Study of Vibration Dose Value and Discomfort due to Whole Body Vibration Exposure for a Two Wheeler Drive

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Abstract—
All the vehicles are exposed to vibrations caused by the roughness of the road or soil profile, which affects the health as well as causes discomfort to the occupants (driver and passengers). In the present study, Vibration Dose Value (VDV) has been recorded for the driver as well as the pillion of two wheeler vehicle for the different road profile having speed breakers, at different speed. The methodology adopted from the International Organization for Standardization (ISO) guidelines for whole body vibration (WBV) exposure having frequency ranges from 0 to 100 Hz. VDV of six healthy male subjects was recorded through the Human Vibration meter via seat-pad tri-axial accelerometers for two minutes drive and psychophysical response were measured with the help of Borg CR10 scale. The Time to reach 15 VDV and comfort decreases with the increase in vehicle speed and speed breaker's height, for both driver and pillion. Pillion feels more discomfort with the increase in vehicle speed and speed breaker's height when compared with driver.

***Keywords*—WHOLE BODY VIBRATION, VIBRATION DOSE VALUE, HUMAN VIBRATION**

INTRODUCTION

All on- and off-road vehicles are exposed to vibrations caused by unevenness of the road or soil Profile, moving elements within the machine or implements. Increased vehicle speed and engine capacity produce a lot of vibration problems which in turn reduces the vehicle life span. The ever expanding technology in modern society has led to increase in movement of people from one place to another. This has resulted in increased number of people getting affected by whole-body vibrations during transportation. These vibrations are known to have effects such as sensory responses like discomfort, injuries and health issues. Human response to whole body vibration is very complex and nonlinear in nature. There are a number of standards which provide guidelines for measurement and evaluation of whole-body vibration, though there are some ambiguities related to the axes in these standards. Also different values of discomfort thresholds are recommended by these standards. Current methods for discomfort evaluation involve various psychophysical methods like subjective rating scales, magnitude estimation methods etc. Stephan Milosavljevic et.al [18], in this study Whole body vibration was measured in 12 farmers during their daily use of all-terrain vehicles (ATVs). The vibrations were measured in accordance with the ISO 2631-1 guidelines for whole body vibration. All those who participated in the experiment were asked to ride their ATV for around 20 min on a typical daily work route of their choice with helmet mounted on their head. The farmers asked to ride when each farmer was sitting on the seat pad containing a tri-axial accelerometer. The exposure vibration data were digitally stored in a 6 channel data logger. Filtering of vibration data and weighted accelerations, VDV calculations were done with the help of LabView software. The questionnaire survey method was used, whether the participants had suffered with low back pain, neck back or neck pain within the past 7 days or within past 12 months and concluded Low back pain was the most usual sicknesses for both 7-day (50%) and 12-month (67%), followed by the neck (17% and 42%) and the upper back (17% and 25%), respectively. All farmers' WBV levels were more during daily use of an ATV. E. Khorshid et.al [5], an experimental study was carryout to access health injuries related to distinct geometry of speed control humps (SCH). The experiment was conducted for a variety of testing conditions are hump profile and dimensions, distinct vehicle speeds, several seat locations. Two peoples participated in whole of the experiment, one was related to testing of front seat driver and another one was for rear seated passenger testing. The WBV for different experimental testing conditions of the vehicles while crossing the SCHs was measured at the driver and seat interface with the help of the seat pad accelerometer. The assessment was based on BS 6841 and ISO 2631-5.The WBV exposure was measured in x and z-axis, not considering y-axis because very small as compared to other axes. Vibrations were measured using LabView software with a National Instruments data acquisition card and all calculation done with the help of MATLAB software and concluded that WBV of the driver's seat for three vehicle categories was affected greatly by hump geometry, especially the hump height. The rear seated passenger was also at high health risk of injury, as compared to the front-seated driver. Martin P.H. Smets et.al [11], WBV was measured on eight surface haulage trucks in three size classes depending upon carrying capacity. Vibration was measured in accordance with the ISO 2631-1 standard during one hour of normal operation. A tri-axial accelerometer sensor was used to measure vibration, placed on the driver seat. Road profile changes from crushed gravel roadbeds to uneven dirt tracks littered with loose rock. The experiment is done during the summer season. A categorical questionnaire survey is used whether participants had musculoskeletal disorders. Discomfort in various body parts was rated by the operator on a four point scale ranging from mild to very severe. The recorded data is transferred to computer from the Datalog unit via SD memory for analysis and concluded 14% of operators reported neck pain of moderate severity, 14% reported upper back pain of mild severity, 29% reported low back pain of moderate severity, and 14% reported knee pain of moderate severity and all surface haulage truck operators are typically exposed to WBV that exceeds the cautionary boundaries set by the ISO 2631-1.

