

# Effect of Fuel Cell Mass on Electric Vehicle Ride Comfort

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**ABSTRACT:** Sprung mass not only affects the safety of the vehicle's movement, but also affects the vehicle ride comfort. In order to evaluate the effect of fuel cell mass on vehicle ride comfort, a dynamic model of quarter electric vehicle is established. The weighted root-mean-square (RMS) acceleration of the vertical vehicle body ( $a_{wb}$ ) according to the international standard ISO 2631-1 (1997) is selected as an objective function to analyze the effect of fuel cell mass on electric vehicle ride comfort. The obtained results indicate that the fuel cell mass has a significant influence on vehicle ride comfort.

**KEYWORDS:** Electric vehicle, Fuel cell, Dynamic model, Ride comfort.

## I. INTRODUCTION

The ride comfort of an electric vehicle is an important factor to evaluate the quality of the electric vehicle manufacturers. A 3-DOF quarter-vehicle dynamic model of an electric vehicle under two input excitation sources such as road surface roughness excitation and in-wheel motor excitation was proposed to evaluate the effects of design parameter of in-wheel motor suspension system (IMs) on electric vehicle ride comfort [1]. Similarly, a dynamic model of quarter vehicle was established with the combination of IWM and road surface roughness excitations the effect of in-wheel motor (IWM) suspension system on electric vehicle (EV) ride comfort [2]. An 11 degrees of freedom of vehicle ride comfort model was proposed to study the influence of the ratio between unsprung and sprung mass on ride comfort of vehicles driven by in-wheel motors [3]. The electric vehicle dynamic model was proposed to evaluate the influence of the dynamics parameters of the electric vehicles on the ride comfort under various operation conditions of the electric vehicles [4]. In order to improve the ride comfort of electric vehicles, a study was proposed to evaluate the influence of the mass of the IWM on the performance of passive and semi-active

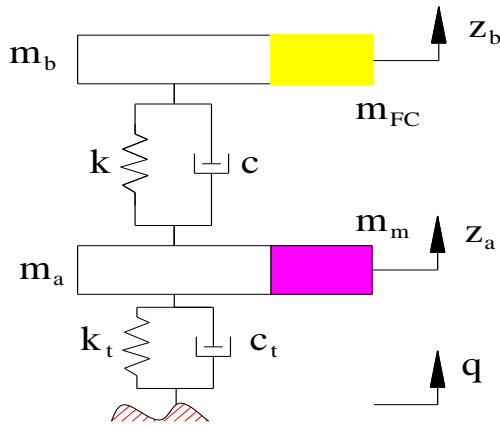
suspension systems of the electric vehicle [5]. a modified GPSO-LQG controller was proposed for one-quarter vehicle suspension with the purpose of optimizing suspension performance for entire speed ranges. one-quarter vehicle suspension model, road surface excitation model and magneto-rheological damper model were proposed to evaluate three weighted coefficients optimized by utilizing the Genetic Particle Swarm Optimization (GPSO) [6]. A simulation analysis on these four models: a sample car with no motor, a motor with fixed joint, and active/inactive control suspension for in-wheel motor was proposed to analyze a new electric wheel with active control of suspension for in-wheel motor [7]. A 14-degree of freedom coupled vehicle dynamic model was proposed to control the active suspension using a dual-loop proportion integration differentiation controller based on the particle swarm algorithm [8].

The major goal of this study is to establish a dynamic model of quarter vehicle under the road surface roughness excitation to analyze the effect of fuel cell mass on electric vehicle ride comfort. The  $a_{wb}$  value according to the international standard ISO 2631-1 (1997) [10] is selected as an objective function to analyze the effect of fuel cell mass on electric vehicle ride comfort.

## II. ONE-QUARTER DYNAMIC MODEL OF ELECTRIC VEHICLE

In order to evaluate the effect of fuel cell mass on electric vehicle (EV) ride comfort, a one-quarter EV dynamic model established under road surface roughness, as shown in Figure 1. In Fig. 1,  $m_b$ ,  $m_{FC}$ ,  $m_m$  and  $m_a$  are the sprung mass of EV body, fuel cell mass, IWM mass, and EV unsprung mass, respectively;  $k_t$  and  $c_t$  are the stiffness and damping coefficients of the tire;  $k$  and  $c$  are the stiffness and damping coefficients of the EV suspension system;  $z_a$  and  $z_b$  are the vertical displacements of the axles such as IWM mass and

EV unsprung mass such as, and vehicle body such as the sprung mass of EV body, fuel cell mass, respectively;  $q$  is road surface excitation.



