Analysis of Train Passenger Comfort Related to the Vibration and Heat It Creates

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Abstract

Oftentimes train passengers feel discomfort due to sitting too long, especially on long-distance journeys. This discomfort can be caused by a hot buttock from rubbing against the chair and the vibration of the chair. The purpose of this paper is to determine the impact of seat vibration on the rate of heat change in the passenger's buttocks so that health risks can be properly avoided. The initial stage of this research is a literature study on vibration, ergonomics - human comfort, health, and simulation. Next step is to create 3D CAD models for train and passenger seats. Finite Element Analysis (FEA) simulation and mathematical calculations were employed to determine the relationship between chair vibration, buttock pressure, and heat generated. Based on the simulation test, it was found that the greater amplitude of vibration, the increase in heat gain and reduce the concentration of buttock pressure on the passenger seats of the train. It can be concluded that there is a strong relationship among vibration parameters, body weight, type of clothing material - train seats, and passenger comfort (feeling hot when sitting).

Keywords

FEA, train, vibration, CAD, human buttock comfortable.

1. Introduction

Train is a mass transportation mode that is very much needed by many countries, as consequence the level of passengers comfort needs to be increased all the time. Many factors can affect passenger comfort, including: quality of infrastructure, accessibility, smell, noise, vibration, and etc. Vibration can cause discomfort and disturbance such as disrupting activities and presenting risks to health (Nassiri, P, et al. 2012). Discomfort or disturbance can arise from vibrations that occur in all parts of the body, for example, the legs, stomach, chest, head or hands (Griffin, M. J. 1990). Low-frequency vertical vibrations (<0.5 Hz) can cause a motion sickness syndrome characterized by pallor, sweating, nausea and vomiting (Crocker, M. J. 2008). Frequencies below 1 Hz in the horizontal direction can still be adapted by human muscles, however when the frequency reaches 1-3 Hz it is difficult for the upper body to maintain the posture position. Whole body vibrations at a frequency of 2 Hz or more may cause discomfort or injury but will not trigger motion sickness. Sevencan, F. et al. (2014) and Portela, B. S., & Zannin, P. H. T. (2021) investigated overall body shaking among bus drivers and their results showed a close association between whole-body vibrations with sleeplessness and fatigue. The most frequently reported health effect of whole-body tremors is back pain (Neil J. M. 2005).

There has been a lot of research that has discussed vibrations on trains. Kim and Suh (2020) developed an anomaly detection application in city train vibration data using a deep learning approach. The results of his research provide a survey on anomaly detection and analyze experimental results using a deep learning approach. Kontoni and Farghaly (2020) use a 3D FEM model to study the vibrations caused by a train on a nearby high-rise building. The results investigated the most suitable technique for reducing the effects of vibrations through open trenches or trenches filled with geofoam. Furthermore, Zou, C., Wang, Y., & Tao, Z. (2020) investigated the relationship between railroad vibration and surrounding soil structures and types. Sundström, J., & Khan, S. (2008) reported that the results of their research showed a significant difference between tasks and posture conditions. Respondents reported greater difficulty reading and writing on a table at frequencies up to 5 Hz.

Based on the explanation above, it is very important to increase comfort due to vibration of train passengers and their environment. The direct and long-term health impacts of passengers need to be taken seriously. Vibration and the feeling of heat on the passenger's buttocks can be one of the factors that passengers feel uncomfortable when traveling long distances. Even according to various sources, sitting too long in an uncomfortable chair can cause various disturbances such as; aches, diabetes, and others. With the vibration in the chair being occupied, it is necessary to have a scientific study to determine its impact. Furthermore, the clothing material, the structure / size of the buttocks and the train seat also need to be known in an effort to provide the best recommendation

2. Research Material & Methodology

There are several key knowledge words to discuss the relationship between vibration and heat on the buttocks of train passengers and their effect on comfort / health. Some knowledge were required, includes: friction and heat, vibration theory, and Finite Element Analysis (FEA) simulation.