A. R. Ismail et.al [1], VDV was evaluated by conducting the experiment on car driver at two different speeds for 10 minute duration. The vibration data were collected using a tri-accelerometer sensor placed between driver and driver seat. All WBV measurement assessments are done based on ISO 2631-1: 1997.The exposure vibration data were digitally stored in a five channel data logger. All WBV parameters are calculated using MATLAB and concluded that vibration exposure of WBV increased with an increase of the magnitude and duration of exposure. The daily value of Exposure to Vibration A (8) and VDV values were increased with increasing journey time and were comparable to exposure limit set by ISO 2631-. Driver in the considered vehicle was possibly exposed to severe levels of WBV during the journey time. I. Hostens, H. Ramon et al. [7], In this study Whole Body Vibrations were assessed and evaluated for the cabin of a combine, driving at different speeds on concrete surface and field road and different suspension of driver seats are mechanical, air suspension respectively. The accelerometer SIT-BAR was used which was installed on the base structure of the cabin and between driver's buttocks. The entire experiment was done with different variables: machine speed, operational condition of the combine and duration. The frequency weighted accelerations were measured with SIT-BAR and changes in comfort value of r.m.s and VDV and concluded vibration dose values in vertical directions shows that the risk of injury in long-term driving and serious risk for injury in driving at high speed on the field road. From lateral vibrations, no discomfort was perceived in long-term driving shown by the comfort values. Comfort values shown that injury can result from long term driving on concrete road as well as field. A seat with air suspension is less uncomfortable than with a mechanical suspension.

Various studies have focussed on the discomfort caused by vibration presents in the trains, all terrain vehicles, four wheeled car and associated conditions (Wilder et al., [4], Basri and Griffin [3], Giacomin and Screti [8], Porter et al. [9], Parsons and Griffin, [10], Morioka, M.J. Griffin [13], Johansson and Johansson [16], P.V. Krishna Kant [17], Milosavljevic et al. [18], Falou et al., [19]). To the best of knowledge of the author, no study has been found in literature which considers the effect of whole body vibration on the two wheeler driver and pillion by measuring the vibration dose value. In the present study, a two wheeler motor bike (Hero Honda, Passion, 2010) has been selected to evaluate the discomfort caused by whole body vibration exposure to driver as well as pillion while crossing the speed breakers. The objective of the current study is to find out the effect of whole body vibration exposure due to vehicle speed and speed breakers on the driver as well as pillion. Guidelines to measure and evaluate the whole body vibration were adopted from the standard ISO-2631-1 [6]. It is hypothesised that for given vehicle and speed breakers, greater discomfort both subjectively and objectively will be experienced by the riders, with the increase of vehicle speed and height of the speed breaker.

EXPERIMENTAL METHODOLOGY

The whole experiment was conducted with a two wheeler on different road profiles having different speed breakers in IIT, ROORKEE, India. Measurements were made for the driver as well as the pillion by considering the different variables: vehicle speed and speed breaker size. All the volunteer subjects had driven the two wheeler on road profiles having speed breakers DARK EYE DA 1005 (Fig. 2) and DARK EYE DA 1006 (Fig. 3). DARK EYE DA 1006 was having length 750 mm, width 250 mm and height 75 mm. Dark eye DA 1005 was having length 350 mm, width 250 mm and height 53 mm. Two minutes of vibration data were recorded by using human vibration meter VM-30H while operating the vehicle as shown in fig 1. Exposure to WBV was measured in accordance with ISO 2631-1 and 2631-5 standards when each subject was sitting on a custom made rubberized seat pad containing a tri-axial accelerometer (KB103SVD).

