EFFECT OF ROAD SURFACE ON VIBRATION OF PASSENGER IN BUS VEHICLE

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ABSTRACT

This paper presents modeling and simulation model of 6 degrees of freedom of car - seat - passenger of a 29-seat County vehicle by the vibration in ¼ model. The excitation forces from three different road surface types are sinusoidal, ramp and ISO 8608:2016 standard. Newton's method is used to formulate the mathematical equations of the model. The simulation method is Matlab Simulink used. The result of simulation of the three cases all receive the values of vibration acceleration and motion vertical amplitude at the floor, seat, buttocks, chest, abdomen and head of the passenger while sitting on the seat to compare with the value. Mean squared RMS of the accelerometer in the international standard ISO-2631-1:1998(E). From there, assess the influence of one of the three types of pavement that has the most impact on passengers.

Keywords: *29 seat County, passenger, vibration, road surface.*

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1. INTRODUCTION

The passengers's comfort depends on vibration of different parts in their body. There are different studies simulating and experimenting vehicle's structure and passengers in order to evaluate, measure, control and describe vehicle's vibration level and its impact on passengers. The purpose is to create technologies that help making vibration frequencies of human organs suitable to that comfort. Low frequencies from minuscule one to 100Hz, which passengers can feel, are usually caused by suspension system. High vibration frequencies are: vibration of body and transmission system, contact of tires with road surface, engine's noise. Usually, vibration of low frequencies, which dominates the spectrum, negatively effects passengers. At the moment of contacting with vibrating object, the vibration is transmitted to passengers as following: particular vibration occurs under acting on the limbs and on the whole body [1]. Long term contact with vehicle's vibration can cause, directly or indirectly, some diseases of passengers. Analyzing resonance in range of 10 - 12Hz in Matlab helps determine acceleration of vehicle's vertical vibration at 4 points of seat legs, where the signals of transmission to passengers are maximum [2]. Mathematical model of 7 degrees of freedom analyzes active force from seat to passenger's thigh and determines the acceleration of vertical vibration from seat to passengers by numerical simulation, the vibration force increases when frequency decreases. In surveying the resonant frequency region of vibrating seat, the cushion material dissipates energy and seats of different types have different energy absorption capacity [4]. In a finite element simulation study of 7 different passenger's positions, the 1st of which is at 10 Hz, the difference in pressure distribution between thigh and seat affects the spine and deforms hard elements of joints and intervertebral discs [5].

Using genetic algorithm, the simulating model of 7 degrees of freedom has optimized some parameters such as frequency, damping level and stiffness.

2. MODELING AND SIMULATING

2.1. Criteria for evaluating the effects of vibration R.M.S

Acording to ISO-2631, the vibration's affect to passengers is the average of acceleration's square value R.M.S as shown is equation (1) [6].

$$a_w = \left(\frac{1}{T} \int_0^T a_w^2(t)dt \right)^{1/2} \quad (1)$$

Where: $a_w(t)$ (m/s^2) is the vibration's acceleration; T the time (s).

For human comfort, the values of vibration's acceleration should be less than 0.315m/s^2 according to R.M.S.

2.2. Modeling vibration system

In this study, the vibration system model is a model of 6 degrees of freedom, including model ¼ of 2 degrees of freedom for County Bus 29 seat and model of seat with passenger.

The model's assumptions: The vehicle is moving in a constant speed V; Only vertical vibrations are considered (Y axis direction); Point contact between the wheel and road surface; The vibration model is linear, where the force location does not change in the whole frequency range of the excitation force; The masses of leg and foot, hand and arm, have no significant affect to kinematic response of passenger's body.

The passenger's and bus body model consists of 6 masses connected with springs and dampers, among which is the buttock and thigh mass contacted with the seat. The complete model shown in Fig. 1.

