RESEARCH ON THE AFFECT OF MECHANICAL PROPERTIES OF SEAT ON RIDING COMFORT

NGHIÊN CỨU VỀ ẢNH HƯỞNG CỦA CÁC ĐẶC TÍNH CƠ HỌC CỦA GHẾ NGỒI ĐẾN SỰ THOẢI MÁI KHI LÁI XE

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ABSTRACT

The popular image of a "comfortable seat" is that of a soft-cushioned chair having a luxurious appearance and feel and giving an instant sensation of conscious well-being. A good seat should have both instantaneous and long-lasting appeal to the user. Designing an optimum seat must take into account many factors including the range of seat user, their activities, and the maintenance of the seat and the environmental aspects of the seat. This research is concerned with the effects of mechanical properties including hip cushion and backrest support, and seat suspension to responses of human subjects. The knowledge of the seat design factors is a vital role to design optimum seat.

Keywords: *Comfortable seat; Mechanical property; Comfort level.*

TÓM TẮT

Hình ảnh thông thường về "chỗ ngồi thoải mái" là một chiếc ghế có đệm mềm mại, có vẻ ngoài sang trọng và mang lại cảm giác sảng khoái ngay lập tức. Một chiếc ghế tốt phải có sức hấp dẫn tức thì và lâu dài đối với người dùng. Thiết kế một chiếc ghế tối ưu phải tính đến nhiều yếu tố bao gồm phạm vi sử dụng ghế, hoạt động của người ngồi cũng như việc bảo trì ghế và các khía cạnh môi trường của ghế. Nghiên cứu này tập trung đến ảnh hưởng của các tính chất cơ học bao gồm đệm hông, hỗ trợ tựa lưng và hệ thống treo ghế đối với phản ứng của người ngồi. Sự hiểu biết về các yếu tố thiết kế là một vai trò quan trọng để thiết kế một chiếc ghế ngồi tối ưu.

Từ khóa: *Ghế ngồi thoải mái; Đặc tính cơ học; Mức độ thoải mái.*

☞

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, 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-DOF and nine-DOF model shown that nine-DOF model produced better matching in transmisibilities (T.G. Nguyen et al., 2020 [1]).

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 [2, 3]) 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 [4]).

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 [5]).

In 2023, the integrated human-vehicle model with seventeen DOFs was constructed by integrating the nine-DOF multi-body model with the 3-D vehicle model was used to analyze and evaluate the affect of driver/passengers position, vehicle speed and acceleration on riding comfort (T.G. Nguyen et al., 2023 [6]). For the purpose of designing optimum seat, the integrated human-vehicle model with seventeen DOFs was used to analyze and evaluate affect of mechanical properties of seat on riding comfort in this research.

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 k_d 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.

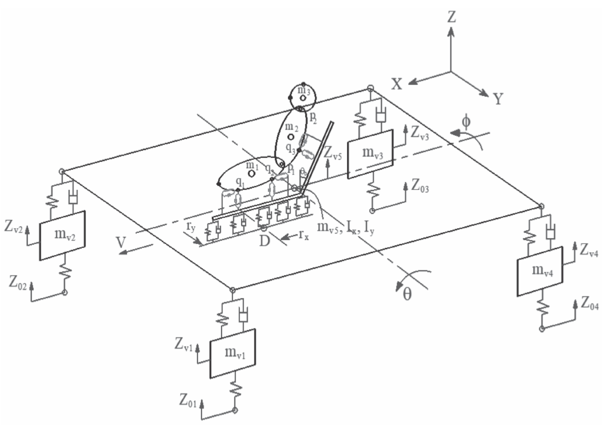


Figure 1. Schematic of integrated human-vehicle model [5]

The integrated human-vehicle model is shown in Fig. 1. Based on the system of EOMs of the nine-DOF multi-body model [1] and the system of EOMs of the 3-D vehicle model [4], the EOMs of a completely integrated human-vehicle model can be expressed by the following matrix form [5]:

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

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 $\ddot{\mathbf{X}}$, $\dot{\mathbf{X}}$, and $\mathbf{X}$ are the acceleration, velocity and displacement vectors of the system; **F** is the force input due to road excitation.

2.2. 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 [7] 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) [7]

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):

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

Where:

- G_r is the road-roughness coefficient.
- V is vehicle velocity.
- $\omega_0 = 2\pi v_0 V$ (v_0 is a spatial cut-off frequency between 0.001 and 0.02 cycle/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).

