International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 03 Issue: 06 | June-2016 www.irjet.net p-ISSN: 2395-0072

A Review on WBV Exposure and its effects on professional bus drivers

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Abstract - *Travelling through buses is one of the major means of transport for the people and also a source of employment. The commercial bus drivers have to drive for at least 8 hours a day in different road conditions which may contain uneven or rough roads due to which they are continuously exposed to whole body vibrations. Low Back pain is one of the major risks which the drivers are facing and various other musculoskeletal disorders like neck pain, herniated disk etc. when they are exposed to these vibrations for a longer duration of time. Various studies have shown that vibration exposure exceeding the ISO limits may cause earlier degenerative changes in spine causing low back pain. These vibrations are transferred from the bus floor to the feet of the drivers and from the seat to the upper body. There have been a lot of investigations on WBV experienced by the drivers and their effects. In this paper, a review has been done on various research works carried out by various researchers in the field of whole body vibrations experienced by the professional drivers and their effects on them.*

***Key Words*: Bus Drivers, WBV (Whole Body Vibrations), Low back Pain, Ergonomically designed seats, R.M.S., VDV.**

1. INTRODUCTION

The whole body vibration can simply be defined as vibrations affecting the whole body. This term is used to describe the human exposure to various mechanical forces that are transmitted to the body such as jolts, shocks, lateral sway and vertical bouncing. According to ISO Standard 2631-1, these vibrations absorbed into the body through supporting surface, seat back and feet (bus floor). The vibrations to which these bus drivers are exposed to be due to vibrations of its engine, rough road surfaces, bad suspension system of the bus [1]. One of the major problems which the professional drivers face due to these vibrations is low back disorder. Various factors which can be the causes of such musculoskeletal disorders are vibrations produced in the vehicles, prolonged sitting, position of the driver's seat in the bus, differences in the anthropometric sizes of the drivers, environment in which they are working (like automatic or manual transmission, brake travel etc.) [2] , awkward postures (N.K. Kumar et al. 2005) and various physiological factors such as age, height, weight, sex, health issues, body mass index etc.[3]

In the driver's cabin, the understanding of location and orientation of steering wheel, driver's seat and pedals location/orientation in the driver's cabin which influence the driver's posture can help in determining the factors which can be the root cause of musculoskeletal injury and discomfort. So, it is a necessity to design the seat ergonomically which companies often neglect [3]. Sometimes the location of the seat is such that it is placed just above the tyre of the bus due to which any obstacle or protrusion on the roads will directly affect the drivers. Sometimes drivers do some kind of modifications themselves in the seats for comfort which would most likely interfere with the functionality. Most of the vibrations which a driver experiences enter the body through seat. The natural frequency for the human trunk falls in the range of 4-8 Hz, the WBV that will mostly affect passengers will occur in this frequency range (T.C.Fai et al. 2008). So, it is important to study and assess the effect of these vibrations. The ISO 2631-1:1997 defines methods for measurement of periodic, random and transient whole body vibrations. It provides guidance on possible effects of vibrations on health, comfort perception and motion sickness.

2. WBV Parameters

According to ISO 2631-1:1997, the frequencies from 0.5 to 80 Hz are typically evaluated when performing WBV analyses for health, comfort and perception and 0.1 to 0.5Hz for motion sickness. The figure 1 below shows how vibration affects humans. This part of ISO is applicable only to supporting surfaces through which these vibrations can be transmitted: feet of the person, the buttocks, back or supporting area of the recumbent person [5].