2.1 Frictions force and thermal energy

The coulomb's law of friction reported that force friction is proportional to normal force. The proportionality factor μ depends on the type of friction material and is called the coefficient of friction. If the friction force is given the symbol F_R, the coefficient of friction with μ, and the normal force with F_N, it can be written in the following formula:

$$F_R = \mu \, . \, F_N \tag{1}$$

Generally, friction is divided into two types of friction, namely static friction and dynamic friction (Meirovitch, L. 2001). Static friction occurs when there is no movement of materials relative to one another, whereas dynamic friction occurs on moving surfaces relative to one another. Surface roughness is described by the friction coefficient μ_S for static and μ_K for dynamic friction. Figures 1 a and b describe the occurrence of static and dynamic friction on the two objects with a certain roughness. Static friction occurs when a displacement force acts on the two objects, but the objects have not started to move relative to each other. The balance of the object depends on the maximum value of friction before the object moves. Dynamic friction occurs when objects move relative to other objects in contact. Dynamic friction will increase with the high value of the surface roughness of the object and the high pressure applied between the objects.

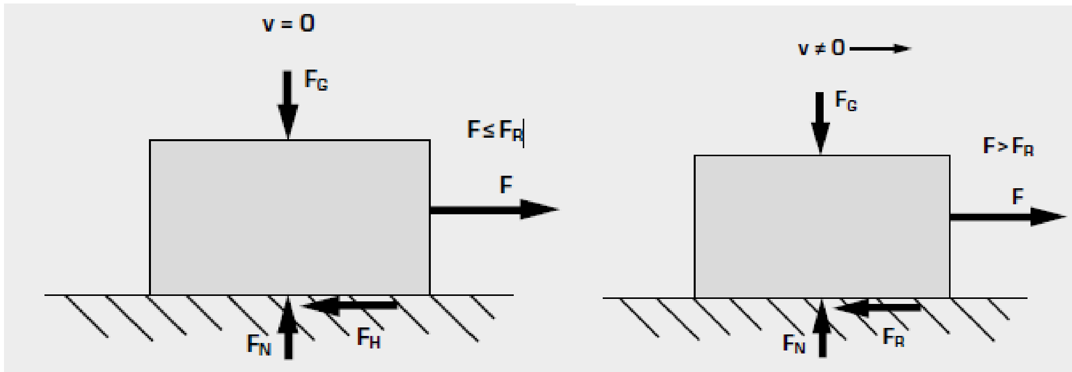

Figure 1. (a) Static friction of two objects, (b) dynamic friction of two objects with surface roughness μ.

Heat energy is the energy contained in a system which correlates with its temperature. Heat is a flow of thermal energy (E_T). The heat energy that arises in objects that rub together is proportional to the frictional force created multiplied by the displacement distance (d), or formulated as follows:

$$E_T = F_R \cdot d \quad (2)$$

The displacement distance (d) in a sinusoidal motion can be defined as in the following formula 3. The value of g is equal to 9.81 m/s^2.

$$d = \frac{g.a}{2\pi^2 f^2} \quad (3)$$

2.2 Vibration on the human body

Every vibration signal has three qualities: its displacement, speed and acceleration, which are closely related. Vibrations can occur in any direction due to the complex motion of simultaneously moving vertically, sideways, and forward/backward. In addition, rotational motion is also possible resulting in a total of six axes of motion (Neil J. M. 2005). Most of the exposure to full-body vibrations occurs in a sitting position when a person is driving or a passenger is in transportation. Because of this, most research into the perception of whole-body vibrations has used the subject in a sitting posture. This study can use two approaches: either to map the perceptual threshold with frequency or to map an intensity curve equal to frequency.

The comfort of a vehicle seat has two main aspects, namely static parameters and dynamic parameters. Some of the static parameters that are investigated in the literature include driver posture, contact pressure, and thermal properties (Parsons 2003). A chair with a poorly dynamic motion-damping design results in great discomfort. SEAT values inherently cover three important factors for a chair's dynamic performance namely: spectrum vibration, transmissibility, and frequency weighted human response. The SEAT value can be formulated as follows (Neil J. M. 2005):

$$SEAT\% = 100\ x\ \frac{VDV_{seat}}{VDV_{floor}} \quad (4)$$

Vibration dose is a parameter that combines the magnitude of the vibration and the time of occurrence. VDV ($m/s^{1.75}$) can be specifically formulated as follows:

$$VDV = \int_0^T (a^4(t)dt)^{1/4} \quad (5)$$

Where a (t) is the acceleration (m/s^2) and T is the total measurement time (s). The SEAT value of 100% indicates that the dynamic nature of the seat has not increased or reduced the driving comfort of the seat; SEAT values greater than 100% indicate that a ride is worse on a chair than on the floor, and a SEAT value of less than 100% indicates that the chair's dynamic properties have been effective at reducing vibration. The European Union has set limits for the exposure of whole body vibration (WBV) following the ISO 2631-1 standard. VDV of 8.5 $m/s^{1.75}$ with a (8) = 0.5

m/s^2 is a sign that needs special attention, while the allowable threshold is with VDV of 17 $m/s^{1.75}$and a (8) = 0.9 m/s^2 (Neil JM, 2005) .