Again, a class C road surface is selected and the velocity is setting at 30m/s [7].

2.3. Mechanical Properties of Hip Cushion

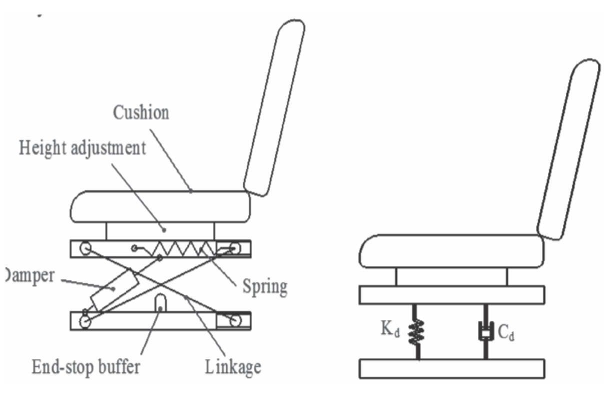
Some studies have shown that "pulsating" seat cushions can improve blood flow to the legs of persons confined for long periods in a car or other vibration environment. Furthermore, from basic vibration theory, it appears obvious that spring-damping structure tends to reduce the vibration transmission before the resonance frequency but enlarges thereafter. In this research, mechanical properties of hip cushion are presented by dampers and springs in parallel connection, both characteristics of the hip cushion are taken into consideration to observe the influence on riding comfort.

2.4. Mechanical Properties of Backrest Support

Several studies have shown that the transmission of vertical vibration to the head of seated human subjects is influenced by backrest support. The transmissibility between the head and floor is measured with and without backrest support by Cho and Yoon (2001) [8]. The measured data show that there is a significant difference between the transmissibility with and without backrest support. The fundamental mode without the backrest support is at 3.4Hz that is much lower than that with the backrest support at 4.2Hz. The peak magnitude of transfer function without the backrest support at 2.4 that is also much lower than that with the backrest support at 3.1. Hence, the backrest support increases the natural frequency and the magnitude of transfer function significantly. However, the backrest support can extend association of muscle forces on the trunk also generates spinal compression, thereby reducing the necessary muscle forces and reducing the compressive loading of the spinal column.

2.5. Mechanical Properties of Seat Structure

On vehicle, seat structure plays an important role to reduce the effect of vibration to driver or passengers seating in driving condition. The suspension of seat structure in most commercial suspension seats is a passive mechanism consisting of damper and some form of spring. The spring may be constructed of steel (e.g. a coil spring or torsion bar) or provided by a column of air. Figure 2(a) present the schematic of a typical seat structure. It has a mechanical under-seat 'X' linkage suspension mechanism. Suspension stiffness is provided by two parallel steel coil springs. Damping is provided by an inclined telescopic damper. Rubber buffers are used to limit the suspension travel. Purpose of this part is consideration to the effects of mechanical properties of seat structure on seated human subject in vertical direction. For this reason, the suspension of seat structure is simplified by a system of couples of linear spring and damper mounting parallelly with corresponding stiffness coefficient k_d and damping coefficient c_d as shown in Figure 2(b). The simulation algorithm is implemented with various spring constants k_d and damping coefficients cd in class C road surface and the vehicle velocity of 30m/s.



a) Schematic of the seat b) Simplified seat model
Figure 2. Schematic and simplified model of the seat

3. SIMULATION RESULTS

3.1. Mechanical Properties of Hip Cushion

In this part, the effect is considerable for the RMS acceleration of driver/passengers, a class C road surface is selected and the velocity is setting at 30m/s. The simulation algorithm is implemented with various spring constants and damping coefficients. The simulation results are shown in Figures 3. It should be noted that the RMS acceleration of the pelvis increases with an increase in the spring constants and almost unchanged belong to increase in the damping coefficient. The optimum hip cushion characteristics are found that the lower stiffness transmits the lower vibration to human body.

