RESEARCH ON THE AFFECT OF DRIVER/PASSENGERS POSITION, VEHICLE SPEED AND ACCELERATION ON RIDING COMFORT

NGHIÊN CỨU VỀ ẢNH HƯỞNG CỦA VỊ TRÍ NGƯỜI LÁI/HÀNH KHÁCH, TỐC ĐỘ VÀ GIA TỐC CỦA XE ĐỐI VỚI SỰ THOẢI MÁI KHI NGỒI TRÊN XE

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ABSTRACT

In the vehicle manufacturing, riding comfort is the most important factors to be considered in the design stage. The prime contribution to riding comfort may be attributed to the design of the vehicle suspension system, which is meant to provide good comfort and road-holding capability. Despite this, certain other factors, such as driver/passengers position, vehicle speed and acceleration, seat properties, sitting posture, and headrest support, all contribute to riding comfort. In this research, the affect of driver/passengers position, vehicle speed and acceleration on riding comfort was systematically analyzed by using the integrated human-vehicle system with seventeen DOFs. The evaluation results could be used for research to enhance the comfort level of passengers.

Keyword: *Comfort level; Vehicle; Passenger.*

TÓM TẮT

Trong công nghiệp sản xuất phương tiện giao thông, sự thoải mái khi ngồi trên xe là yếu tố quan trọng nhất được xem xét trong giai đoạn thiết kế. Đóng góp chính cho sự thoải mái của người ngồi trên xe có thể là việc thiết kế hệ thống treo nhằm mang lại sự thoải mái và khả năng bám đường tốt. Mặc dù vậy, một số yếu tố khác, như: Vị trí của người lái/hành khách, tốc độ và gia tốc của xe, đặc tính của ghế, tư thế ngồi và gối tựa đầu..., tất cả đều góp phần tạo nên sự thoải mái khi lái xe. Trong nghiên cứu này, tác động của vị trí lái xe/hành khách, tốc độ và gia tốc của xe đến sự thoải mái khi lái xe được phân tích một cách có hệ thống dựa trên mô hình tích hợp người – xe với 17 bậc tự do. Kết quả đánh giá có thể được sử dụng cho việc nghiên cứu nâng cao sự thoải mái của hành khách trên phương tiên giao thông.

Từ khóa: *Mức độ thoải mái; Phương tiện giao thông; Hành khách.*

1. INTRODUCTION

The human body is exposed to vibration in many kinds of maneuver, e.g. sports, work performances, as well as during travelling. People will not only get tired quickly but also can not attain high performance under vibration condition. Vibrations can result in discomfort, interference, and health impairment. To evaluate riding comfort, the driver was most often assumed to be one rigid mass interconnected by a seat spring and dashpot with the vehicle body. In 2000, a lumped-parameter model with four DOFs was employed by Wanger and Liu [1] for riding quality assessment with integration of full vehicle model. In 2001, a nine-DOF multi-body model was suggested by Cho and Yoon to simulate the human body in sitting posture [2]. In 2020, a nine-DOF multi-body model was selected to discuss and compare to a four-DOF lumped-parameter model. The comparison of the experimental data with those of four- and nine-DOF model shown that nine-DOF model produced better matching in transmisibilities (T.G. Nguyen et al., 2020 [3]).

A vehicle suspension system can also be considered as a lumped-parameter model. In 2021, two kinds of vehicle models (2- and 3-D model [4, 5]) were selected to evaluate the affect of vibration on driver with two different road surfaces. In this case, the passenger was considered as a driver. The simulation results showed that, the 2-D model was restricted to the analysis of uniform road surfaces with the same input to both left and right tires. The 3-D model was recommended for analyzing the affect of vibration on passengers due to unevenness in the road (T.G. Nguyen et al., 2021 [6]).

In 2022, the nine-DOF multi-body model was considered as a driver. An integrated human-vehicle model with seventeen DOFs was constructed by integrating the nine-DOF multi-body model with the 3-D vehicle model for the purpose of enhancing the comfort level of passengers. The simulation results shown that the integrated human-vehicle model got better approximate the actual measurement of human vibrations and/or riding evaluation (T.G. Nguyen et al., 2022 [7]).

