International Journal of Engineering & Technology, 7 (4.38) (2018) 1624-1626

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Association Between Vehicle Seat Dynamics and Ride Comfort Criteria

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Abstract

The upfront prediction of subjective ride comfort involves the investigation of vehicle seat structural dynamics coupled with the human body. It has been numerously stated in prior researches that a limit of less than 100Hz, which is the external vibration's normal description for human sensitivity, would be the output for basic seat resonance. Based on our findings, there are three particular mode shapes which had been indicated to be less than 80Hz. The seat shapes were fore/aft, twisting and lateral shapes. Despite many have proven that ride comfort requirements are quite subjective in nature, researchers are still in ongoing process of developing human vibration standards. For that purpose, they would always evaluate their seats, which were mostly rigid, to acknowledge and ascertain that their seat production process needs to be carried out from time to time. For this study, 17 samples have voluntarily participated, and they have been arranged in pairs to compare these individuals. Inquiries about different resonating ride segments and non-resonating ride segments have been made for the samples to answer. The objective of this action is to ensure that constant values of frequency weighted R. M. S. vibration remain at the same level. As such, the current experimental technique employed would technically require a range of modifications and review at some point – mainly concerning the seat's structural dynamics, where the designs and positions of the experimental technique's structure is of particular concern. The main target of this research would be to contribute significantly to the domain of ride comfort and body vibration, in which researchers would produce quantitative outputs that can be referred to and utilized in the future as an improvisation for the existing test standards.

Keywords: *Ride comfort, structural dynamics, human vibration*

1. Introduction

For years and still at present, ride comfort of passengers has always been critically discussed, assessed, and researched regardless of the types of transportation (Nahvi, Fouladi, Jailani, & Nor, 2009; Park & Min, 2013). With health, comfort and safety being three of the most significantly discussed for determining the criteria for ride comfort, this naturally subjective quality would be connected with many objective causes or factors, for instance contour of seat cushion, transmissibility of vibration, etc. (Dempsey, Leatherwood, & Clevenson, 1979; Griffin, 1990). Hence, authorities and governing agencies worldwide have produced a range of international standards to clearly outline vibration-related risks in human health and also their individual behaviours – this has been systematically defined (A. Standard, 2001; I. Standard, 1997). With the lack of seat system's structural dynamics done previously, researchers have decided to focus on (1) the actual dynamic process of human bodies altering the seat system's features and (2) improving ride comfort with various mode shapes and resonances (Maeda, Mansfield, & Shibata, 2008). It is commonly known that resonance, modal properties and mode shapes' structural movements of seat structures vary according to their respective frequencies. Typically, the frequencies of previous automotive seat testing fall below 100Hz because of the exposure to various excitation sources like a variety of road surfaces and different powertrain. This consequently makes the vibration of the seat to rise whenever the respective frequencies of both input vibration and seat structure resonant overlap. As automotive seat structures are mainly exposed to vibration below 100Hz from excitation sources such as the vehicle powertrain and the road surface, there will be an increase in seat vibration when the frequencies of the input vibration coincide with the seat structure resonant frequencies. However, researchers have already expected a certain perception of inaccuracy for this study's testing procedure and ride comfort criteria because rigid seats were used as primary reference and setup for the development of the existing ride comfort standards.

2. Methodology

2.1. Human Participants

17 male undergraduates voluntarily participated as samples – listed below is their summary of demographic info:

- None has any history or currently suffering from back pain and/or health problems
- the mean of age is 23 years
- the mean of height is 168.2cm
- the mean of weight is 69.3 kg
- hence, the mean of BMI is 22.6 kg/m^2 (SD is 2.54)

All students involved have unanimously agreed and signed the informed consent agreements after they have been completely briefed about the objectives of this research.

2.1. Experimental Design

A paired-comparison test was chosen as the method to evaluate the extent of the seat's structural dynamics influence on the ride comfort. An actual car seat was mounted to the vibration table. In this experiment, the excitation force was generated from the MTS-Hydraulic actuator in a multi-axial direction to the vibration table. Both seat pan and seat back were attached with accelerometer pad to evaluate the rate of vibration that has been transferred on the samples' bodies. The pad was labelled with X, Y, and Z as three different axis and it was connected to the vibration analyzer. The weighting and multiplication factor was configured according to the ISO 2631-1 (I. Standard, 1997). As for the seatback angle, the seat was inclined backward from the vertical direction at 15^{o}. Actual measurement was carried out according to the ISO 2631-1 International Standard. The sitting posture for comfort test setup was shown in Figure 1. Figure 1 shows sitting posture of a volunteer during the test sequence.

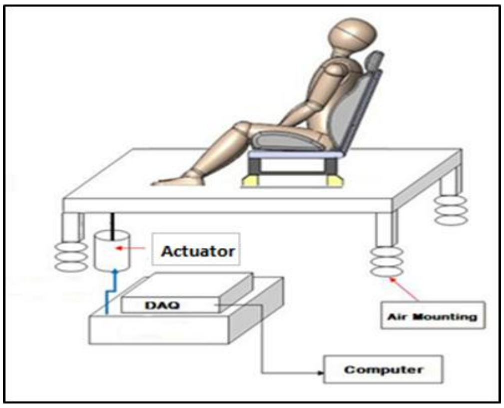

Figure 1: Figure shows sitting posture of a volunteer during the test sequence.

2.2. Experimental Procedures

In the experiment, a specifically-tailored survey on ride comfort was given to be answered by the students who have been instructed to sit and confirm their most relaxed point and form. With their hands on the lap, their back on the seatback and the footrest supporting their feet (to avoid vibration), they were then guided to concentrate on a red cross which has been designed to be at parallel level with their eyes. The main content of the survey was about comparing various ride segments; these have been done by exciting the seat at different frequencies (twisting resonant, respective lateral, and fore-aft). For the frequency bands, a total of two non-resonance and 3 resonance frequencies had been utilized.