2.3 Research Methodology

The purpose of this paper is to determine the relationship between friction due to vibration and heat generated when passengers sit on a train bench. Friction acts on three different objects, namely the surface of the seat, clothing, and the outer skin on the passenger's buttocks. The experimental design was carried out by involving the material factors of passenger pants from cotton and polyester, body weight (3 levels: 50 Kg, 70 Kg, 90 Kg), and vibration which refers to the results of research by Suwandi at al. (2009) and Chak Y.T. et al. (2010). The muscle portion of the buttocks-thigh model is modeled using a non-linear isotropic visco-hyperelastic material model to describe human soft tissue. The soft tissue density of human buttocks is 1000 kg / m3 (E. Pennestrì et al. 2005). Experimental design testing was carried out with a Finite Element Analysis (FEA) simulation.

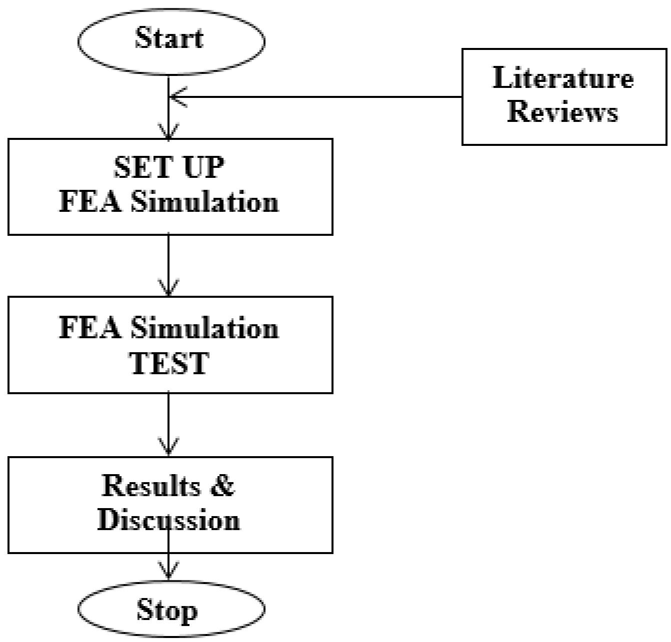

Figure 2. Flowchart of heat measurement due to friction during vibration on train passengers.

Figure 2 describes the sequence of work which includes literature study, simulation set-up, analysis and discussion. The 3D CAD model is used to determine the contact pair between the buttocks-thigh model and the cushion. In the simulation, it is assumed that the human is sitting on a cushion and then vertical - horizontal vibrations are applied to the bottom of the cushion. Surface-to-surface contact with a friction coefficient of 0.5 (M. Grujicic et al. 2009). External force is applied to the CAD simulation model due to human weight. Upper Human weight in sitting condition was calculated based on 55.1% of the total human body weight (Shen W. et al. 1999). The Mooney – Rivlin hyperelastic model was selected for muscles comportment (Bui, H.T. et al, 2018). Young modulus for human muscle is 10,000 Pa (International Commission on Radiological Protection 2018). The constitutive relation of seat cushion foam was selected to model is the hyper-elastic material (Thong Bui et al. 2020). Train seats in this simulation refer to Polyurethane (PU) foam material with a young modulus = 11 Mpa (Alzoubi M. Et al. 2014), density = 1600 Kg/m^3, yield strength = 4.5 Mpa.

