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Analysis of Passenger Ride Comfort

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Abstract. In this study, the effect of vehicle vibrations on human beings is investigated. The computations were made with the help of a simulation program using a full vehicle model with driver and the results were evaluated using international ISO 2631 standard. The physical model of the investigated system is formed by a full-vehicle model and a driver. The road roughness is used as an input to the system and the responses are compared with the related standard. Finally, the results are discussed.

1 Introduction

By the widespread use of vehicles in all over the world, the effects of vibrations on human beings during the ride of vehicles has been taken into account. In daily life, most people are exposed to vibrations that affect the human beings' health. Many researchers revealed those vibrations may cause the loss of performance on working people [1], [7]. Even more, there are some standards on this issue (ISO 2631, BS 6841 etc.). Vibrations during the ride of vehicle are originated from the road roughness and the rotating components which include the tire assemblies, the driveline and the engine. To prevent these ride vibrations, the suspensions for vehicles have been developed [4], [6]. Active and passive control systems of different designs for different vehicles exist. Furthermore, with the use of developed control technology with suspensions as a result of studies on active suspension systems are also available [4]. To prevent these vibrations, new seat designs are investigated [14]. The present study was conducted to understand the effects of road roughness as a ride vibration which has a stimulating effect on the driver. For this purpose, the physical model of the investigated system is formed by combining a full-vehicle model and a human model used in the literature. There are many studies in which used human body like a dynamic system, can be found [8], [15]. The human body used in this study is taken from these studies [8]. The road roughness is entered as an input to the established system. The road roughness is created with the help of one of the road indexes [10]. The vibrations that affect human body are investigated. The numerical solution has been evaluated using the response of the driver. The comfort of the human modeled are compared with the ISO 2631 standard data.

2 The vehicle-driver system

The physical model of the investigated system is formed by a full vehicle model and a human model by considering the human body as a dynamic system as well. Road roughness is used as an excitation source.

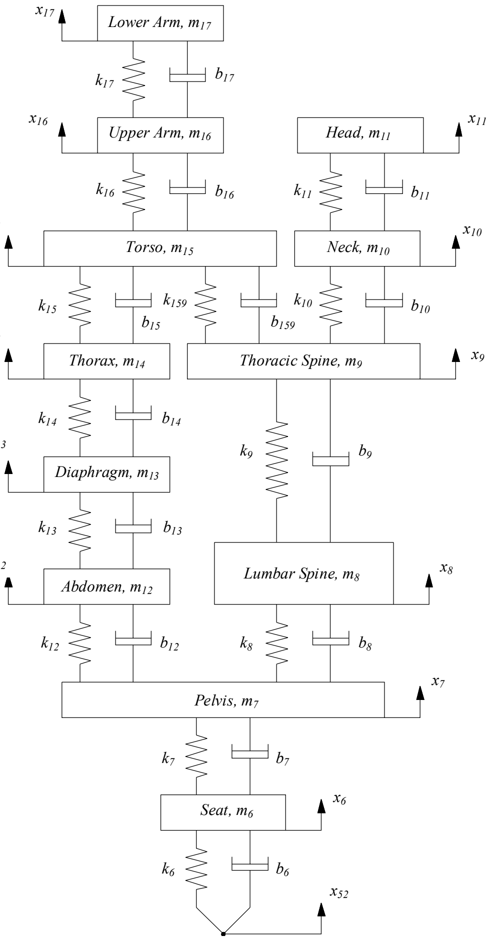

Fig. 1. The Driver Model [2]

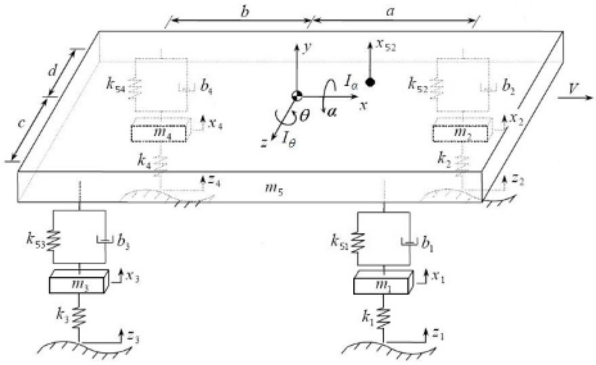

Fig. 2. The Vehicle Model

2.1 Human Model

There are lots of available models for modeling human body as a dynamic system. Liang, Chiang, 2006, conducted a study about some related models with the system parameters [8]. 11 dof human dynamic model used in this study is shown in Figure 1.

