weight at the front axle, weight at the rear axle and vehicle total weight respectively.

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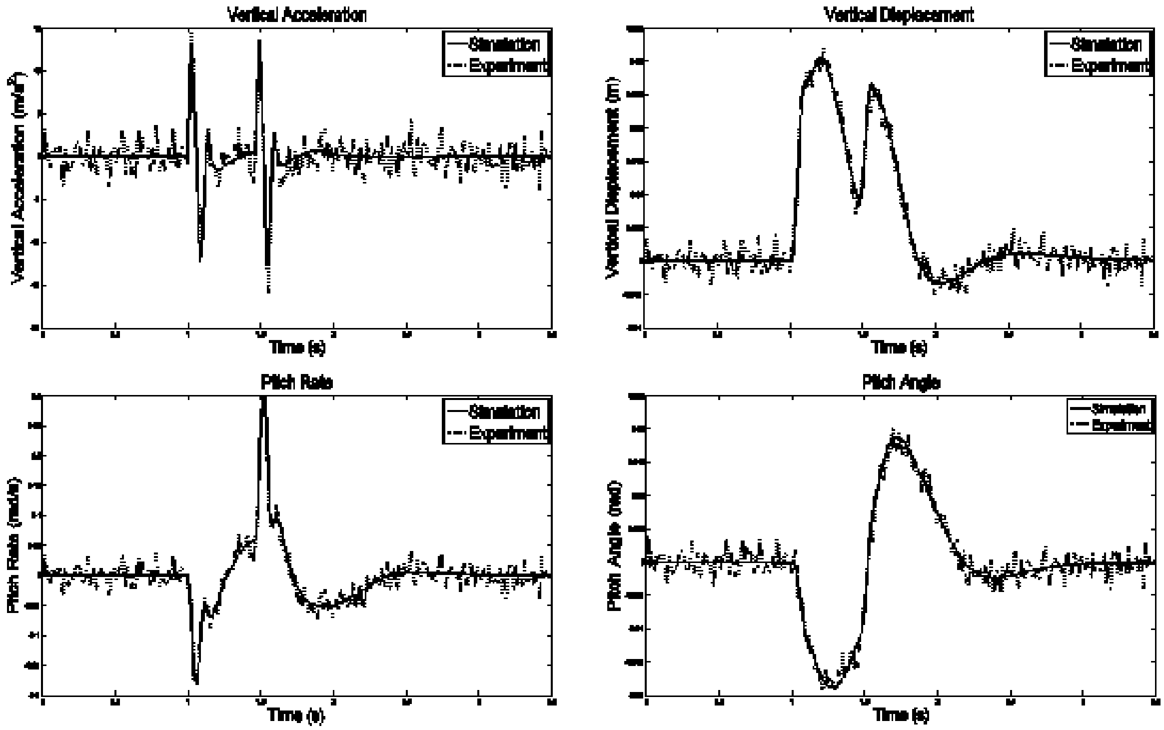

Figure-2. Validations between simulation and experimental data during pitch test.

SIMULATION RESULTS

The EV conversion's ride model is evaluated using the pitch test. In pitch test, the simulation model is subjected to a road profile (bump arrangement), which will create pitching motion on the vehicle. The bump input was arranged perpendicular to the direction of EV conversion's travel.

The vehicle model was simulated to move at a constant speed of 20 km/h before hitting a bump input with the height, width and length of 0.075m, 0.4m and 2.44m respectively. The simulation time used to run the simulation model is 3.5 s. The speed was chosen to be the same as the experimental validation for a fair comparison. Table-1 shows the RMS values of the studied responses on the vehicle before the conversion, after the conversion while Figure-4 shows the results of the studied responses in time domain form. The frequency response of the vehicle before and after conversion can be referred to Figure-3. Based on Table-1 and Figure-4, it can be seen that the changes of weight distributions due to the modifications towards an electric vehicle did not affects the EV conversion's ride comfort significantly. However it is observed that the changes of weight distribution did effects vehicle's vertical displacement when the rear wheel hit the bump; 40:60 weight distribution model is having a higher vertical displacement compared to the 60:40 weight distribution model. This is due to the location changes of the centre of gravity. In the 40:60 weight distribution model, the CG is to be towards the rear axle and since that the studied responses is observed at the CG, the effects when the front axle hit the bump are less 'affected' because the CG is located towards the rear axle. In terms of frequency response of the EV conversion (Figure-3), the major frequency response for the EV conversion remained the same as before the modifications were done which is at 1.583 Hz.

Table-1. RMS values of the studied responses during pitch simulation test.

