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POWER SPECTRUM DENSITY (PSD) ANALYSIS OF AUTOMOTIVE PEDAL-PAD

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Abstract

Vibration at the pedal-pad may contribute to discomfort of foot plantar fascia during driving. This is due to transmission of vibration to the mount, chassis, pedal, and then to the foot plantar fascia. This experimental study is conducted to determine the estimation of peak value using the power spectral density of the vertical vibration input at the foot. The power spectral density value is calculated based on the frequency range between 13 Hz to 18 Hz. This experiment was conducted using 12 subjects testing on three size of pedal-pads; small, medium and large. The result shows that peak value occurs at resonance frequency of 15 Hz. The PSD values at that resonance frequency are 0.251 $(m/s^2)^2/Hz$ for small pedal-pad, followed by the medium pedal-pad is at 0.387 $(m/s^2)^2/Hz$ and lastly for the large pedal-pad is at 0.483 $(m/s^2)^2/Hz$. The results indicate that during driving, the foot vibration when interact with the large pedal-pad contributed higher stimulus compared with the small and medium pedal-pad. The pedal-pad size plays an important role in the pedal element designs in terms of vibration-transfer from pedal-pads on the feet, particularly to provide comfort to the driver while driving.

Keywords: Foot-transmitted Vibration, Pedal-pad, Power Spectral Density.

1. Introduction

Drivers use their right foot to control the deflection of the accelerator pedal, which in turn controls the longitudinal dynamic of the car. Normally, to operate and handle accelerator pedals, the heel rests on the floor of the car and the foot plantar fascia is in contact with the accelerator pedal-pad [1]. An accelerator pedal is a device which is used in many types of vehicles that allows an operator to control engine power, remotely. Generally, it is paired with a brake pedal and sometimes a clutch, enabling a driver to control the speed of the vehicle almost exclusively with his feet. An accelerator pedal is typically connected directly to a throttle either by using cables or, electronically to a computer that could mechanically adjust the throttle based on pedal input.

Vibration occurs in the car when the car engine is turned on and then transmitted to the mounting, chassis, car-body parts (e.g. pedal) and human body (e.g. foot) [2, 3, 4]. Vibration increases when the vehicle is in a dynamic situation. This is caused by uneven road surfaces and change of vehicle velocity [5]. Vibration causes discomfort to the driver and passengers, but more so for the driver who operates and controls the vehicle. When there is vibration in the driver's compartment area, the driver may be distracted and lose focus while driving a vehicle.

When discussing the vibration that a driver or passenger experiences in his vehicle, it is important to consider the vehicle and human as a coupled dynamic system [5]. In addition, there are usually a number of possible sources of vibration that can reduce the perceived comfort of the occupants. Two possible vibration sources are the road input at the tyre contact patches as well as the induced vibration from the power-train and ancillaries [6]. The vibration from these sources is filtered by the structural dynamic transmission paths from the points of excitation to the pedal-pad, which are usually attached to the car-body or side of the engine room of the vehicle. According to Giacomin et al. [6], the resultant vibration may be amplified in some frequency regions and attenuated in others, depending on structural resonance occurring in the transmission path. As a pedal-pad is constructed in different sizes, it also results in additional modification of the vibration. In addition, since the lower extremities can be modelled as a mechanical system consisting of masses connected by spring and dampers, the resultant transmissibility will also depend on the foot plantar fascia which is in contact with the accelerator pedal-pad – in particular, the size of the pedal-pad surface. Finally, the human sensitivity to vibrations is a function of both frequency and direction [7]. This should be taken into account when evaluating the measurement vibration levels to determine perceived human comfort.

Vibration of foot plantar fascia may contribute to discomfort, annoyance, or interference with a driver’s activities, with the sensations varying in strength according to the vibration magnitude, the vibration frequency, the direction of vibration, and the contact conditions with the vibration surface [7, 8]. Usually studies conducted by researchers on vibration transmissibility focus on vibration measurement objectives at vertical axis [9, 10]. According to Parsons et al. [11], vertical vibration is more effective on the feet compared to horizontal vibration. Morioka and Griffin [7] mentioned in their article that at frequencies less than 50 Hz, the foot is most sensitive to vertical vibration. According to the ISO 2631-1:1997 standard [12], a frequency range of 0.5 Hz to 80 Hz is considered ideal for the perceived health and comfort of a person’s back and feet while seated.

Since there is a lack of studies on foot-transmitted vibration from pedal acceleration, it is worthwhile to conduct a study on this issue. At Present most car manufacture it not considered pedal-pad size when they produce a car. More over researcher found that different manufacture produce with various size of pedal-pad. The researcher assumed that size of pedal-pad may influence vibration transmitted to driver's plantar facial during interact with pedal-pad. Therefore, the objective of this research is to determine foot-transmitted vibration from three different sizes pedal-pad with used the power spectral density (PSD) analysis method.