The position of both driver/passengers is one of the most important factors affecting riding comfort. Different locations in a vehicle provide various vibration exposures to those inside, especially in large-size vehicles such as buses. Studying on position of both driver/passengers will find out which sitting position can probably reduce the level of discomfort in the vehicle. That is also a good advice for people who always get trouble when seating on vehicle. In this case, the effect is considerable for the RMS acceleration of driver/passengers. In this research, the integrated human-vehicle model with seventeen DOFs was used to analyze and evaluate the affect of driver/passengers position, vehicle speed and acceleration on riding comfort.

2. MODELING CONSTRUCTION

2.1. Integrated human-vehicle model

In this case, the motions of each part of seated human model are considered in plane motion (translational motions in x and z directions, rotational motion respect to y-axis). So, the pitch motion of the vehicle also is considered as a role of input excitation to seated human model. Accordingly, an integrated human-vehicle system can be achieved by deleting the driver mass from 3-D vehicle model and substituting the seated ☞

human model. Assume that, the vehicle body and the vehicle seat are interconnected by a system of parallel linear springs and dampers with corresponding stiffness coefficient kd and damping coefficient c_d, these coefficients were determined by increasing of the initial ones until the biodynamic response errors between the vehicle body and the vehicle seat were less than 1%. For this reason, the translational motion in vertical direction and the rotational motion respect to y-axis of the vehicle seat are considered as the translational motion in vertical direction of vehicle-seat position on vehicle body and rotational motion of vehicle body respect to y-axis.

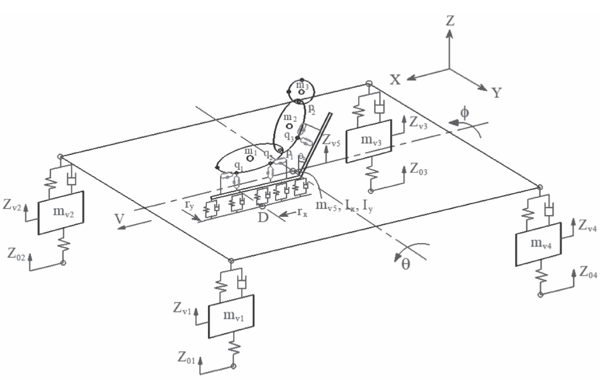


Figure 1. Schematic of integrated human-vehicle model [7]

The integrated human-vehicle model is shown in Fig. 1. Based on the system of EOMs of the nine-DOF multi-body model [3] and the system of EOMs of the 3-D vehicle model [6], the EOMs of a completely integrated human-vehicle model can be expressed by the following matrix form [7]:

$$\mathbf{M\ddot{X}} + \mathbf{C\dot{X}} + \mathbf{KX} = \mathbf{F} \tag{1}$$

The terms M, C and K in Eq. (1) are the 17×17 mass, damping and stiffness matrices of the integrated human-vehicle model, respectively; and $\mathbf{\ddot{X}}$, $\mathbf{\dot{X}}$, and $\mathbf{X}$ are the acceleration, velocity and displacement vectors of the system; F is the force input due to road excitation.

2.2. Random Road Profiles

The road-roughness excitation is also modeled into mathematical model. Many previous researches assert that excitations encountered by a vehicle in situations, such as highway driving are well characterized as random. Therefore, in this part of the study the different road classes, prescribed by ISO 2631 [8] and defined by the road roughness coefficients G_r, as listed in Table 1, are considered as the inputs for the vehicle wheels. Simulations of the integrated human-vehicle model in different random road profiles are also conducted, followed by an evaluation of the riding quality level for each profile.