For measuring the vibration, a vibration sensing device (accelerometer) shall be placed between the person and the principal contact area and the corresponding devices for measuring the level of vibrations [5]. The following parameters are measured for an assessment of exposure to vibrations:

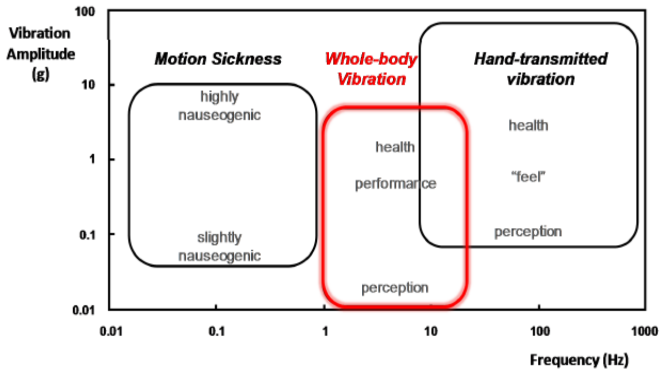

Fig-1: Frequency Categories showing effects of vibrations.

1. Vibration acceleration (m/s^2).
2. Vibration exposure direction (three directions fore and aft, back and forth, vertically up and down).
3. Vibration frequencies and duration of exposure.

Vibration is oscillatory in nature centering around a centre value; therefore, mean or average of the values will result in positive values cancelling out negative values resulting in mean of zero. Therefore to calculate the magnitude of frequency weighted acceleration data, ISO 2631-1:1997 has provided two alternatives:
One is calculating the r.m.s acceleration [5] representing the mean of a vibration signal by squaring each value before calculating the mean and then taking square root. It is calculated in m/s^2 and is given by:

$$A_{W\,r.m.s} = \sqrt{\frac{1\int_0^T a_w^2(t)\,dt}{T}}$$

$A_{Wr.m.s.}$ is the frequency weighted root mean square acceleration
T is acceleration measurement duration
$a_w(t)$ is the frequency weighted acceleration at time t

A major limitation of r.m.s is that it is relatively insensitive to shocks and jolts experienced in a signal. For this reason, the other alternative i.e. calculating vibration dose value [5] is the preferred method. It is the method for indicating the magnitude of a vibration signal. It is calculated in $m/s^{1.75}$ and is given by:

$$VDV = \sqrt[4]{\int_0^T a_w^4(t)\,dt}$$

T is acceleration measurement duration
$a_w(t)$ is the frequency weighted acceleration at time t
Another parameter, Crest Factor is used to check which one is more applicable either VDV or Root Mean Square acceleration. Crest factor is the ratio of peak acceleration to the R.M.S. weighted acceleration and is given as:

$$CF = \frac{\max(a_W(t))}{r.m.s.(a_W)}$$

According to ISO 2631-1, if CF is less than or equal to 9 then r.m.s value is taken into consideration otherwise VDV is used [5].

Based on an average of 8 hour daily equivalent exposure, the values above which human body would have chances of adverse health effects due to these vibrations are shown below:

Table 1: Limits set by the standards

	ISO 2631-1		European Union Directive/44/EC		ISO 2631-5	
	A_w	VDV	A_w	VDV	S_{ed}	Probability of an adverse health effect
	m/s^2	$m/s^{1.75}$	m/s^2	$m/s^{1.75}$	MPa	
Action Limit	0.5	9.1	0.5	9.1	0.5	Moderate
Exposure Limit	0.8	14.8	1.15	21	0.8	High

3. Literature Review:

Many studies and researches have been conducted by various researchers in this field showing various evidences of WBV and its effects on the health of the drivers. Various studies have been reviewed and presented below:
In a study by Ahmad Fuad Mohd. Noor et. al., the differences in WBV exposures was calculated between different models of buses of NISSAN and HINO and standardized Nordic questionnaires for the analysis of musculoskeletal symptoms. The study had been done on 36 drivers. According to his study, all the models of the buses were below ELV for A(8) and VDV(8) but the model NISSAN JPS251P exceeds the EAV limits with A(8)=0.52m/s² and the models HINO RK1JSKA with VDV(8)= 11.1m/s$^{1.75}$, HINO AK1JRKA with VDV(8)= 9.95 m/s$^{1.75}$, and NISSAN JPS251S with VDV(8)= 12.65 m/s$^{1.75}$ exceeds the EAV limit. The direction for maximum vibration values for both A(8) and VDV(8) was z axis which was in the case of NISSAN JPS251P