Response	60:40 Weight Distribution	40:60 Weight Distribution	% of Changes
Vertical Acceleration	2.198	2.198	0
Vertical Displacement	0.01025	0.00998	2.6
Pitch Rate	0.05008	0.04888	2.4
Pitch Angle	0.007666	0.007793	-1.7
Average			0.8

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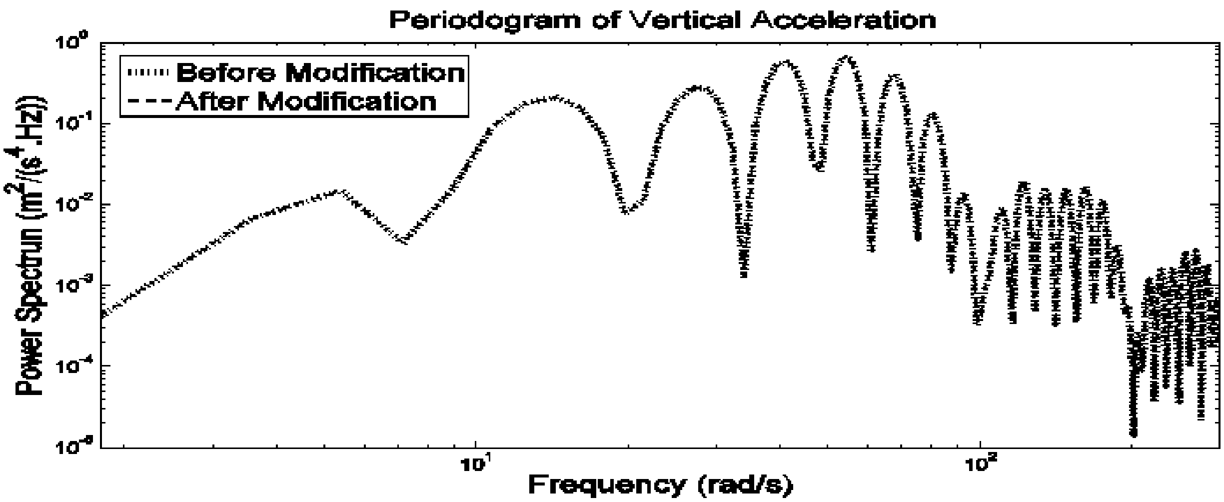

Figure-3. Frequency domain analysis during pitch simulation test.

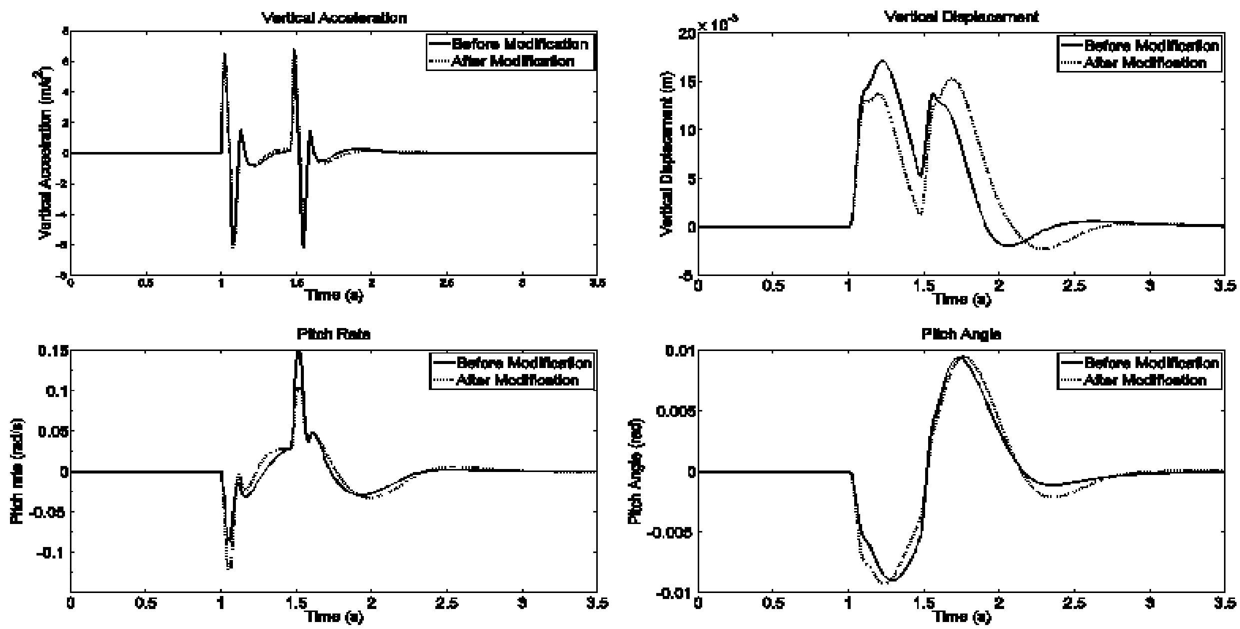

Figure-4. Evaluations during pitch simulation test.

CONCLUSIONS

As for conclusions, the vehicle modifications into an electric vehicle do not significantly reduce the vehicle ride comfort performance except the vehicle's vertical displacement response. The changes of vehicle's weight distribution had change the CG of the EV conversion towards the rear axle, causing excessive responses (vertical displacement and pith angle) only to be happened when the rear wheels hit the bump.

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