Table 1. Road-roughness coefficients G_r (m^2/cycle/m) classified by ISO 2631 (1997) [8]:

Road Class	**A very good**	**B good**	**C average**	**D poor**	**E very poor**	**F**	**G**
G_r (10^{-6})	4	16	64	256	1024	4096	16384

The disturbance to the wheels on the front axles can be represented by two white-noise signals ($w_1(t)$ for left side and $w_2(t)$ for right side) passing through the first-order filter G(s):

$$G(s) = \frac{\left(2\pi G_r V\right)^{1/2}}{s + \omega_0} \qquad (2)$$

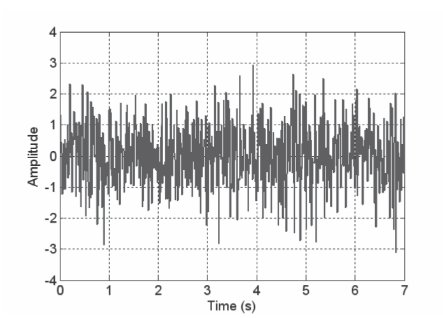
where

G_r: Is the road-roughness coefficient,

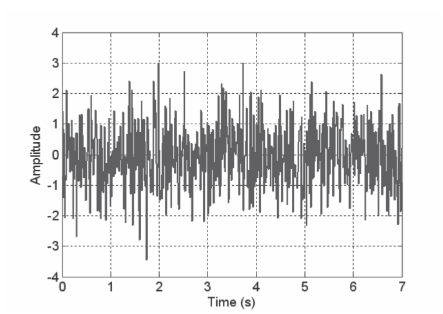
V: Is vehicle velocity,

$\omega_0 = 2\pi\upsilon_0 V$ (υ_0: Is a spatial cut-off frequency between 0.001 and 0.02cycle/m and used to limit the displacement to be finite at vanishingly small spectral frequencies).

Moreover, it is reasonable to consider the excitation at the rear wheels as a pure time delay, t_0 of those at the front wheels, and t_0 the ratio of wheelbase (L) to vehicle velocity (t_0 = L/V).



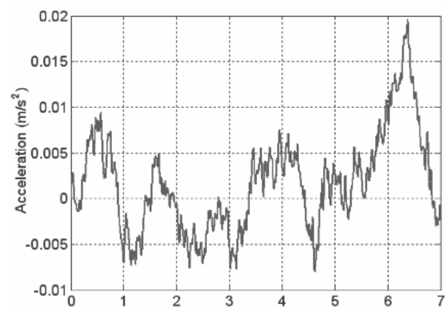
(a) $w_1(t)$



(b) $w_2(t)$

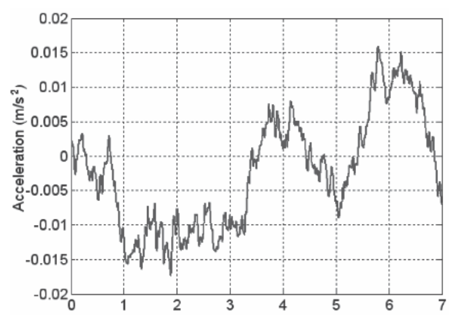
Figure 2. White-noise signals

From a built-in function in the MATLAB software program, the white-noise function of a zero mean in the time domain can be obtained. As shown in Fig. 2. By assuming that the vehicle is moving at a speed of 30 m/s, and by specifying G_r, the excitations due to surface irregularity for the front wheels can be obtained. Furthermore, for most multi-axle vehicles, the disturbances between the wheels on different axles differ little in straight-line driving. Accordingly, the excitations at the rear wheels can be considered simply as a pure time delay in relation to those at the front. To make more obviously, a simulation of road-roughness excitation of road class C (G_r = $64.10^{-6}m^2$/cycle/m) is shown in Fig. 3. With four-wheel inputs and the mathematical model of an integrated human-vehicle system, the dynamic problem of a seated human in driving conditions can be solved. The simulation algorithm is shown in Fig. 4.