with A(8)=0.52m/s^2 and VDV(8)=12.65m/s$^{1.75}$ which shows that vibration in this axis elevated the risk of health impairment of the drivers especially lumber spine. SPSS analysis revealed that there was moderate occurrence of LBP. The suggestions were, assessment must be done to control vibration exposure onto drivers, to implement the health monitoring, training for drivers on safety and health, job rotation for drivers to minimize the exposure [6].

Olanrewaju et al (2007) conducted a study to investigate the driver's exposure to posture demand, MMH and whole body vibrations. A sample of 80 drivers was selected for questionnaire regarding information about experience of driving, posture adopted while driving and information about health. For this study, 12 drivers were selected and observed in their driving route for their sitting posture, style of driving, number and time of each stop made, surface of road driven and time spend on each surface and vibration measurement at seat were obtained for three different type of buses according to ISO 2631(1997). The results showed that the drivers were exposed to discomforting levels of vibration stress particularly vertical vibrations and shock/jerking events. From the observations, the posture which was often adopted by the drivers was straight Torso and occasionally the torso leaned against backrest as in the questionnaire data and the actual time spent by the drivers driving was 60% of the daily work time. The reason for the straight torso or unsupported was using the seats with poor back rests. Transient and mild back pain was found to be prevalent among the drivers which showed a less effect on work efficiency. Various suggestions for controlling the risks of LBP were given: firstly to minimize or eliminate the need for holding the torso straight by minimizing the sitting duration during driving by taking regular breaks and do stretching and exercise(Anderson 1992) and ergonomically designed seats should be used [7].

A study by R.P. Blood et.al. (2009), three different seats were evaluated for WBV exposures on 12 bus drivers who drove the bus on four routes which includes city streets, freeways(old and new) and a road containing 10 bumps. No differences between seats in VDV exposures were found but were shown in TWA Peak and Raw (+) Peak exposures. The value for daily acceleration dose (D_k) was found lower for seat 1 (manufacturer 1) as compared to seat 2 (manufacturer 2) when measured at the seat pan. When standard foam seat pan (Seat 2(manufacturer 2)) was compared with the silicone foam seat pan (Seat 3(manufacturer 2)) there was no significant difference was found for the exposures but significant differences were measured at the floor with the A_w, Raw (+) Peak and Raw (-) Peak values being different. The comparison between floor and seat showed that the seats transmitted 83.6 to 92.3 for A_w and 76.3 to 80.4 for VDV and no differences in Aw and VDV transmissions were found between Seats 1 and 2 and Seats 2 and 3. All the seats were able to lower the transmission of peak values from floor to seat but seat 3 transmitted more of the peak vibrations. Comparison between different road types showed that for street segment for VDV z axis, the exposure slightly exceed the action limit and for A_w z axis exposures were below the action limit. In freeways, high value of VDV exposures were found in z axis above the action limit of ISO 2631-1 and also freeways had the highest exposure of A_w due to continuous nature of vibrations. The suggestions given were the route rotation should be done so that the drivers do not spend whole time on the rough routes and should drive in different segments of routes [8].