**Figure 1.** A one-quarter EV dynamic model established under road surface roughness

Equations of motion: From the electric vehicledynamic model as shown in Fig.1, the dynamic equation of the quarter vehicle using Newton's second law are written as follows

$$(m_b + m_{FC})\ddot{z}_b = -[k(z_b - z_a) + c(\dot{z}_b - \dot{z}_a)] \quad (1)$$

$$(m_a + m_m)\ddot{z}_a = [k(z_b - z_a) + c(\dot{z}_b - \dot{z}_a)] - [k_t(z_a - q) + c_t(\dot{z}_a - \dot{q})] \quad (2)$$

Road surface excitations [9]: In this study, the filtering white noise method is used to describe the time domain excitation of the road surface based on reference [9] and time domain representation of the road surface can be given

$$\dot{q}(t) + 2\pi f_0 q(t) = 2\pi n_0 \sqrt{G_q(n_0)} v w(t) \quad (3)$$

where,  $G_q(n_0)$  is the road roughness coefficient which is defined for typical road classes from A (very good) to H (very poor) according to ISO 8068(1995) [10],  $v=f/n$  is the speed of vehicle from 10 m/s to 30 m/s,  $n$  is the road space frequency from  $0.013 \text{ m}^{-1}$  to  $3.33 \text{ m}^{-1}$ , and it can guarantee the temporal frequency of road surface  $f$  ranges from 0.33 Hz to 28.3 Hz which is the low excitation frequencies of road surface transmitted to vehicle body;  $f_0$  is a minimal boundary frequency with a value of 0.0628 Hz;  $n_0$  is a reference spatial frequency which is equal to 0.1 m;  $w(t)$  is a white noise signal.

### III. VEHICLE RIDE COMFORT CRITERIA [1]

The time-domain method can be applied to evaluate the vehicle ride comfort according to ISO 2631-1 (1997) [11], in this study, the vibration evaluation based on the basic evaluation methods including

measurements of the weighted root-mean-square (RMS.) acceleration defined as

$$a_{wz} = \left[ \frac{1}{T} \int_0^T a_z^2(t) dt \right]^{1/2} \quad (4)$$

where,  $a_z(t)$  is the weighted acceleration (translational and rotational) as a function of time,  $\text{m/s}^2$ ;  $T$  is the duration of the measurement,  $s$ .

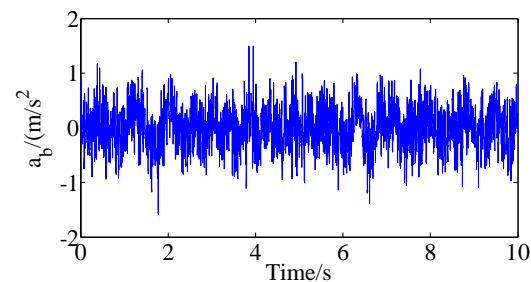
For indications of the likely reactions to various magnitudes of overall vibration in the public transport and vehicle, a synthetic index-called the root-mean-square (RMS) acceleration,  $a_{wz}$  can be calculated from formula Eq.(4); besides, the RMS value of the acceleration in vehicle would be compared with the values in Table-1.

**Table 1.** Comfort levels related to  $a_w$  threshold values [10]

$a_w/(\text{m/s}^2)$	Comfort level
$< 0.315$	Not uncomfortable
$0.315 \div 0.63$	A little uncomfortable
$0.5 \div 1.0$	Fairly uncomfortable
$0.8 \div 1.6$	Uncomfortable
$1.25 \div 2.5$	Very uncomfortable
$> 2$	Extremely uncomfortable

### IV. RESULTS AND ANALYSIS

In order to evaluate the effect of fuel cell mass on vehicle ride comfort with design parameters [12]. The simulation result of the time domain acceleration responses of the vertical motion vehicle body mass ( $m_b$ ) and fuel cell mass ( $m_{FC}$ ) when the vehicle moves on ISO class B surfaces road condition at vehicle speed of 72 km/h is shown in Figure 2. From the achieved results in Fig.2, we could determine the value of the RMS acceleration of the vertical vehicle body ( $a_{wb}$ ) through Eq.(4) according to the international standard ISO 2631-1 is  $0.3632 \text{ m/s}^2$ . This result, compared with Tab.1, shows that human may feel a little uncomfortable.