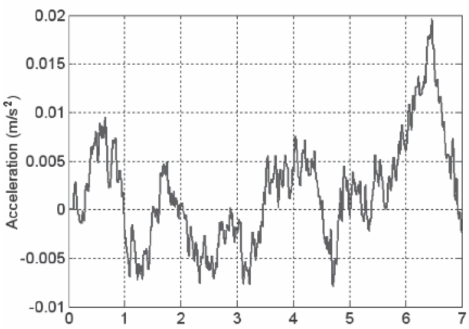
Time (s)

(a) Front left wheel $Z_{01}(t)$



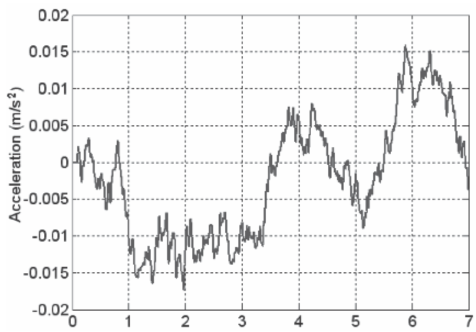
Time (s)

(b) Front right wheel $Z_{02}(t)$



Time (s)

(c) Rear left wheel $Z_{04}(t)$



Time (s)

(d) Rear right wheel $Z_{03}(t)$

Figure 3. The road-roughness excitation for each wheel

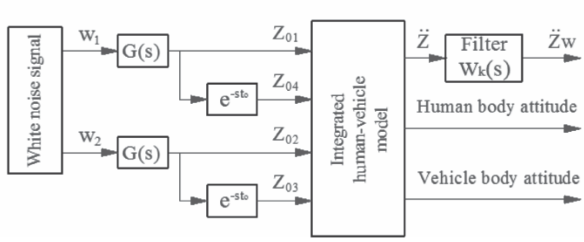
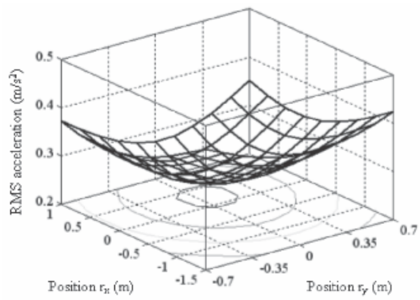


Figure 4. Block diagram of simulation algorithm for biodynamics of human-vehicle system

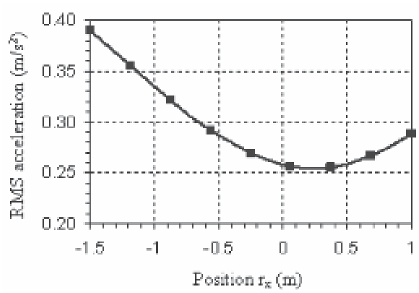
3. SIMULATION RESULTS

3.1. Position of driver/passengers

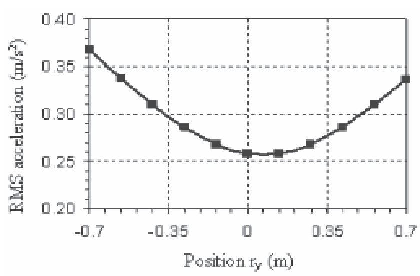
In this case, the effect is considerable for the RMS acceleration of driver/passengers. On the basis of the integrated human-vehicle model and a random class C road profile, the RMS accelerations of the pelvis can be evaluated for seated human subjects at different position with various values of r_x and r_y in x- and y-direction, respectively. The simulation results are shown in Fig. 5. There exists a comfort zone in the shape of an ellipse surrounding the x-axis where the acceleration of driver/passengers is moderate. From the simulation results, it can be noted that the best position for seated human subjects to experience the least vibration in the pelvis of 0.247m/s^2 is located at (0.063m, 0.14m) from the vehicle's CG along the x- and y-axis, respectively, while the point with maximum vibration of 0.361m/s^2 is located at (-1.5m, -0.7m).



