ANALYSIS OF VIBRATION EXPERIENCED BY PASSENGERS AND THEIR SEATS IN A BUS VEHICLE

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ABSTRACT

This paper presents an analysis of the vibration experienced by passengers on a 29-seat bus, using the finite element method and Ansys Workbench software for simulation. The 3-D model was created to simulate real-life conditions, with a sinuous road surface that causes direct forces on the four wheels, leading to vehicle vibration. The force model was analyzed from the floor of the vehicle, specifically in one seating position, to assess the level of vibration that the seat and occupants experience. This analysis can be extended to other seating positions on the vehicle. The vibration parameter of human comfort level was evaluated based on frequency, as per the international standard ISO 2631-1. The research results can be used as a reference for designing seat cushions and seating positions in buses, to improve the comfort level of passengers.

Keywords: *Bus, Seat and passengers, Vibration.*

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1. INTRODUCTION

The movement of both external and internal forces creates mechanical vibrations in the parts and components of a vehicle, which in turn causes vibrations in the human body and seats. These vibrations are assessed for each part of the body [1, 2]. Research has analyzed the relationship between acceleration parameters and the amplitude of oscillation, determining the vibration distribution at different positions in the vehicle [3]. The level of vibration of the seat and its effects on different parts of the human body can be characterized through mathematical modeling and numerical simulation. The seven-degrees-of-freedom model (7-DOF) analyzes the dynamics of the seat and human oscillations with vertical displacement when force is excited from the floor of the vehicle to the seat. Different types of seats have different energy absorption capacities, and the cushion materials of seats may dissipate energy [4].

The finite element analysis (FEA) method and numerical simulation in Ansys Workbench 2022R1 software were used in this research.

2. SEAT AND HUMAN MODELING

2.1. Model of seat and human

A three-dimensional model of a 29-seat Huyndai County bus has been designed. It allows for vibration analysis in any position, such as a human sitting in the fourth row (Fig. 1).

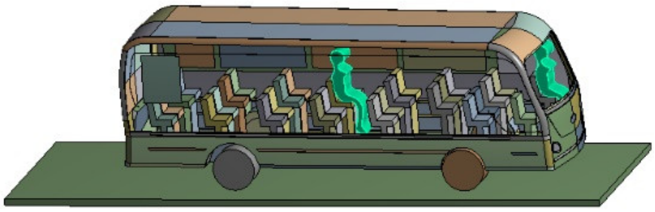
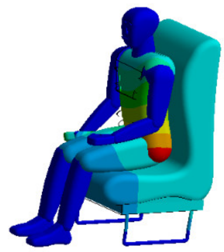
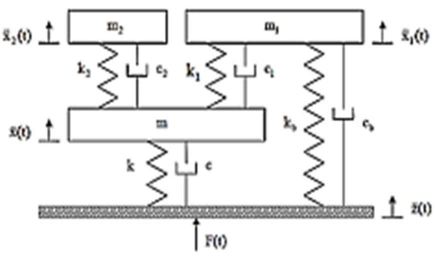


Fig. 1. The model of bus, seat and passengers



a) Seat and human



b) Mathematical model

Fig. 2. Seat and passenger modeling

The human body is like an elastic mechanical system, with a natural frequency of vibrations ranging from 3 to 30Hz. It is capable of absorbing vibrations with frequencies up to 8000Hz. When we sit in a seat, the thighs, buttocks, and back of the shoulders come in direct contact with the seat. However, the other parts of the body such as arms, legs, back, abdomen, chest, neck, and head can move relative to each other. By quantitatively assessing the comfort quality of the vehicle, it is possible to measure the level of human comfort, which ranges from discomfort to serious health risks.

The international standard ISO2631 provides guidance for assessing human comfort with vibrations at frequencies from 0.5 to 100Hz by frequency weighting aw (m/s^2). The frequency weighting is the inverse of the human's comfort level, which is determined by equation (1) [5].

$$a_w = \left[\sum (W_i a_i)^2\right]^{\frac{1}{2}} \quad (1)$$

Here, W_i and a_i are the respective actual measured weighting and acceleration factors for a particular frequency (i). The seat and passenger model shown in Fig. 2 includes a 3-dimensional model and a mathematical model of the seats and passengers sitting in the fourth row on the left side of the vehicle.