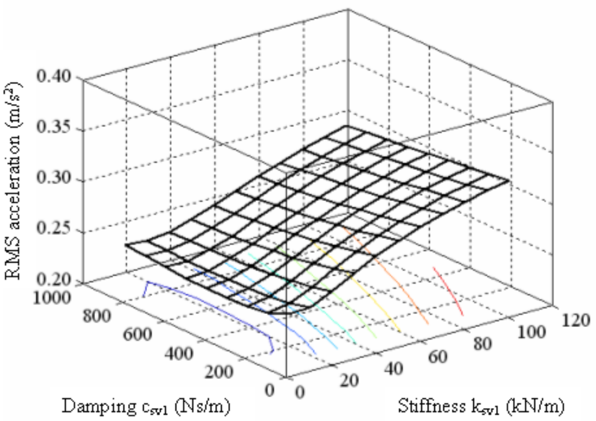


Figure 3. Influence of hip cushion mechanical properties to RMS accelerations of human body over road class C

3.2. Mechanical Properties of Backrest Support

In this part, a simulation of integrated human-vehicle model is performed to illustrate the influence of mechanical properties of seat structure. Again, a class C road surface is selected and the velocity is setting at 30m/s. The simulation algorithm is implemented with various spring constants and damping coefficients. The simulation results are shown in Figures 4. The RMS acceleration of the pelvis increases with an increase in the stiffness coefficient up to 80 kN/m and remains almost constant in value thereafter. On the other hand, damping coefficient has the reverse effect. Nevertheless, this decrease is inappreciable, it is almost unchanged belong to increase in the damping coefficient.

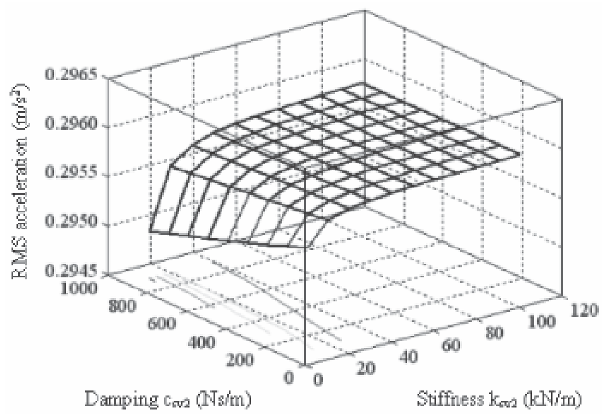


Figure 4. Influence of backrest support mechanical properties to RMS accelerations of human body over road class C

3.3. Mechanical Properties of Seat Structure

In this part, a simulation of integrated human-vehicle model is performed to illustrate the influence of mechanical properties of the backrest support. A class C road surface is selected and the velocity is setting at 30m/s. The simulation results are shown in Figures 5. It should be noted that the RMS acceleration of the pelvis decreases with an increase in the damping coefficient up to 1300 Ns/m and remains almost constant in value thereafter. On the other hand, seat stiffness has the reverse effect. An increase of stiffness tends to increase the pelvic acceleration until it reaches about 8000 N/m, after which point the acceleration remains approximately the same. This influence occurs similar effects on the simulation results ☞

with different road class (E and G). For this reason, the lower stiffness of seat structure is offered a more comfortable seat. Otherwise, the low stiffness of the seat structures causes them to deflect through many centimeters when loaded by the weight of driver/passengers. They are normally limited at about 10 cm of vertical travel so the stiffness must be adjusted according to subject mass in order that the seat operates about central position.

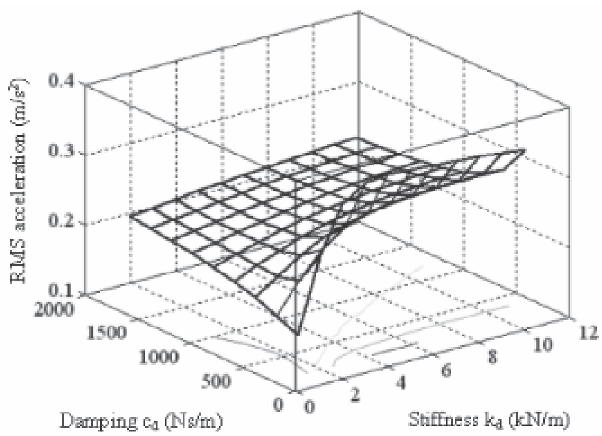


Figure 5. Influence of seat structure mechanical properties to RMS accelerations of human body over road class C

4. CONCLUSIONS

In this research, the influences of mechanical properties of seats including hip cushion, backrest support, and seat structure on riding comfort were evaluated. It has been noted that an increasing of stiffness coefficient tends to increase discomfort at given speeds and road surfaces up to certain value. However, damping coefficient has the reverse effect. This decrease is inappreciable, riding condition is almost unchanged belong to increase in the damping coefficient.❖

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