The parameters of model are: Unspung mass m_c = 692 (kg); Spung mass m_{th} = 3950 (kg); Seat mass m_{gh} = 5 (kg); Buttock and thighs mass m_m = 20 (kg); Thorax mass m_b = 40 (kg); Head mass m_d = 5(kg); Tire stiffness (one tire) K_L = 49320 (kN/m); Tire damping C_L = 1100 (Ns/m); Suspension stiffness K_{tr} = 741843 (kN/m); Suspension damping C_{tr} = 17537 (Ns/m); Seat suspension stiffness K_{gh} = 52537.5 (N/m); Seat suspension damping C_{gh} = 900 (Ns/m); Buttock and legs stiffness K_m = 40 (kN/m); Buttock & legs damping C_m = 2500 (Ns/m); Body stiffness K_b = 35 (kN/m); Body damping C_b = 750 (Ns/m); Head stiffness K_d = 130 (kN/m); Head damping C_d = 250 (Ns/m).

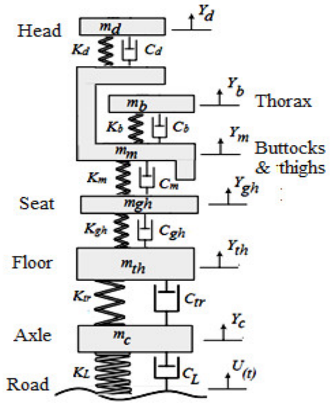


Fig. 1. Vibration model of vehicle - seat - passenger [4]

Applying Newton equation, we build a system of 6 equations describing vertical movements of vehicle, seats and passengers (vehicle - seat - passenger) (2).

$$\begin{cases} m_c\ddot{Y}_c = K_L(U_{(t)} - Y_c) + K_{tr}(Y_{th} - Y_C) + K_{gh}(Y_{gh} - Y_{th}) \\ \quad + K_m(Y_m - Y_{gh}) + K_b(Y_b - Y_m) + K_d(Y_d - Y_m) \\ \quad + C_L(\dot{U}_{(t)} - \dot{Y}_c) + C_{tr}(\dot{Y}_{th} - \dot{Y}_C) + C_{gh}(\dot{Y}_{gh} - \dot{Y}_{th}) \\ \quad + C_m(\dot{Y}_m - \dot{Y}_{gh}) + C_b(\dot{Y}_b - \dot{Y}_m) + C_d(\dot{Y}_d - \dot{Y}_m) \\ m_{th}\ddot{Y}_{th} = K_{tr}(Y_C - Y_{th}) + K_{gh}(Y_{gh} - Y_{th}) + K_m(Y_m - Y_{gh}) \\ \quad + K_b(Y_b - Y_m) + K_d(Y_d - Y_m) + C_{tr}(\dot{Y}_C - \dot{Y}_{th}) \\ \quad + C_{gh}(\dot{Y}_{gh} - \dot{Y}_{th}) + C_m(\dot{Y}_m - \dot{Y}_{gh}) + C_b(\dot{Y}_b - \dot{Y}_m) \\ \quad + C_d(\dot{Y}_d - \dot{Y}_m) \\ m_{gh}\ddot{Y}_{gh} = K_{gh}(Y_{th} - Y_{gh}) + K_m(Y_m - Y_{gh}) + K_d(Y_d - Y_m) \\ \quad + C_{gh}(\dot{Y}_{th} - \dot{Y}_{gh}) + C_m(\dot{Y}_m - \dot{Y}_{gh}) + C_d(\dot{Y}_d - \dot{Y}_m) \\ m_m\ddot{Y}_m = K_m(Y_{th} - Y_{gh}) + K_b(Y_b - Y_m) + C_m(\dot{Y}_{th} - \dot{Y}_{gh}) \\ \quad + C_b(\dot{Y}_b - \dot{Y}_m) \\ m_b\ddot{Y}_b = K_m(Y_m - Y_b) + K_bY_b + C_m(\dot{Y}_m - \dot{Y}_b) + C_b\dot{Y}_b \\ m_d\ddot{Y}_d = K_m(Y_m - Y_d) + K_dY_d + C_m(\dot{Y}_m - \dot{Y}_d) + C_d\dot{Y}_d \end{cases} \quad (2)$$

Where: Y_c, Y_{th}, Y_{gh}, Y_m, Y_b, Y_d are vertical movements of axle, floor, seat, buttocks and thighs, thorax and head of passenger. U(t) is excitation forces function by time of road surface.