Ornwipa Thamsuwan et. al.(2012) conducted a study on WBV exposure between two buses i.e. high floor and low floor buses with the same seat attached to them with 12 drivers for high floor and 15 drivers for low floor driven on 4 road surfaces i.e. city roads(stop and go type), freeways(newer and older), circular road with speed breakers. The results showed that the WBV exposures bus were reduced in high floor bus as compared to low floor bus on smooth freeways with no parameter exceeding the action limits. A high floor bus had lower values of $S_{ed}(8)$ as compared to low floor buses in all the three axis in case of rough freeway. On both the buses, the z axis and the vector sum exposures exceeded the A(8) and VDV(8) action limit values (0.5 m/s^2 and 9.1 m/s$^{1.75}$, respectively). In case of city streets, the high-floor coach bus showed lower WBV exposure values. In high-floor bus, all the WBV exposure parameters showed higher values as compared to low-floor bus in which only vector sum A(8) and VDV(8) exposures were above action limits in case of speed bumps. On both the buses, the seat attenuated only 10% on average the vibrations from the floor to the seat except in case of speed humps where both the seat amplified the vibrations. Various suggestions were given: the use of high floor buses in speed humps should be avoided, regular breaks should be provided to the drivers, less than 10 hours of continuous driving when driving in smoother roads and less than 3 hours of driving in rougher roads. In order to reduce the bus driver's exposures to health risks, route rotation should be done so that drivers shall not keep on driving on the same route (rough roads) which could be a possible and better administrative control [9].

A study by Maria Alzira de Araujo Nunes(2015), the level of vibrations for the intercity buses were recorded in different roads located in the central region of brazil covering 6 brazil states according to ISO 2631-1(1997). For this study, 16 bus drivers drove buses of same model in 7 routes from 160 Km to 650 Km. The results showed that for three routes but (BSB/BES, BSB/ARR, BSB/URA), the mean A_{sum} exceed the action limit of the HGCZ, none exceeds the exposure limit. The same routes exceeded the action limit for VDV exposure. The routes BSB/AVN and BSB/CTL did not exceed the VDV action limit. The route URA/RIB a private road showed the lowest value for the WBV exposure (0.52m/s^2) due to better conservation of its pavement than others. This study showed that drivers were exposed to WBV value below the exposure limit but for some route (BSB/UNAI) above the action limit.

The study suggested the need for health surveillance, appropriate routes should be assigned to suited buses and proper rotation across routes for the drivers [10].
A study by Per M.G. Jonsson et.al. (2014) showed the WBV comparison between high floor and low floor buses and also the effects and interactions of bus and seat design. For this study, 12 drivers were selected to drive the buses on routes to and from airport Gothenburg Sweden including city roads, freeways, and bumps. The two different types of seats (air suspension and pedestal seat) and two types of buses were compared for WBV exposures. The study showed that WBV exposures were reduced by air suspension seat in low floor bus but increases in the high floor bus which may indicate a mismatch between seat and bus suspension on high floor bus [7]. In low floor bus, no differences were found in WBV exposure for both types of seats. As it was found that the air suspension seat amplifies the WBV exposures in high floor bus which puts a suggestion that a different type of seat can be used in high floor bus [11].

A study by Keith T Palmer et. al. (1999) was done on the working population of Great Britain for the occupational exposure to WBV to identify sources of exposure and occupation where such exposures arise. The study showed that the occupation which exceeds the VDV value above $15 m/s^{1.75}$ were forklift truck drivers, mechanical truck drivers, farm owners and managers, farm workers. The most common sources of occupational exposure to WBV are cars, vans, forklift trucks, lorries, tractors, buses, and loaders. Cars, buses, and vans were the sources of exposure that were reported among women. In case of men, lorries driven for longer durations [12].

4. Conclusion

Based on the various literature reviews, this conclusion has been made that the drivers are exposed to WBV exceeding the limits set by various standards depending on various factors like bus conditions, road surfaces, design of seats etc. These WBV puts an adverse impact on driver's efficiency to do work and also the health of the driver affecting not only the back of the driver but also other musculoskeletal disorders, joint and muscle stiffness etc. The better solution to reduce such problems is to provide a better ergonomically designed seat for the drivers so that the vibrations which are transmitting from the floor to the seat shall be minimized. Proper duty rotation of the drivers across routes so that a driver should not keep on driving along the same route for long duration. Bus suspensions should be better.

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