(a) Influence of both r_x and r_y



(b) Influence of r_x (r_y = 0.28 m)



(c) Influence of r_y (r_x = -0.25 m)

Figure 5. RMS acceleration of pelvis at different sitting positions in road class C at a velocity of 30 m/s

3.2. Velocity and Acceleration of Vehicle

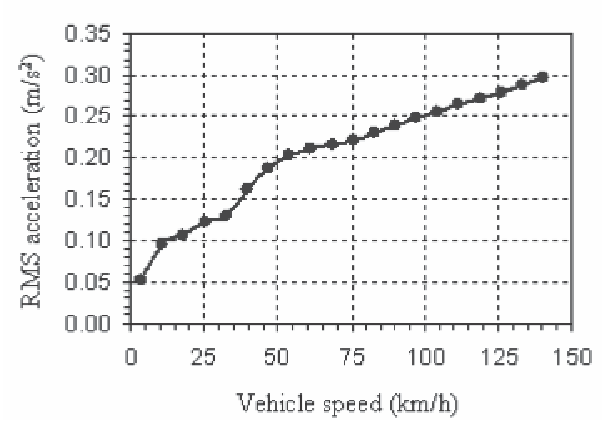
As stated in the preceding discussion, the displacement disturbance in a random road profile can be represented as a white-noise signal w(t) passing through a first-order filter G(s), as in Eq.(2). Alternatively, the differential equation for road roughness q(t) can be described by the following equation (Zhang et al., 2002) [9]:

$$\dot{\mathbf{q}}(t) + 2\pi\upsilon_0 V.\mathbf{q}(t) = \sqrt{2\pi G_r V}.\mathbf{w}(t) \quad (3)$$

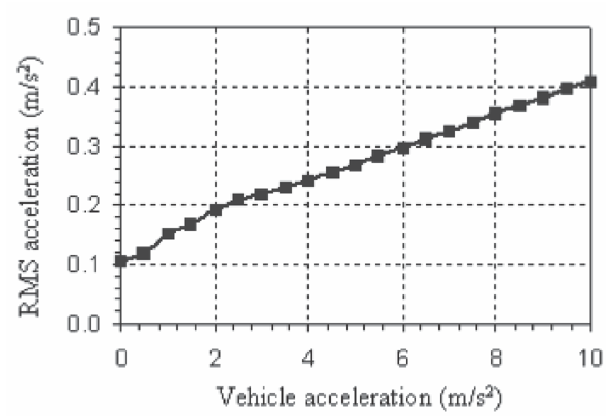
The foregoing equation stipulates that road roughness q(t) depends on the vehicle's velocity V. While a vehicle is running at various speeds with an acceleration a_v, the road excitation becomes a non-stationary random process in the time domain although the road input is stationary in the space domain. Moreover, the velocity is a function of acceleration a_v in the accelerating process; hence, q(t) is also related to a_v.

$$\dot{\mathbf{q}}(t) + 2\pi\upsilon_0(V_0 + a_v t)\mathbf{q}(t) = \sqrt{2\pi G_r(V_0 + a_v t)}.\mathbf{w}(t) \quad (4)$$

To observe the influence of velocity and acceleration on riding quality, road class C is selected as the target for disturbance. Also, the simulation algorithm in Fig. 4 is implemented again with various velocities and accelerations. The simulation results are shown in Fig. 6. It can be observed that RMS accelerations of the pelvis of seated human subjects increase monotonically as the vehicle speed increases. As the result, riding quality decreases with an increase in velocities under certain riding condition. The acceleration of a vehicle has an influence on riding quality similar to that of velocity. Higher vehicle acceleration tends to enlarge the RMS accelerations of human subjects.



(a) Influence of vehicle speed



(b) Influence of vehicle acceleration with an initial speed of 10 m/s

Figure 6. Influence of vehicle speed and acceleration on RMS accelerations of human bodies in road class C

4. CONCLUSIONS

In this research, the affect of driver/passengers position, vehicle speed and acceleration on riding comfort is systematically analyzed by using the integrated human-vehicle system with seventeen DOFs. The research results on position of driver/passengers indicate which seating position can probably reduce the level of discomfort in the vehicle. That is also a good advice for people who always get trouble when seating on vehicle. The simulation results on the affecting of vehicle speed and ☞

acceleration on riding comfort can be used for research to enhance the comfort level of driver/ passengers.❖

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