2.2 Vehicle Model

In this study, the human model is brought together with a full vehicle. The full vehicle model used in this study is shown in Figure 2. The body and wheel masses of the vehicle are assumed to be rigid bodies. The model has seven degrees of freedom. These are body bounce, roll, pitch and vertical motion of each of the four wheels.

2.3 Road Roughness

Studies have provided the opportunity to use the road roughness based on the quality of road. There are some standardized indexes about the quality of different roads [10]. One of the most important of these is the IRI (International Roughness Index). In this index road profiles are created by combining the random and harmonic vibrations. Road roughness can be expressed as follows;

$$H(l) = (1-q)\cdot H_0(l) + q\cdot H_1(l) \qquad (1)$$

IRI is defined as accumulated suspension stroke (mm) in a reference passenger car divided by travelled distance (m).

$$G_{H_0}(\Omega) = C\cdot\Omega^{-w} \qquad (2)$$

$$IRI = a\cdot\sqrt{C} \qquad (3)$$

$$a = 2{,}21\cdot e^{\left(-0{,}356\Delta w + 0{,}13(\Delta w)^2\right)} \qquad (4)$$

$$\Delta w = w - 2 \qquad (5)$$

Ω : The circular (angular) spatial frequency or wavenumber.
C : The unevenness index.
w : The waviness.

The value of “w” usually ranges from 1.5 to 3, with the typical value w = 2. If w = 2, than a = 2.21. Similarly, Here, *$H_0(l)$* is the random component of the road profile with the PSD of form (2), and *$H_1(l)$* is the harmonic component of the road profile of the form.

$$H_1(l) = A_d\cdot\cos(2\pi l / l_1) \qquad (6)$$

$$A_d = \sqrt{2D_0 q/(1-q)} \qquad (7)$$

The partial variances D_0, and D_1 of the components *$H_0(l)$*, and *$H_1(l)$* are expressed as follows

$$D_0 = C(2\pi)^{-w+1}(w-1)^{-1}\left(L_M{}^{w-1} - L_m{}^{w-1}\right) \qquad (8)$$

Where A_d is the amplitude of the harmonic undulation, and l_1 is its wavelength. Many different ways can be defined with many different types of parameters. Some parameters generally used are shown in Table 2. The road profile parameters used in this study are given at Appendix[10].

Table 1 Nominal and mean values of some different road profiles [10]

C_{nom}/C_{sim} (10^{-6} rad m)	w_{nom}/w_{sim} (1)	q (1)	l_1 (m)	A_d (mm)	IRI_{sim} (mm/m) ($IRI_{nom} = 2.21$)
0.6602/0.6362	1.5/1.5105	0	—		2.1812
1/0.9384	2/1.9987	0	—		2.1907
1.5767/1.6028	3/3.0381	0	—		2.2484
0.2516/0.2648	2/2.0180	0.1	2.21	0.6610	2.2198
0.8564/0.9527	2/2.1020	0.1	6.25	1.2274	2.2120
0.7843/0.9771	3/3.1783	0.1	6.25	2.3489	2.2221
—/0.0013	—/6.6759	1	6.25	3.0123	2.2083

2.4 Related standard of body vibrations

The vibration environment is one of the most important criteria by which people judge the design and construction quality of a car. Being a judgment, it is subjective in nature, from which arises one of the greatest difficulties in developing objective engineering methods for dealing with ride as a performance mode of the vehicle.

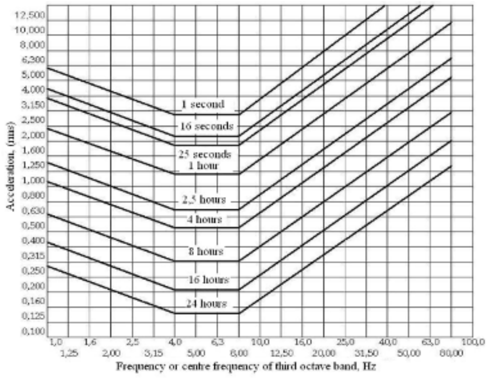

Fig. 3. Vertical vibration exposure criteria (ISO 2631)

Experiments have been mostly concerned with changes in food assimilation, muscular activity, reproductive activity etc. as well as actual internal injury. Psychological effects such as perception, discomfort, and pain, have recently been studied in some detail. Most of the studies have been carried out on vehicle drivers and aircraft pilots, whose ability to perform complex tasks under adverse environmental conditions, including vibration, is particularly important. Over time, becoming an integral part of the design of machine vibration isolation, vibration measurement and analysis accurately has become an important need [1]. Experimental data collected, for defining limits of vibration exposure to human beings, have resulted in a set of vibration criteria specified in ISO Standard 2631. This standard brings this data conveniently together as a set of vibration criteria curves for vertical and lateral vibration over the frequency range 1 to 80 Hz. These are shown in Figure 2 for vertical.