2.3. Simulating vibration system

Use Matlab Simulink software to simulate vibration model. The overall diagram Simulink includes wheel blocks, body, seats, buttock and thigh, thorax and head of passenger. The passenger's body includes 3 interconnected blocks, similar to the vehicle's suspension system consisting of elastic and dumping components

The excitation forces are representative for 3 types of road surface: Sin model, bumpy Ramp and D-E road of ISO 8608:2016.

Amplitude h(t) of excitation force from road surface is determined in equation (3) [5].

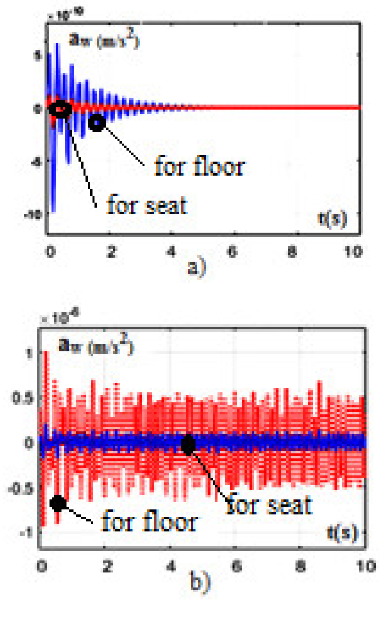
$$h(t) = \sum_{i=0}^{N} \sqrt{\Delta n}.2^k.10^3.\left(\frac{n_0}{i\Delta n}\right).\cos\left(2\pi.i.\Delta n.v.t + \varphi_i\right) \quad (3)$$

3. RESULTS AND DISCUSSION

3.1. Analyzing of Vibration acceleration amplitude

The simulation of vehicle - seat - passenger model in survey time of 10 seconds in 3 types of road surface (Sin, bumpy Ramp and bumpy D-E according to ISO 8608) is shown in Fig. 2. In the results, vertical acceleration is determined.

The acceleration of body (floor) and seat ranges from $5m/s^2$ to $10m/s^2$ and gradually decreases until its stop when the wheel passes bumpy top in Sin surface shown in Fig. 2(a). The acceleration is in range of $1m/s^2$ and does not tend to decrease in Ramp surface as shown in Fig. 2(b). In D-E surface of ISO 8608:2016, the acceleration periodically increases in range of $5m/s^2$ as shown in Fig. 2(c). According to the simulation, the vibration acceleration of vehicle's suspension system is in accordance with regulations on frequency range of vehicle's comfort.



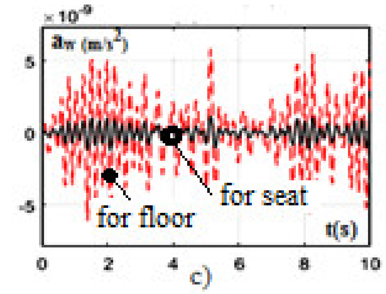


Fig. 2. Vibration acceleration apmlitude of floor and seat

The acceleration of passenger's head, buttock and thigh, thorax is smaller than the acceleration of vehicle's body and seat as shown in Fig. 3 (a,b,c). However, in surface ISO 8608:2016, the vibration acceleration of buttock and thigh ranges from -6m/s^2 to +6m/s^2, which is a little higher than that in Sin and Ramp surface due to energy characteristics PSD of D-E surface is higher than that in Sin and Ramp surface.

The DOE matrix and experimental results of the EDD process. For constructing a Kriging surrogate, it is necessary to obtain the unknown correlation parameter θ_k and scalar factor β. The correlation parameter θ_k and scalar factor β were observed using the maximum likelihood method.