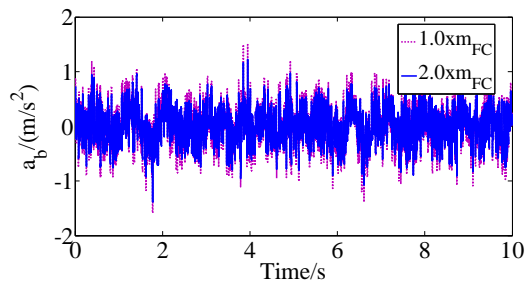
**Figure 2.** The simulation result of the time domain acceleration responses of the vertical motion vehicle

body mass ( $m_b$ ) and fuel cell mass ( $m_{FC}$ ) when the vehicle moves on ISO class B surfaces road condition at vehicle speed of 72 km/h

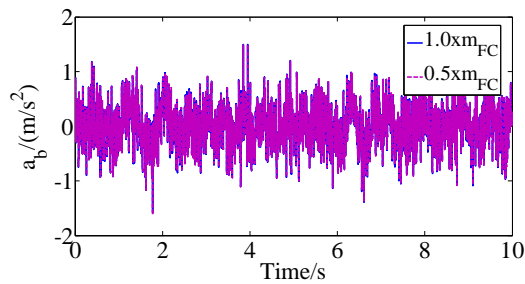
Three values of fuel cell mass  $m_{FC}=[0.5, 1.0, 2.0]x m_{FC}$  with  $m_{FC}$  is the mass value of the original fuel cell mass[12] are selected to investigate its effects on electric vehicle ride comfort. Time domain acceleration responses of the vertical motion vehicle body mass ( $m_b$ ) and fuel cell mass ( $m_{FC}$ ) when the vehicle moves on ISO class B surfaces road condition at vehicle speed of 72 km/h with variable mass values of fuel cell is shown in Fig.3. The values of the RMS acceleration of the vertical motion vehicle body mass ( $m_b$ ) and fuel cell mass ( $m_{FC}$ ) with variable mass values of fuel cell are shown in Table 2.

**Table.2.** The values of the RMS acceleration of the vertical vehicle body with variable mass values of fuel cell

Parameters	$0.5x m_{FC}$	$1.0x m_{FC}$	$2.0x m_{FC}$
$a_{wb}/(m/s^2)$	0.3756	0.3632	0.3106



(a) With the increase of  $m_{FC}$



(b) With the decrease of  $m_{FC}$

**Figure 3:** The simulation result of the time domain acceleration responses of the vertical motion vehicle body mass ( $m_b$ ) and fuel cell mass ( $m_{FC}$ ) when the vehicle moves on ISO class B surfaces road condition at vehicle speed of 72 km/h with variable mass values of fuel cell

From the results of Figure 3, we can see that the peak values of time domain acceleration response of vehicle body respectively decrease with the increase of  $m_{FC}$ . The value of the RMS acceleration of the vertical motion vehicle

body mass ( $m_b$ ) and fuel cell mass ( $m_{FC}$ ) with  $2.0x m_{FC}$  value reduces by 14.48% in comparison with  $1.0x m_{FC}$  value, which makes vehicle ride comfort improve. The peak values of  $a_b$  respectively increase with the decrease of  $m_{FC}$ . The  $a_{wz}$  value with  $0.5x m_{FC}$  increases by 3.3% in comparison with  $1.0x m_{FC}$  value. This makes vehicle ride comfort decline

## V. CONCLUSION

In this study, a dynamic model of quarter electric vehicle is established to evaluate the effect of fuel cell mass on vehicle ride comfort. The  $a_{wb}$  value according to the international standard ISO 2631-1 (1997) [is selected as an objective function to analyze the effect of fuel cell mass on vehicle ride comfort. The major conclusions that can be drawn from the analysis can be summarized as follows: (1) The peak values of time domain acceleration response of vehicle body respectively decrease with the increase of  $m_{FC}$ , and on the contrary, the peak values of  $a_b$  respectively increase with the decrease of  $m_{FC}$ ; (2) The  $a_{wb}$  values with  $2.0x m_{FC}$  value reduces by 14.48% in comparison with  $1.0x m_{FC}$  value, which makes vehicle ride comfort improve; and (3) The  $a_{wz}$  values with  $0.5x m_{FC}$  increases by 3.3% in comparison with  $1.0x m_{FC}$  value which makes vehicle ride comfort decline.

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