3 Ride Comfort Analysis

First of all, the simulation of mathematical model for the physical model shown in Figure 2 was obtained. The road roughness is taken as input. Acceleration responses graphs and compared with the ISO 2631 standard graphics. The results are shown in Figure 4-14.

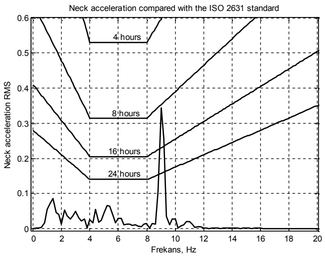

Fig. 4. Neck acceleration compared with the ISO 2631 standard

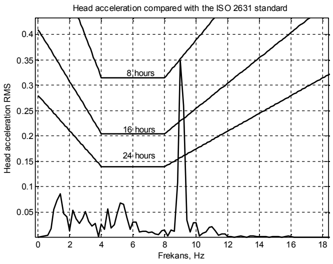

Fig. 5. Head acceleration compared with the ISO 2631 standard

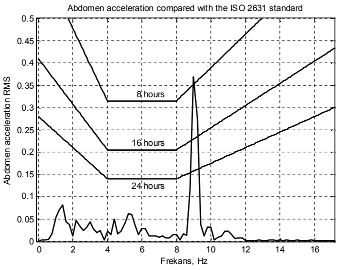

Fig. 6. Abdomen acceleration compared with the ISO 2631 standard

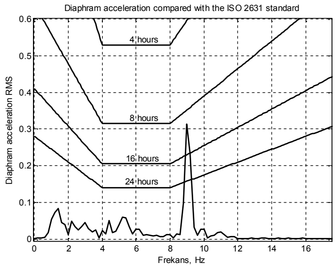

Fig. 7. Diaphragm acceleration compared with the ISO 2631 standard

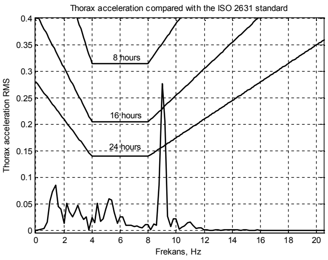

Figure 8 Thorax acceleration compared with the ISO 2631 standard

The natural frequencies of the sprung mass and unsprung mass are 1.2 Hz and 9.5 Hz for the vehicle, respectively. Frequency responses of body parts show that approximately 1.2 Hz and 9.5 Hz frequencies are two dominant natural frequencies. These frequencies could be related to the sprung and unsprung masses of the vehicles. Therefore, it can be concluded that the driver of the car will be affected in these frequency ranges.

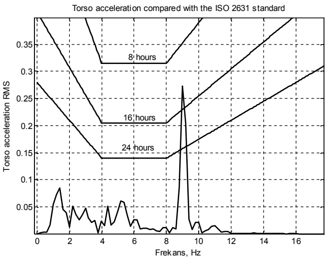

Fig. 9. Torso acceleration compared with the ISO 2631 standard

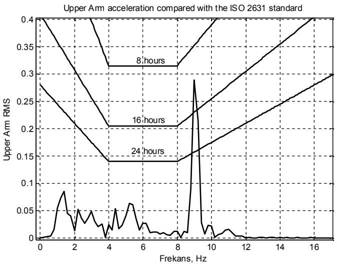

Fig. 10. Upper Arm acceleration compared with the ISO 2631 standard

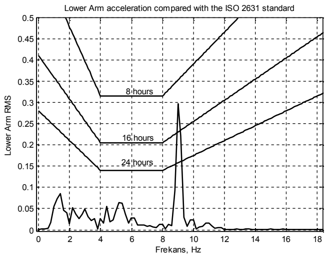

Fig. 11. Lower Arm acceleration compared with the ISO 2631 standard

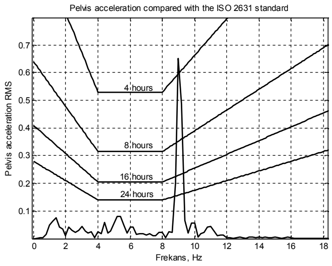

Figure 12 Pelvis acceleration compared with the ISO 2631 standard

By using the outputs of the simulations shown in Figure 4 to 14, a person exposed to ride vibrations feels his/her neck and head symptoms after 5-6 hours, abdomen, diaphram symptoms after 7 hours, torso, thorax upper and arm symptoms after 8 hours, pelvis discomfort after 3 hours and lumbar spine after 4 hours. It can be easily seen in table 1 that, if a driver have exposed to ride vibration, have a frequency, around 9 Hz for 6-7 hours, driver feels a general sense of discomfort, lower jaw symptoms, abdominal pains, need to urinate and muscle contraction.