Anthropometric data

Six healthy male subjects were participated in the experiment .They were highly experienced in two wheeler driving with an average experience of 6.66 years

Table: 1 Anthropometric data of test subjects

Subject	Age (years)	Weight (kg)	Height (cm)	Driving Experience (yr's)
Sub 1	25	59	160	7
Sub 2	24	75	172	7
Sub 3	24	72	176	8
Sub 4	25	71	167	6
Sub 5	23	65	167	4
Sub 6	29	73	164	8
mean	24.83	69.16	167.66	6.66

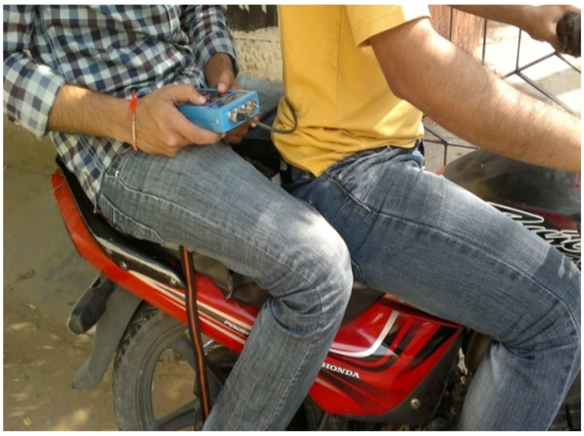

Fig.1 Seat pad accelerometer placed between the vehicle seat and driver's buttocks.

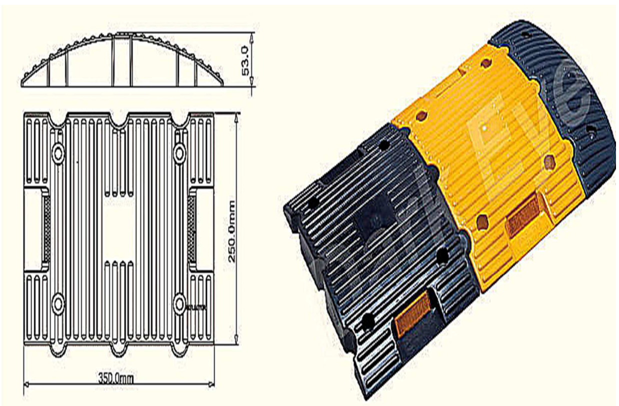

Fig 2: Speed Breaker DARK EYE DA 1005

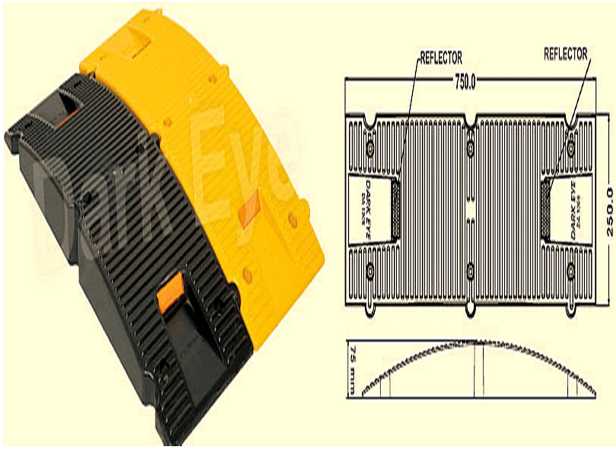

Fig 3: Speed Breaker DARK EYE DA 1006

MEASUREMENT PARAMETERS

Crest Factor

The crest factor (CF) is a dimensionless quantity defined as the ratio of the peak acceleration to the r.m.s acceleration [12, 15]. The lowest possible crest factor is 1, which occurs for a square wave; a sine wave has a crest factor of 1.4. If any signals contained a single instantaneous shock, then the CF would increase, but the r.m.s. might not be substantially affected. The Value of CF indicates whether r.m.s. or Vibration dose value (VDV) is appropriate for the assessment of whole body vibration. The CF threshold is not universally agreed upon, BS 6841 (1987) [2] and ISO-2631 standards define a CF value of 6 and 9 to designate when r.m.s. method become inferior to VDV method (M. J. Griffin, 1990 [14]).