2. Experimental Procedure

2.1. Apparatus

The vehicle used in this experiment is a popular Malaysian-made compact car, with a three-cylinder DOHC engine and 989cc capacity. The vibration measurement signal is conducted at the foot during controlling and handling accelerator pedal. In this experiment, three different pedal-pad sizes made from steel plate grade SS400 are used, as shown in Fig. 1.

A small pedal-pad refers to actual pedal-pad size, which is currently used in one of the national cars (8 cm in length and 3.5 cm in width). The other two pedal-pad sizes increase by 2 cm in length and 1.5 cm in width (medium pedal-pad size is 10 cm x 5 cm and large pedal-pad size is 12 cm x 6.5 cm), as shown in Fig. 1. The Pulse front-end frame model 3560 C with controller module type 7536 and 6-channel input module type 3039 by Bruel & Kjaer, is used as a measurement tool. The Pulse front-end will be linked to a Compaq laptop by Ethernet connection. The Pulse Labshop version 14.0 software is used to analyse the data. Vibration is measured using a lightweight piezoelectric accelerometer.

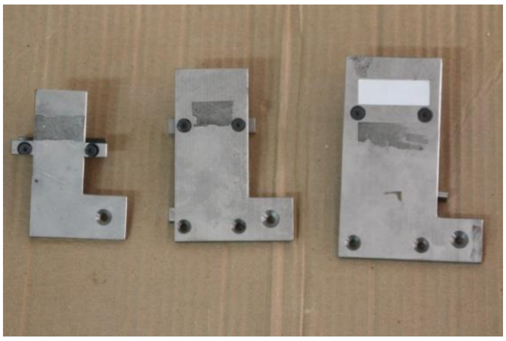

Fig. 1. Three different sizes of pedal-pads

2.2. Procedures

Six male and six female participated in this study. In this study, the respondents are selected based on criteria's; years experienced in driving - more than five years and must hold valid Malaysian driving license. The experiment is conducted within the Putrajaya area. Two subjects are involved in the experiment. One of the subjects drives the car while the other subject collects the data using the computer.

To measure the vibration, a single-axis accelerometer is placed on the foot. A single-axis accelerometer measures vibration in Z-axis. The method of fixing equipment and accelerometer on the foot is illustrated in Fig. 2. The accelerometer mounting is a clean, flat surface with proper torque or adhesives which are crucial for proper vibration monitoring. Improper mounting of an accelerometer onto the test structure can lead to both erroneous data and permanent damage to the accelerometer [13].

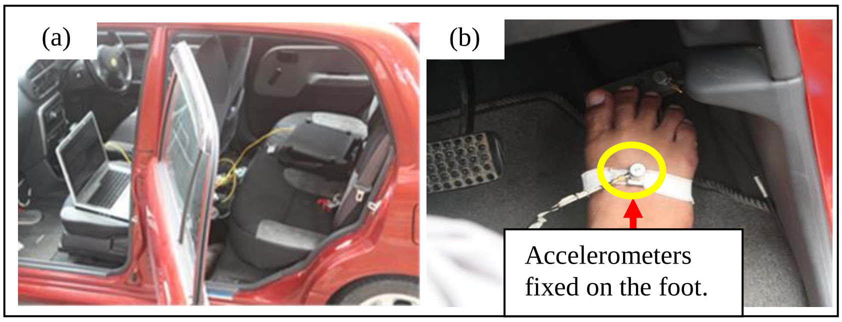

Fig. 2. The method of affixing the (a) equipment and (b) accelerometer on the foot

The effective vibration analysis begins with acquiring accurate time-varying signals from accelerometer. The raw analog signal was processed by Pulse Labshop version 14.0 software. In order to obtain the work-flow and data, the researcher has to setup Pulse Labshop template which consists of four important windows, comprising of; configuration organizer, measurement organizer, function organizer, and display organizer. The time domain for signal-recording period was 32 second (512 samples per-second), delta time is 0.001953 second and number of samples collected (N) is 16384 samples. For frequency domain are delta frequency 0.03125 Hz, in sampling frequency range 0.03125 Hz to 200 Hz, and number of samples is 6401 samples.

3. Result and Discussion

The purpose of this experiment is to determine response or vibration stimulus at the foot during plantar facial interacts with pedal-pad in vertical vibration magnitude by using power spectral density analysis method. Power spectral density data in unit $(m/s^2)^2/Hz$ are used in this analysis. Comparative study also conducted with the three different sizes of pedal-pad. Fig. 3 shows the results obtained between the frequencies ranges of 0.5 Hz to 80 Hz for the three different sizes of pedal-pad.