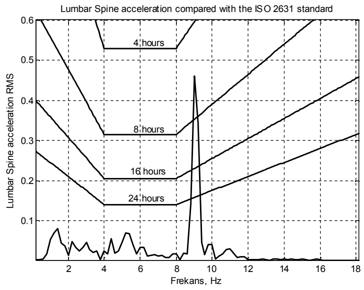

Fig. 13. Lumbar Spine acceleration compared with the ISO 2631 standard

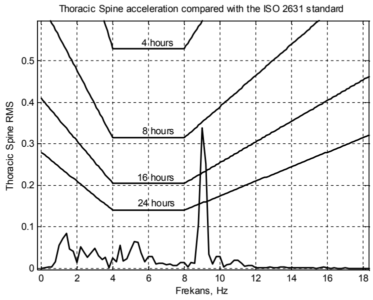

Fig. 14. Thoracic Spine acceleration compared with the ISO 2631 standard

4 Conclusion

The results show that, ride comfort can be interpreted by the help of ISO 2631. If a driver has a journey at a rate of 72 km/hour from 5 to 6 hours on a smooth road, she/he feels uncomfortable. On frequency ranges from 8 to 10 Hz, driver will feel uncomfortable because of physiological muscle spasms and abdominal pain. Thus, it can be concluded that a human-being, should not be exposed to vibrations more than 5 hours under these conditions. In addition, it should be noted that only the roughness of road was chosen as excitation, whereas, there may be many other discomfort factors in vehicles. It must be remembered that road profile used in this study belongs to smooth road parameters.

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5 Appendix

Table 2 System and Road Parameters

m_1	66.50 kg	m_2	66.50 kg	k_1	211180 N/m
m_3	45.18 kg	m_4	45.18 kg	k_2	211180 N/m
m_5	1108.64 kg	m_6	28.00 kg	k_3	211180 N/m
m_7	27.23 kg	m_8	2.002 kg	k_4	211180 N/m
m_9	4.806 kg	m_{10}	1.08 kg	k_{51}	27000 N/m
m_{11}	5.445 kg	m_{12}	5.906 kg	k_{52}	27000 N/m
m_{13}	0.454 kg	m_{14}	1.362 kg	k_{53}	20770 N/m
m_{15}	32.697 kg	m_{16}	5.47 kg	k_{54}	20770 N/m
m_{17}	5.297 kg	a	1.945 m	k_6	500.0 N/m
b	2.115 m	c	0.58 m	k_7	370.8 N/m
h	1.6 m	sy	0.785 m	k_8	52621.0 N/m
b_1	2015 N.s/m	b_2	2015 N.s/m	k_9	52621.0 N/m
b_3	935 N.s/m	b_4	935 N.s/m	k_{10}	52621.0 N/m
b_6	500 N.s/m	b_7	370.8 N.s/m	k_{11}	52621.0 N/m
b_8	3581.6 N.s/m	b_9	3581.6 N.s/m	k_{12}	877.0 N/m
b_{10}	3581.6 N.s/m	b_{11}	3581.6 N.s/m	k_{13}	877.0 N/m
b_{12}	292.3 N.s/m	b_{13}	292.3 N.s/m	k_{14}	877.0 N/m
b_{14}	292.3 N.s/m	b_{15}	292.3 N.s/m	k_{15}	52621.0 N/m
b_{159}	3581.6 N.s/m	b_{16}	3581.6 N.s/m	k_{159}	877.0 N/m
b_{17}	3581.6 N.s/m			k_{16}	97542.0 N/m
d	1.16 m	q	0.1	k_{17}	97542.0 N/m
sa	0.295 m	L_M	$2\cdot\pi/0.1$	h	0.035 m
Sq	$0.9527\cdot10^{-6}$	w	2	L_m	$2\cdot\pi/80$
V	20 m/s	l_1	2.21		