Root Mean Square (r.m.s.)

The r.m.s method calculates the acceleration value by the square root of mean value obtained from the integration of the squared value of the signal [12, 15]. . For the signal containing shocks, the r.m.s rapidly increases during each of these events, but also decays as the averaging time increases. The weighted r.m.s acceleration is expressed in ms^{-2} for translational vibration as follows

$$a_w = \left[\frac{1}{T} \int_0^T a_w{}^2 (t) dt \right]^{1/2}$$

Where $a_{w(t)}$weighted acceleration time history and T is duration of measurement.

Vibration Dose Value (VDV)

Vibration Dose value shows a fourth power relationship between vibration magnitude and dose value of vibration which affects the health as well as comfort of human beings [12, 15]. VDV always accumulates for the vibration exposure and does not decay during periods of low value of vibration magnitude. As recommended by the ISO 2631 standard, daily vibration dose value (VDV) in the region of 15 $(ms^{-.75})$ usually causes severe discomfort and health related problems. VDV has calculated as follows:

$$VDV = \left[\int_{t=0}^{t=T} a_w{}^4 (t) dt \right]^{1/4}$$

Where $a_{w(t)}$ weighted acceleration time history and T is duration of the measurement.

The purpose of the frequency weighting procedure is to compensate and to normalize for differences in human susceptibility and sensations at different frequencies.

The assessment of vibration in a vehicle depends upon the method of measurement and evaluation of human responses. The level of comfort also depends upon the subjective trade-off between the journey time, the reason for the journey, and the passenger's expectations of the journey comfort. In this study category ratio judgement method Borg CR – 10 scale (Table: 3) has been used for the subjective assessment of discomfort.

Table 2: Guide for the application of frequency-weighting curve for principle Weightings.

Frequency weighting	Comfort
W_k	Z-axis, Seat surface
W_d	X-axis, Seat surface Y-axis, Seat surface

Table: 3 Borg CR-10 scale

0	Nothing at all	
0.3		
0.5	Extremely weak	Just noticeable
0.7		
1	Very weak	
1.5		
2	Weak	Light
2.5		
3	Moderate	
4		
5	Strong	Heavy
6		
7	Very Strong	
8		
9		
10	Extremely strong	"Maximal"
11		
•	Absolute maximum	Highest possible

RESULTS

The ISO 2631-1 recommends frequency weighting for computing VDV's in the X, Y, and Z orthogonal directions calculated in Eq. (1) as the weighted fourth power of acceleration

$$VDV_i = (w_i)\left[\int_{t=0}^{t=T} a_{w(t)}{}^4 (t) dt \right]^{1/4} \quad (1)$$

Where $a_{w(t)}$weighted acceleration time history and T is duration of measurement with values of W_x =1.4 , W_y = 1.4 , W_z = 1 for x, y z direction respectively.

The total VDV (tVDV) were obtained for each direction of vibration

$$tVDV = (VDV_X^4 + VDV_Y^4 + VDV_Z^4)^{1/4}$$

The VDV obtained from each experiment for two minutes duration of data collection which was further extrapolated to calculate time to reach 15 VDV $(ms^{-1.75})$.