To build a system of differential equations (2) describing dynamics for the model, Newton's law applies (2) [6].

$$\begin{aligned} & m_1\ddot{x}_1 + k_1(x_1 - x) + c_1(\dot{x}_1 - \dot{x}) + k_b(x_1 - z) + c_b(\dot{x}_1 - \dot{z}) = 0 \\ & m_2\ddot{x}_2 + k_2(x_2 - x) + c_2(\dot{x}_2 - \dot{x}) = 0 \\ & m\ddot{x} + k(x - z) + c(\dot{x} - z) + k_1(x - x_1) + c_1(\dot{x} - \dot{x}_1) \\ & + k_2(x - x_2) + c_2(\dot{x} - \dot{x}_2) = 0 \end{aligned} \quad (2)$$

The exciting forces F(t) take from equation (3):

$$\begin{aligned} F(t) &= m\ddot{x} + m_1\ddot{x}_1 + m_2\ddot{x}_2 \\ &= k(z - x) + c(\dot{z} - \dot{x}) + k_b(z - x_1) + c_b(\dot{z} - \dot{x}_1) \end{aligned} \quad (3)$$

Where: m_1 is the mass, k_1 is the stiffness coefficient, c_1 is the damping coefficient of the human body; m_2 is the mass, k_2 is the stiffness coefficient, c_2 is the damping coefficient of the backrest; m is mass, k is stiffness coefficient, c is damping coefficient of seat cushion; k_b is the stiffness coefficient, c_b is the damping coefficient of the human foot; x,z is the corresponding oscillation amplitude; F(t) is the excitation force from the floor of the vehicle.

Once the stiffness and damping parameters are known, the Runge-Kutta-4 method can be used to solve in the time domain. However, each vehicle has different seat cushion characteristics, so determining the parameters will become complicated and elaborate. Using the simulation method can overcome this drawback because then only need to care about the type of material and that has been available in the simulation software. The assumptions of the mathematical model used: There is independence between the head and the rest of the body; The tilt angle of the backrest is fixed.

2.2. Acting Forces F(t) from floor to seat

The road surface profile is described mathematically by the method ISO8608:1995 [7], or it can be described as a sinusoid. For simplicity, a sinusoid pavement in this study is used. The vibration of the body structure causes vibration of the floor plate, the simulation results are obtained. The approximate amplitude of floor plate vibration is taken as the excitation force to the seat structure. It is causing vibration of the seats andpassengers. The graph of the amplitude-frequency of the acting forces from the floor at node position 2612 (4th row of seats) has the largest force amplitude of about 17.2 (mm) at 72 (Hz) frequency. The acting force on the person sitting at the contact position of the buttocks, below the thighs, above the back and the force amplitude values are summarized shown in Fig. 3 [8].

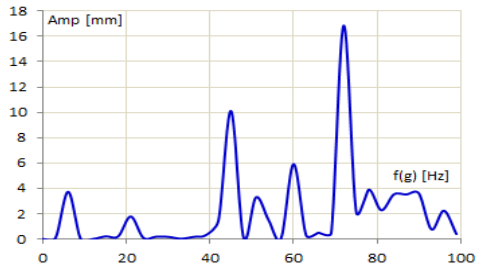


Fig. 3. Force F(t) excitation from the floor to the seat and the human

3. SIMULATION AND RESULTS ANALYSIS

3.1. FEM Equation

The finite element method establishes the relationship between the nodal force and the nodal displacement of the structure by meshing the structure in the continuous domain into the discrete domain such that the vibration frequencies of the elements are higher than the vibration frequencies of the overall structure, if not guaranteed, further re-meshing. The structure of the element has nodes, the displacements of the nodes are the basic variables that need to be determined. The nodal forces acting at the nodes according to the principle of equivalent force are expressed as functions of the node displacement. The computational accuracy of the finite element method is proportional to the number of elements, but the increased numerator will require a high computer memory capacity. The FEM equation for the seat and human structure model is (4).

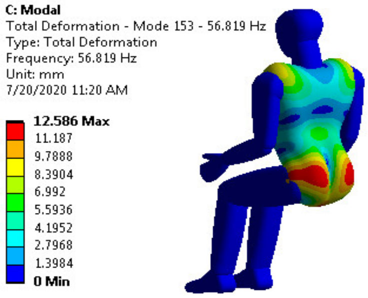
$$M\ddot{X}(t) + K\dot{X}(t) + CX(t) = F(t) \quad (4)$$

Where: M is the mass matrix, K is the stiffness matrix, C is the resistance matrix, and F(t) is the excitation force vector, they are determined by equations (5).

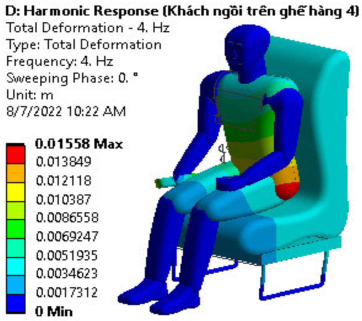
$$\begin{aligned} & M = \begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m \end{bmatrix} \qquad K = \begin{bmatrix} k_1 + k_b & 0 & -k_1 \\ 0 & k_2 & -k_2 \\ -k_1 & -k_2 & k + k_1 + k_2 \end{bmatrix} \\ & C = \begin{bmatrix} c_1 + c_b & 0 & -c_1 \\ 0 & c_2 & -c_2 \\ -c_1 & -c_2 & c + c_1 + c_2 \end{bmatrix} \quad F = \begin{bmatrix} 0 & 0 & 0 & -m_1 & -m_2 & -m \end{bmatrix}^T \end{aligned} \quad (5)$$