3. Results and Disussion

Based on the explanation in the research methodology, it is necessary to carry out a static FEA simulation to determine the pattern of pressure on the buttocks and clothes worn on the train seats. This FEA simulation provides an overview of the contact area of the buttocks in various variations of weight and train clothing materials as shown in Figure 3. The area of contact does not affect the magnitude of the friction force, but will affect the distance that the passenger is shifting the buttocks. The change in distance will affect the heat generated. Figure 3b is the FEA simulation result on train passengers wearing cotton clothes with a body of 50 Kg (upper body weight = 27.55 Kg = 270 N). In the same way, simulations were also carried out for body weight of 70 kg (= 378.4 N), and body weight of 90 kg (= 486.5 N).

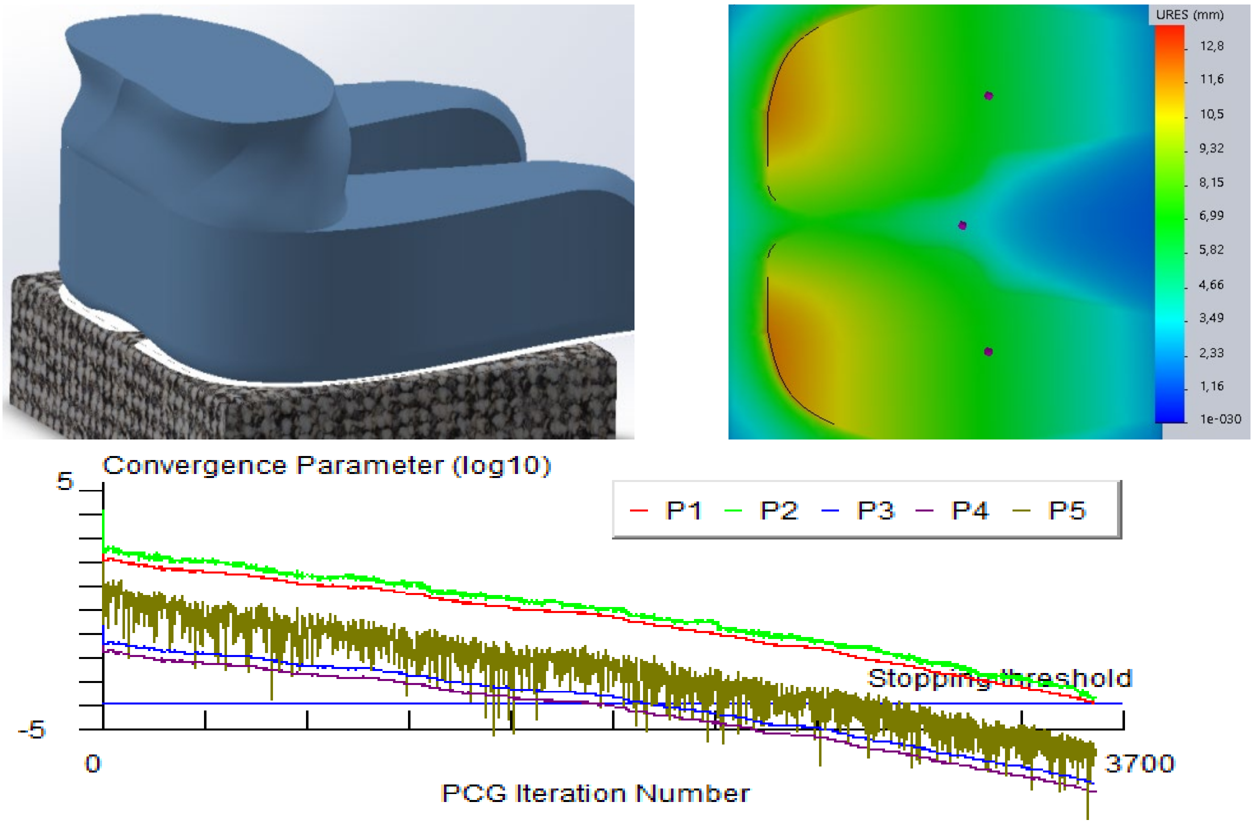

Figure 3. (a) CAD simulation model. (b) The simulation results of the contact between the passenger's 50 Kg buttock and the train seat.