$$\frac{VDV_1}{VDV_2} = \left[\frac{t1}{t2}\right]^{1/4}$$

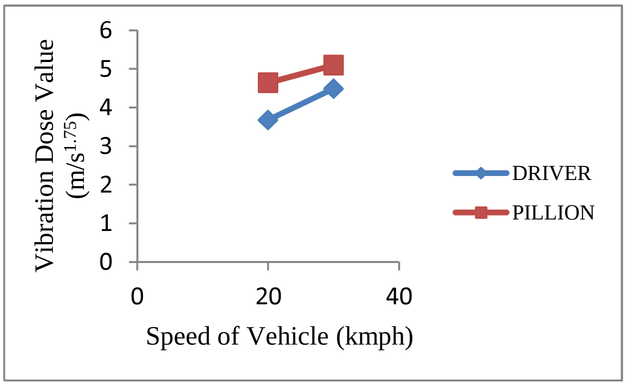

Fig: 4 Mean value of VDV of six subjects on Speed Breaker Dark Eye DA 1005.

Fig: 4 shows that, for driver and pillion, the VDV value at speeds 20 kmph and 30 kmph are 3.7 $ms^{-1.75}$, 4.4 $ms^{-1.75}$ and 4.6 $ms^{-1.75}$, 5 $ms^{-1.75}$ respectively for the speed breaker DARK EYE DA 1005.

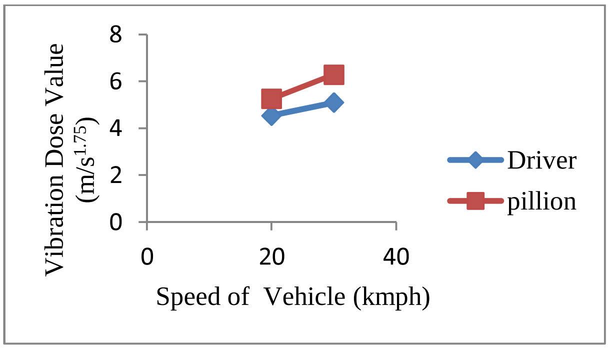

Fig: 5 Mean value of VDV for six subjects acting as driver and pillion at a speed of 20 kmph and 30 kmph on Speed Breaker Dark Eye DA 1006.

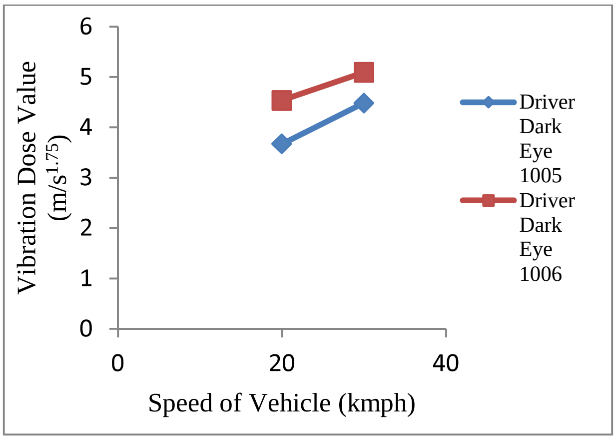

Fig: 6 Comparison of Mean VDV values for driver on Speed Breaker Dark Eye 1005 and Speed Breaker Dark Eye DA 1006.

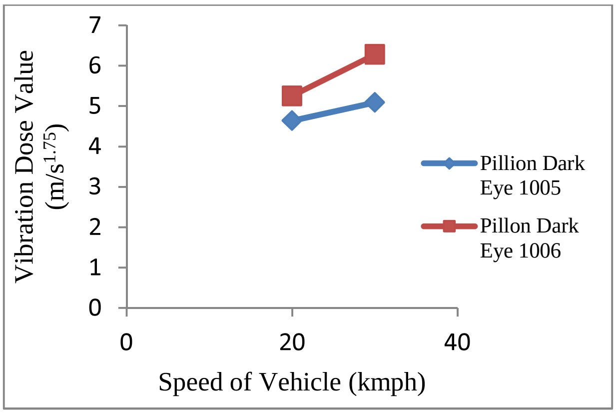

Fig: 7 Mean VDV values for pillion on Speed Breaker Dark Eye DA 1005 and Speed Breaker Dark Eye DA 1006.