3.2. Vibration of seat and human

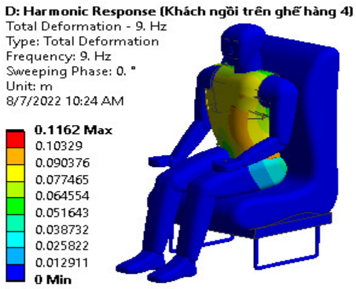
Simulation results get the vibration of each part of the body. The shoulders and the whole body are bentin an "S" shape in the longitudinal plane, other positions can get similar results. An illustrative result at the passenger position in the 4th row, at the frequency of 56,819 (Hz), largest displacement amplitude of 12,568 (mm) in the back area. The distribution according to the color spectrum representsthe vibration values of the body parts at different frequencies, predicts the correlation between the position of the part and the amplitude and frequency of the vibration shown in Fig. 4.



a) Modal vibration



b) At 4Hz



c) At 9Hz

Fig. 4. Vibration of human on the 4th row

Using the fast Furie transform (FFT) analysis to build the frequency - amplitude relationship of the vibration of each part of the human, the amplitude of the vibration will change according to the period of the active force. The value of the simulated vibration frequency is compared with the reference shown in Table 1.

Table 1. Vibration amplitude of parts on the human body of the 4th row (mm)

Part of Human	ISO 2631-1 (Hz)	Simulation	
		Frequency (Hz)	Amplitude max. (mm)
Head	0 - 25	12	0.025
Torso	4 - 5	4	0.262
Thorax	64 - 80	72	0.254
Back	10 - 12	12	0.025
Abdomen	4 - 8	7	0.199
Pelvis	2 - 20	16	0.012

The graph of frequency-amplitude of vibration and distribution by body part is shown in Fig. 5.

Comparison with the reference frequency shows that the frequency ranges received from the survey results in the simulation are within the allowable frequency range. When the seat cushion stiffness is increased in the frequency region corresponding, the amplitude of vibration of each part of the body increases, in which the head and thorax regions increase the frequency more than the rest.

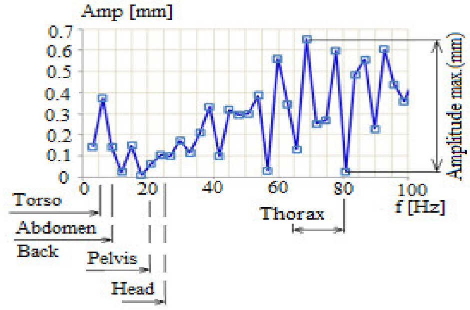


Fig. 5. Graph of frequency - amplitude of vibrations on passengers on the 4th row seats

4. CONCLUSION

The seat's mathematical model was analyzed based on the force of the road surface on the chassis and how it affects the human body through the seat. The comfort level was determined by assessing the weighted frequency of the human vibration acceleration.

To analyze the vibration frequency of human seats for each part of the body, the finite element method was used to build models and simulate them in the Harmonics environment of the Ansys Workbench software, in accordance with the international standard ISO 2631-1. 3-D modeling tools were used to create realistic load and boundary conditions, resulting in reliable analysis results.

The research findings allowed for the selection of an appropriate type of cushioning material and structure to minimize the force acting on the occupants in the design of bus seats.

REFERENCES

[1]. Engel Z. W., Kowalski P., "Investigation of the influence of simultaneous vibroacoustic exposures on the operator," *Journal of Theoretical and Applied Mechanics*, 46(4), 799-811, 2008.

[2]. Nader M., "Influence of mechanical vibrationsthe human body in the means of transport and its modeling," *Archiwum Transportu - Archives of Transport*, 2000.

[3]. R. Burdzik, L. Konieczny, *Vibration Issues in Passenger Car*. Silesian University of Technology, 2014.

[4]. W. Abbas, O. B. Abouelatta, M. El-Azab, M. Elsaidy, A. A. Megahed, "Vibration in car seat- occupant system: Overview and proposal of a novel simulation method," *Scientific Research,* 2, 710-719. *AIP Conference Proceedings,* 2080, 040003, 2019. https://doi.org/10.1063/1.5092921

[5]. ISO 2631-1:1997. Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements

[6]. Wei L., Lewis C. H., Griffin M.J., *Evaluating the Dynamic Performance of Seats Without Using Human Subjects.* ISVR Technical report No.286, 2000.

[7]. ISO 8608:1995 Mechanical Vibration - Road surface profiles - Reporting of Measured Data.

[8]. Nguyen Thanh Quang, "Finite Element Analysis in Automobile Chassis Design," *Applied Mechanics and Materials*, 889, 461-468, 2019. DOI: 10.4028/www.scientific.net/AMM.889.461.