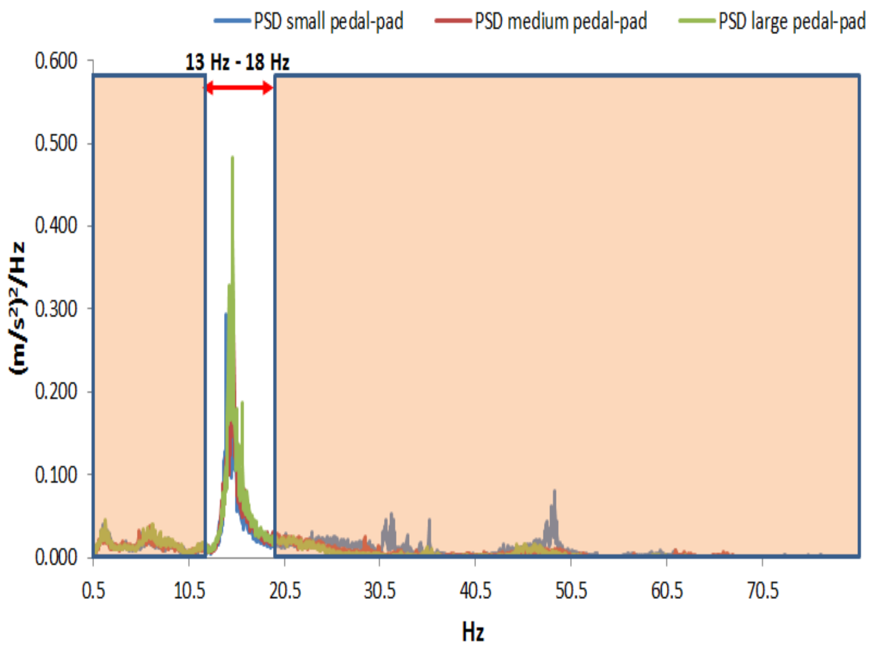

Fig. 3. PSD between the frequency ranges of 0.5 Hz to 80 Hz for the three different sizes of pedal-pad

The result indicates that the value of the power spectrum density shows an active response to foot vibration during interaction with pedal-pad which are between frequency range 13 Hz to 18 Hz. Based on this result, the three different sizes of pedal-pad also found that there are located in the same frequency range. Thus, this article only focused on the between frequency range 13 Hz to 18 Hz to make a comparison on foot vibration during interacting with the three different sizes of pedal-pad. Fig. 4, shows the results for the three different sizes of pedal-pad for between frequency range 13 Hz to 18 Hz.