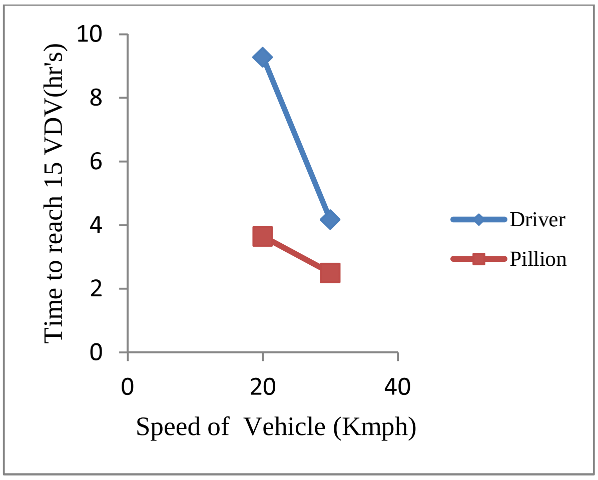

Fig: 8 Mean Time to reach 15 VDV value for the driver and pillion for Speed Breaker Dark Eye DA 1005.

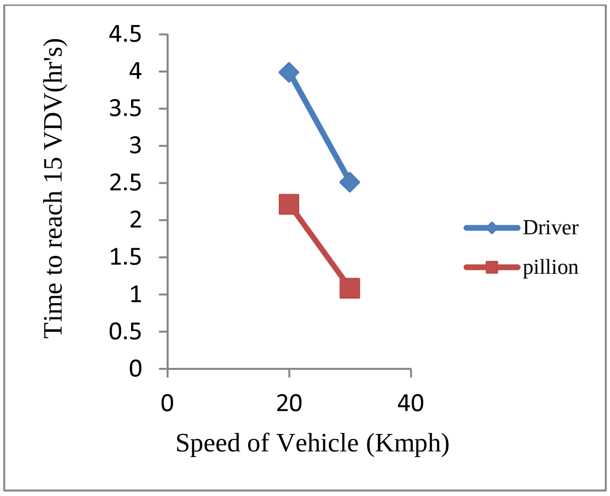

Fig .9 Mean Time to reach 15 VDV value for the driver and pillion for Speed Breaker Dark Eye DA 1006.

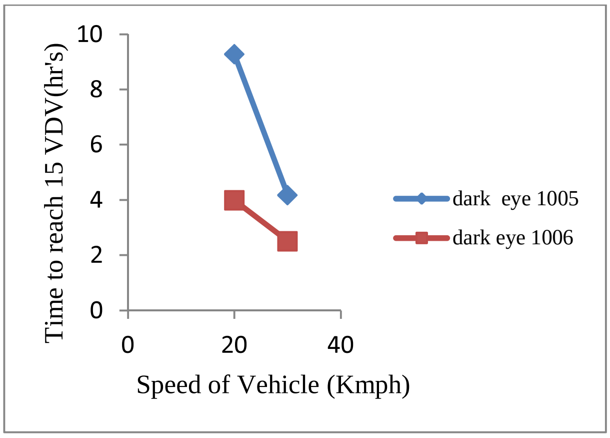

Fig: 10 Mean Time to reach 15 VDV value on Speed Breaker Dark Eye DA 1005 and speed breaker Dark Eye DA for the driver.

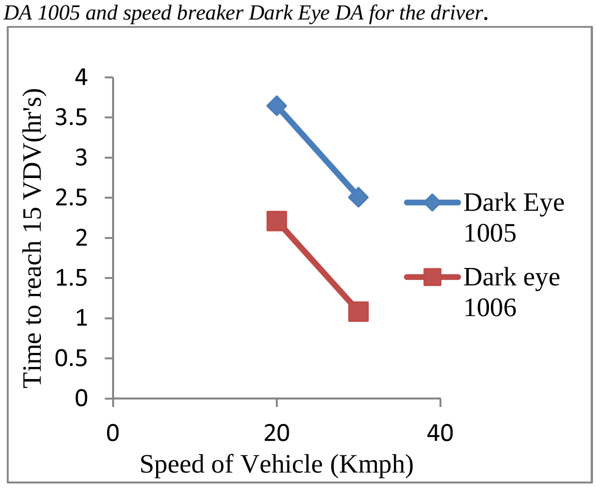

Fig: 11 Mean Time to reach 15 VDV value on Speed Breaker Dark Eye DA 1005 and Speed Breaker Dark Eye DA 1006 for Pillion.