The buttocks of train passengers in addition to getting compressed contact with the seat due to body weight, will also get frictional forces due to vibrations of the movement of the train carriages. Vibration results from changes or variations in the position of the center of gravity (cog) of the train carriage. These vibrations will be transmitted to the floor of the train, seats, and will eventually create vibrations in the X, Y, Z direction of the human body. Based on the measurements made by Suwandi in his research on the vibration analysis of Indonesian trains on the Bandung - Cicalengka route, a table of train vibrations (frequency, longitudinal and transverse acceleration) was obtained. For the measurement of heat arising from vibrations, the heat generated is dominated by longitudinal friction between the passenger pants and the seat of the train. Table 1 describes the frequency data and longitudinal train vibration acceleration data measured on the train floor using an accelerometer type B&K 4370. Based on this data and using formula 3, it can be calculated the magnitude of the displacement due to the vibration that occurs. For example, the first measurement with a vibration frequency value of 0.40 Hz and longitudinal acceleration will produce a longitudinal displacement (horizontal direction) value of 1,448 m.

Table 1. Vibration diplacement based on frequency and acceleration for passanger with 50 Kg Weight (sources: Suwandi et al. 2009) (cont.)

No	Frequency f (Hz)	Longitudinal Acceleration a_Z (m/s^2)	Constant G (m/s^2)	Longitudinal Displacement D_L (m)
1	0,40	0,467	9,81	1,448
2	0,50	0,833	9,81	1,655
3	0,63	1,210	9,81	1,514
-	-	-	-	-
-	-	-	-	-
46	50,00	32,000	9,81	0,006
47	63,00	36,667	9,81	0,005
48	80,00	42,667	9,81	0,003

Based on formula 2 and the results of the longitudinal displacement calculation in table 1, it can be explained that the heat generated by the friction between the train seats and the buttock of the passengers can be calculated. Friction testing is carried out on two different types of clothing materials, namely cotton and polyester. The fabric frictional coefficient was measured as per ASTM D1894 standard using a computer aided friction tester (Rathina M. 2015). Cotton consists of cellulose (94%), protein (1.3%), pectin substance (1.2%), and wax (0.6%) (Lee, J. T., et al., 2010). The coefficient of kinematic friction of cotton on cotton is 0.4 and polyester on polyester is around 0.3 (Mahmoud M. and Ibrahim A. A 2016). The heat generated for 1st measurement of 50 kg passenger weight and wearing material cotton is 156.8 Nm or 37.38 cal, for polyester is 28.03 cal. From 48 measurements with a body weight of 50 kg and wearing cotton cloth, the highest heat value was 678.12 cal in the movement time of 1.25 seconds, the lowest was 0.07 cal in the movement time of 0.006 seconds, and the average = 32.67 cal with the movement time of 0.032 seconds. By using the average value of heat energy during sitting due to vibration, if a person travels by train for 5 hours, it will produce heat on the clothes on the buttocks of 18. 377 kcal. The value is high enough that it can cause fatigue and possibly other diseases.

Fatigue in passengers can occur due to the conversion of the body's kinetic energy in the buttocks in contact with the seat surface. The vibrations from the train are transmitted to the passenger's body through the seats. As a form of mechanical energy, vibrations can generate heat. In addition, the heat in the seat also occurs due to body heat being transferred to the seat. This transfer of heat energy causes the chair to warm up after sitting on it. However, with vibrations, more heat is transferred from the body to the chair because mechanical vibrations increase the kinetic energy obtained from the human body (Pathan 2021). Therefore, passenger fatigue can be caused by draining the body's energy while sitting on the train.

This research is preliminary research to determine the impact of variations in the center of gravity on a train during a trip that causes vibrations that result in passenger comfort levels. This research needs to be refined by making direct measurements of changes in heat generated through heat sensors or thermal photos, the need to test how many vibrations on the train floor are transmitted to vibrations on the seat base, and vibrations in the passenger body. Formulations 4 and 5 in the future will be used to measure the level of effectiveness of the chair in reducing vibrations. Chair design, posture when sitting, seat materials, and mechanization of the seats will be further studies in improving the health and comfort of train passengers.

4. Conclusion

Researchers have succeeded in showing a strong relationship among vibrations on a train, changes in motion energy to heat energy, and its relation to passenger health and safety. The Finite Element Analysis simulation is useful for describing the contact relationships between seats, clothes, and the passenger's body. The area that is formed due to pressure while sitting is not related to the friction force, but will affect the value of the displacement of the passenger's body (buttocks) which also results in the amount of heat generated. Further studies are needed to be related to the impact of body weight, displacement, and heat it causes.

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