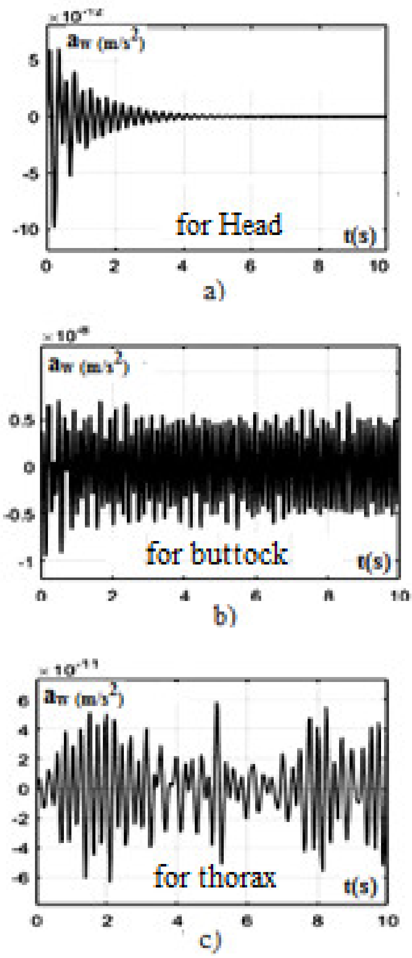


Fig. 3. Vibration acceleration amplitude of head, buttocks and thorax

Vibration acceleration of thorax and head in Sin surface ranges from -7e-13m/s^2 to +7e-13m/s^2 as shown in Fig. 4 (a,b,c) , which is much smaller than that in Ramp and ISO 8608:2016 surface since the damping characteristics are effective in Sin surface.

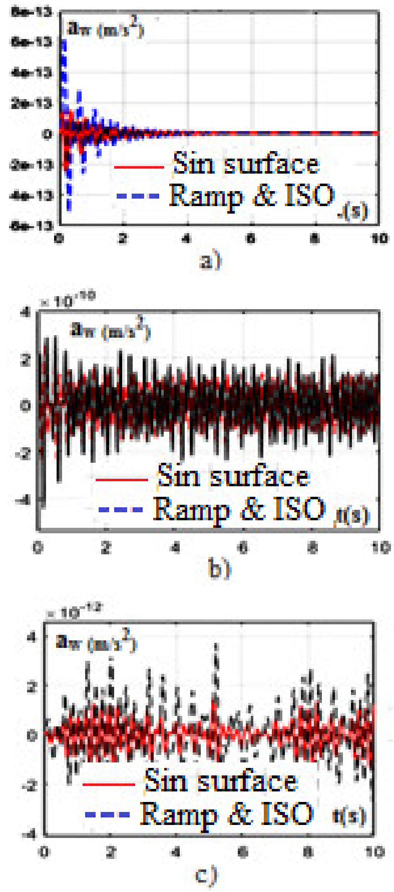


Fig. 4. Vibration acceleration amplitude of thorax

3.2. Evaluating smoothness of the vehicle's movement

The above equation (1) evaluates the influence of vibration to passengers using average square values of RMS according to ISO 2631-1:1997(E). RMS tool in Simulink gives results shown in Table 1.

Table 1. Comparison of RMS values in different types of road

	RMS (m/s^2)		
	Sin type road	Ramp type road	Road type ISO 8608
Vehicle's body	3329e-07	2462e-13	4985e-09
Seat	6658e-08	4923e-14	997e-10
Buttocks and thighs	3329e-09	2462e-15	4985e-11
Thorax	8323e-11	6154e-17	1246e-12
Head	473e-11	2968e-17	1903e-13

In the results, the vibration affect to passengers is 0.315m/s^2 in all 3 types of road. The passengers do not feel unpleasant of vehicle's vibration based on ISO 2631-1:1997(E).

4. CONCLUSION

Model vehicle - seat - passenger of 6 degrees of freedom and simulation in Matlab Simulink allow analyzing vertical vibration acceleration while the vehicle runs in different road types such as Sin type is 3329e-07m/s^2, Ramp type is 2462e-13m/s^2 and D-E type of ISO 8608:2016 is 4985e-09m/s^2. Simulation results show that vehicle's suspension affects the vibration level of each part of human body are buttock, thorax and head. By assessing average square values RMS in simulation module, we get the vibration affect to passenger's comfort level.

Observable signals in floor positions of three types sin is 6658e-08m/s^2, ramp is 4923e-14m/s^2 and Iso 997e-10m/s^2 of road surfaces, where vibration is transmitted into seats and passenger's body, can be used to analyze energy of vibration that affects passenger in particular frequency ranges. From that we determine vibration time of passengers in order to enhance vehicle's operation smoothness and select optimal parameters for suspension system in design. Selected parameters consist of type of suspension system, type of seat, cushion material, suitable seat suspension structure, that help reduce excitation force to passengers.

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