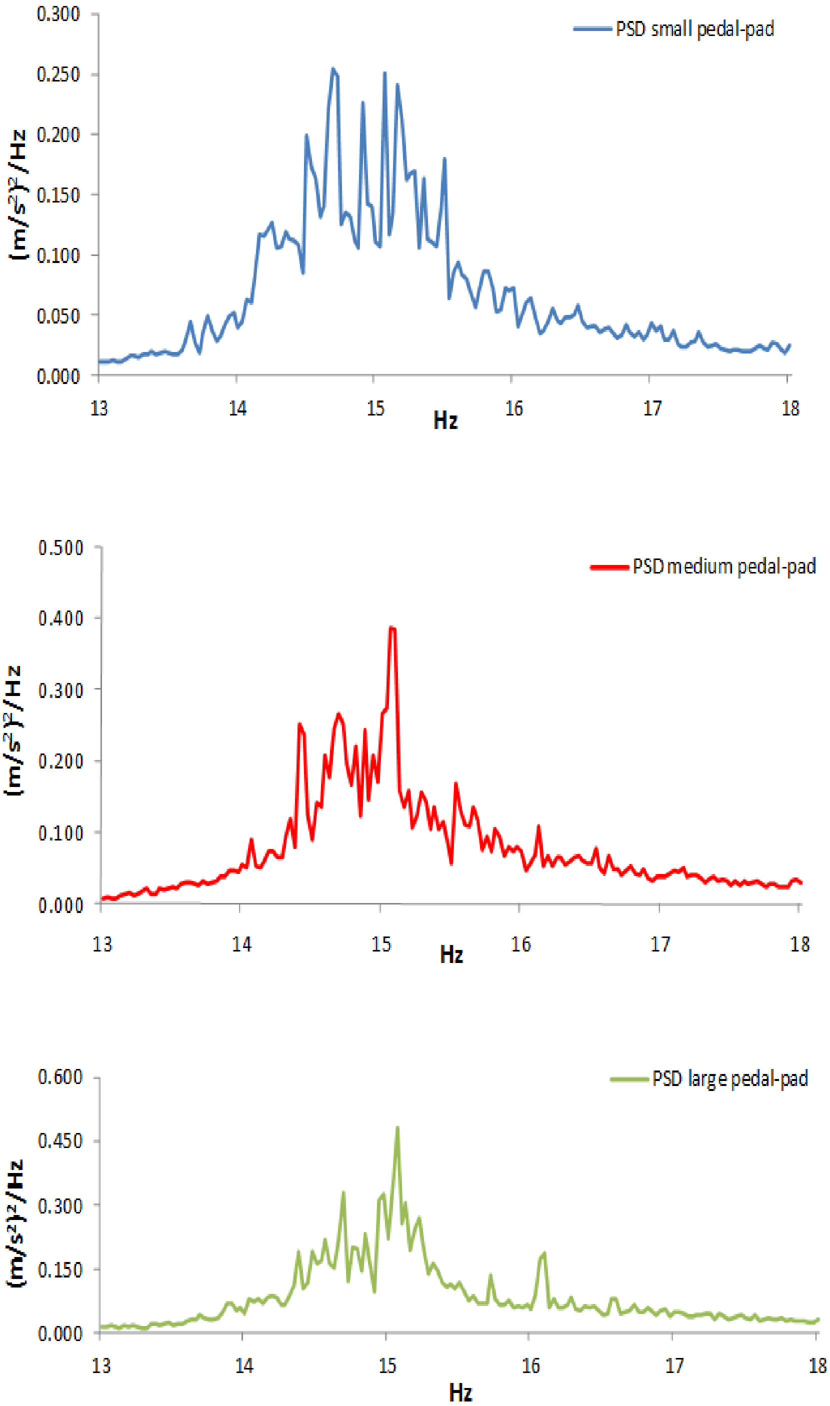

Fig. 4. PSD between the frequency range of 13 Hz to 18 Hz for (a) Small size pedal-pad, (b) Medium size pedal-pad, and (c) Large size pedal-pad

The results obtained from the foot vibration for the three different sizes of pedal-pad for the between frequency range 13 Hz to 18 Hz shows that the peak value occurs in resonance frequency 15 Hz. Fig. 5 shows the result of peak value at resonance frequency 15 Hz for the three different sizes of pedal-pad.

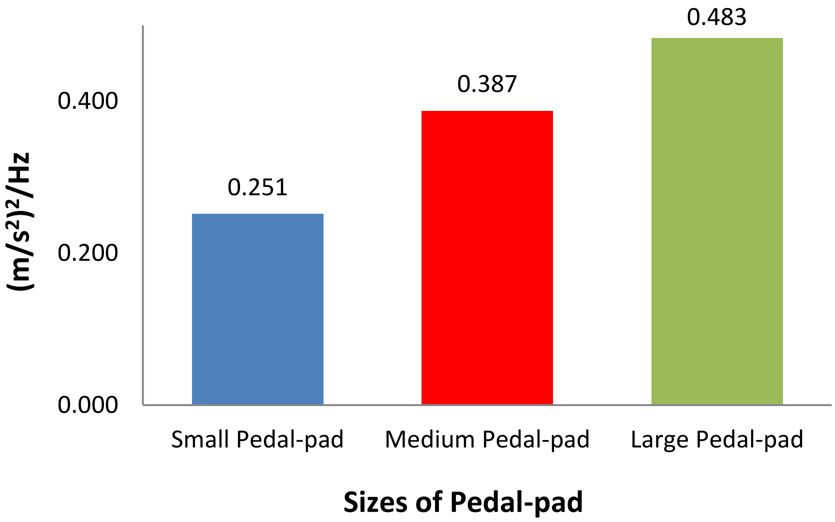

Fig. 5. Peak value at resonance frequency 15 Hz for the three different sizes of pedal-pad

Figure 5 illustrates that the highest peak value is 0.483 $(m/s^2)^2/Hz$ for large pedal-pad and the lowest peak value is 0.251 $(m/s^2)^2/Hz$ contributed by small pedal-pad. Based on these results, it can be concluded that the foot vibration during contacted with large size pedal-pad contributed highest response or stimulus compared with the medium and small size pedal-pad. On the other hand, small size pedal-pad contributed less response or stimulus to foot vibration.

4. Conclusion

From the study and the results obtained from vibration transferred pedal-pad to the foot, it can be concluded that, pedal-pad size plays an important role in the pedal element designs in terms of vibration-transfer from pedal-pads on the feet, particularly to provide comfort to the driver while driving. It’s proven that the large size pedal-pad contributed strongest vibration transferred compared to the small and medium size of pedal-pad.

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