With that, it can now be ascertained that only their torso and also their body's lower part would have experienced vibration. In total, every student experienced seven ride sequences and every sequence had two ride segments where they needed to score – standard ride and test ride. In this experiment, standard ride has been chosen to be the reference ride, thus researchers had indicated its fixed value at 100. Standard ride was presented prior to the test ride – this process was repeated twice. The value of total vibration which had been transmitted to the students was maintained to be 0.2 m/s^2. The time duration for every segment was half a minute and the rest that occurred between every segment was 10 seconds. The students would then score the test ride segment to be compared with standard ride segment after they finished the twin cycle of process. The range of the score is from 1 to 200; 200 here indicate double the amount of discomfort experienced compared to 100, which was the fixed value of standard ride. Hence, lower-than-100 values mean lower discomfort levels. Table 1 shows the test sequence for different ride segments.

3. Results

The obtained result of the subjective response from the 17 volunteers on non-resonance 1, non-resonance 2, lateral, fore-aft and twisting mode shapes were analyzed presented in Figure 2. The figure shows the average score given by the volunteers for different ride segments in paired- comparison test. The red line with the value of 100 represents benchmark score for the ride segments according to the ISO 2631-1 (I. Standard, 1997). When the value of total vibration was maintained at 0.2 m/s^2, the scores were expected to be ideally close to 100. From Figure 2, it was observed that in sequence 1,2,3,5 and 6, the average scores given by the volunteers were nearing 100; this confirmed the fact that the students had almost similar levels of comfort felt during the experiments. The significant amount of discomfort perceived by volunteers were in sequence 4 and 7 where twisting mode has higher discomfort level rated by volunteers. Based on the scores analysed, it can be interpreted as twisting resonant segment was the most uncomfortable compared to respective lateral and fore-aft segments. The values have been further verified with paired-sample T-tests by producing every test sequence's P-value. P-values from Table 2 suggested fluctuation from 100 recorded from test sequences 1-6 was not significant. There was also a possibility of chance ($P > 0.01$), which also reflects insignificant output for the subjective score differences. These outputs had been deemed to be insufficient to factually indicate if there is a significant contrasting value between standard ride and test ride segments – aside from test sequence 4 and test sequence 7. They actually yielded $P < 0.01$, which clearly pinpoint a significant difference between the two rides. From this notion, researchers would like to clarify that the previous discomfort statement regarding twisting mode for test sequences 4 and 7 was not because of chance; it was rather suggesting twisting mode would cause adverse effects following the variables and test methods in the experiments. Another contributing factor would be inadequate measurements recorded by the accelerometer pad, most probably because of the positions of the pad on the students' bodies.

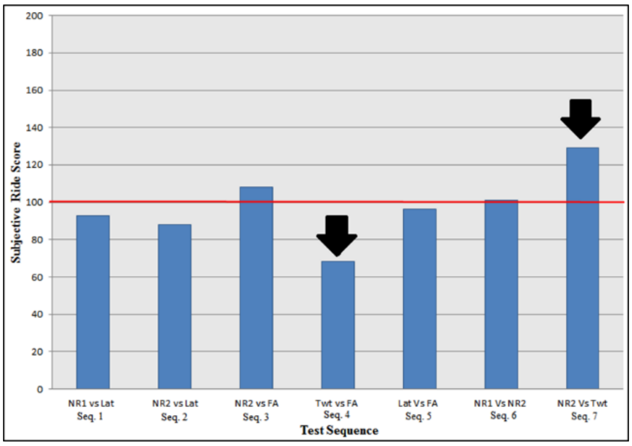

Figure 2: Averaged subjective scores of each test sequence – This figure shows the average scores given by the volunteers for each test segment. It shows the twisting ride segment is significantly more uncomfortable

Table 1: The ride sequence for the test.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Standard Ride Segment	Non-resonance 1	Non-resonance 2	Non-resonance 2	Twisting resonance C	Lateral-resonance A	Non-resonance 1	Non-resonance2 **Vs.**

Test Ride Segment	Vs. Lateral Resonance A	Vs. Lateral Resonance A	Vs. Fore-aft Resonance B	Vs. Fore-aft Resonance B	Vs. Fore-aft Resonance B	Vs. Non-Resonance 2	Twisting Resonance C

Table 2: P-Value for different ride segments

Sequence	Ride Segments	*P*- Value
1	Non-Resonance 1 vs. lateral	0.188
2	Non-Resonance 2 vs. lateral	0.036
3	Non-Resonance 2 vs. Fore-aft	0.110
4	Twisting vs. Fore-aft	0.001^{***}
5	Lateral vs. Fore-aft	0.529
6	Non-Resonance 1 vs. Non-Resonance 2	0.826
7	Non-Resonance 2 vs. Twisting	0.001^{***}

4. Conclusion

The present study concluded the notion of human discomfort can be specifically measured and its levels can be directly affected by dynamic features of a seat's design and structure – both physical experiment and written survey were effective in achieving this objective. The analysis of the experiment clearly put twisting mode ride segment at the top in terms of discomfort levels experienced by the students and the maintained value of vibration magnitude (complied with ISO 2631-1) showed no effects in preventing that (I. Standard, 1997). It is now recommended for seat manufacturers and researchers to review or improvise the existing technique of measuring ride comfort related to seat dynamics. This would significantly assist in generalizing the prediction of the best ride comfort that is suitable and flexible for every feature in seat dynamics.

Acknowledgements

The researchers would like to express their gratitude to Universiti Kuala Lumpur for providing the financial support to complete this study.

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