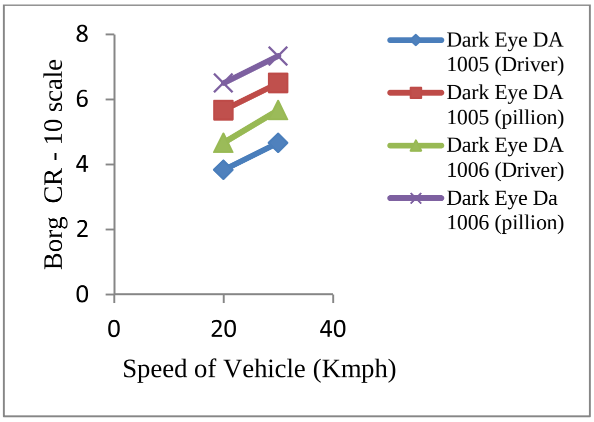

Fig: 12 Mean value of discomfort of driver and pillion on Dark Eye DA 1005 and Dark Eye 1006 .

Fig.5 shows, that for driver and pillion, the VDV value at speeds 20 kmph and 30 kmph are 4.5 $ms^{-1.75}$, 5 $ms^{-1.75}$ and 5.2 $ms^{-1.75}$, 6.2 $ms^{-1.75}$ respectively for the speed breaker of DARK EYE DA 1006. VDV value for the driver has been found to be less compared to the pillion for both the speed breakers i.e. driver is exposed to less vibration severity as compared to the pillion on the same vehicle.

Fig. 6 shows that VDV values for driver at 20 kmph 30 kmph for speed breaker DARK EYE DA 1005 and DARK EYE DA 1006 are 3.7$ms^{-1.75}$, 4.5$ms^{-1.75}$ and 4.4 $ms^{-1.75}$ and 5$ms^{-1.75}$respectively. From Fig.7 Shows that VDV values for pillion at 20 kmph and 30 kmph for speed breaker DARK EYE DA 1005 and DARK EYE DA 1006 are 4.6 $ms^{-1.75}$, 5.2 $ms^{-1.75}$ and 5 $ms^{-1.75}$, 6.2 $ms^{-1.75}$respectively.'Time' to reach 15 VDV increases rapidly for pillion compared to the driver of the same vehicle as the speed of the vehicle and height of speed breaker increases (fig8-11). Subjective rating on the Borg's scale by the participants also shows the same pattern for discomfort as for VDV (fig. 12) i.e. discomfort increases with the vehicle speed and speed breaker's height for the driver as well as a pillion, but the increase is more for pillion compared to the driver. Results from objective and subjective measurements shows that pillion is exposed to more vibration than a driver of the same motorbike which encourage for the improvement of the vehicle seat and suspension system.

CONCLUSION

Two wheeled vehicles are in commonly used by the people in their daily life. An attempt has been made to quantify the whole body vibration exposure using Vibration Dose Value methods and subjective method. It was observed that VDV and discomfort are increased with the increase in vehicle speed and speed breaker's height for the driver as well as pillion. The time to reach 15 VDV increases as the vehicle speed and speed breaker's height decreases for both driver and pillion. The pillion is exposed to more vibration severity compared to the driver, therefore pillion feels the discomfort more than the driver of the same two wheeled vehicle. It is recommended that the speed breaker DARK EYE DA 1005 be used instead of DARK EYE DA 1006 to keep the VDV within the acceptable limit and preventing adverse health effects. The design of the seat and suspension system of two wheeled vehicle can be optimized by considering the human factors for both driver and pillion.

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