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# A Study on Evaluation of Whole-Body Vibration from Vehicle for Different Road Surfaces

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**Abstract :** The purpose of this study is the measurement of whole-body vibration for different road surfaces. Experimental measurements were taken on asphalt, cement, and off-road surfaces as defined by ISO 2631-1. Each experiment was conducted under the same set of conditions (measurement duration, times, speed, vehicle type). Measurement duration was 10 minutes and 3 separate measurements were taken on each road surface. Vehicle speed was 60 km/h. In accordance with ISO 2631-1, an acceleration sensor is set up between the driver's seat and the human body. For evaluation, RMS(root-mean-square) values were taken as suggested by ISO 2631-1. The results suggest "health guidance caution zones", and the evaluation was based on obtaining the vector sum with "health guidance caution zones".

**Key words:** whole-body vibration, ISO2631-1, RMS(root-mean-square), road surface, health guidance caution zones

## 1. Introduction

With rapid industrialization, we are interested in not only material things but also improvement in life style. By the 『Survey of public opinion about perception of noise to whole country population』, 32.2% of population answered that want improvement with the problem of noise and vibration (2002). Research on noise is active. On the other hand, vibration research is not available. Standards about effect of vibration to human body exist; EU DIRECTIVE 2002/44/EC, ACGIH, BS 6841etc. But standards are unsatisfactory. This study measures whole-body vibration in a car , and evaluates the vibration effect on the human body by ISO2631-1.

## 2. THEORY

In the ISO 2631-1 there are recommendations, for evaluation of mechanical vibration and shock exposure to whole-body. It measures along 3 axes; x axis(left and right), y axis (front and rear), z axis (top and bottom).

Acceleration measured along the 3 axes applies a frequency weighting multiplication factor (x,y axis = 1.4, z axis = 1), and then evaluates RMS(root-mean-square). RMS with the following;

$$a_{\omega}(t_0) = \left(\frac{1}{\tau}\int_{0-\tau}^{t_0} [a_w(t)]^2 dt\right)^{\frac{1}{2}} \qquad \text{.....................(1)}$$

Where, $a_w(t)$ : exposure vibration virtual value ($m/s^2$, $rad/s^2$)
t : measurement time

VDV (Vibration Dose Value) is fourth power vibration dose method. VDV is defined as ;

$$VDV = \left\{\int_{o}^{\tau}[a_{\omega}(t)]^4 dt\right\}^{\frac{1}{4}} \qquad \text{........................(2)}$$

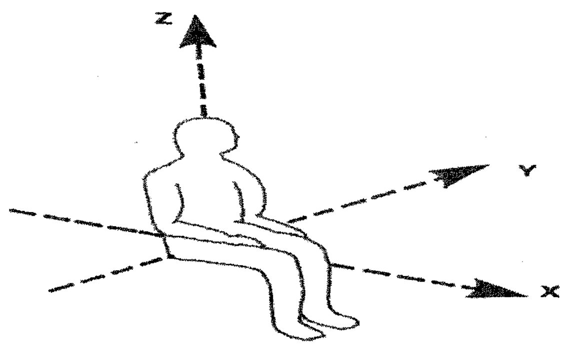


**Fig. 1.** Coordinate system for Whole-body.

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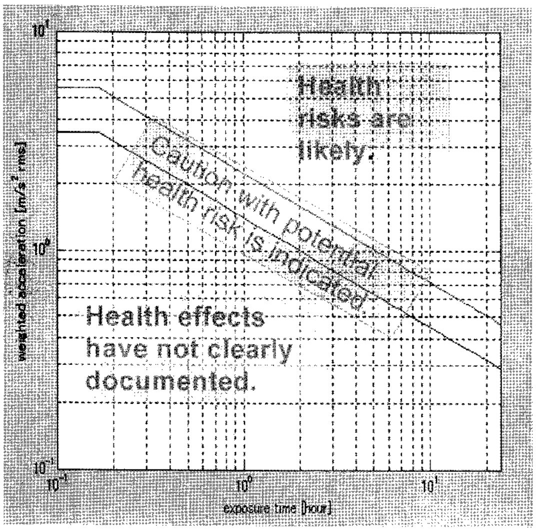



**Fig. 2.** The chart of evaluation by ISO2631-1.

The obtained acceleration values are weighted for frequency and defined as among with x,y,z axes relation.

$$a_v = (kx^2a^2_{wx} + ky^2a^2_{wy} + kz^2a^2_{wz})^{1/2} \quad \text{...........(3)}$$

where, $a_{wx}$, $a_{wy}$, $a_{wz}$ are the weighted RMS accelerations with respect to the orthogonal axes x,y,z, respectively:
kx,ky,kz are multiplying factors
kx=ky=1.4, kz=1 : frequency weighting

Fig. 2 is chart of evaluation by ISO2631-1. It shows "Health guidance caution zone". This "Health guidance caution zone" is shown as a function of the relation between vibration exposure time to human body and RMS. For exposures below the zone health effects have not been clearly documented and/or objectively observed; in the zone caution with respect to potential health risks is indicated and above the zone health risks are likely(1997).

## 3. Experiment

### 3.1 Experiment conditions

To obtained changed measurement values by the different road surfaces under the same conditions (speed, vehicle type, measurement time), measurements were conducted on asphalt, cement, and off-road. Measurement duration is about 10 minutes, measurements were taken 3times, and speed was 60 km/h. All experiments used the same car.

An acceleration sensor and data recorder were used in the experiment. According to ISO2631-1's seated position measurement, the acceleration sensor shall be located so as to indicate the vibration at the interface between the human body and the source of its vibration.

**Table 1.** Condition of measurement

| Road surfaces | Sampling Time (second) | N | speed |
|---|---|---|---|
| Asphalt<br>Cement<br>Off-road | 600 | 3 | 60km/h |

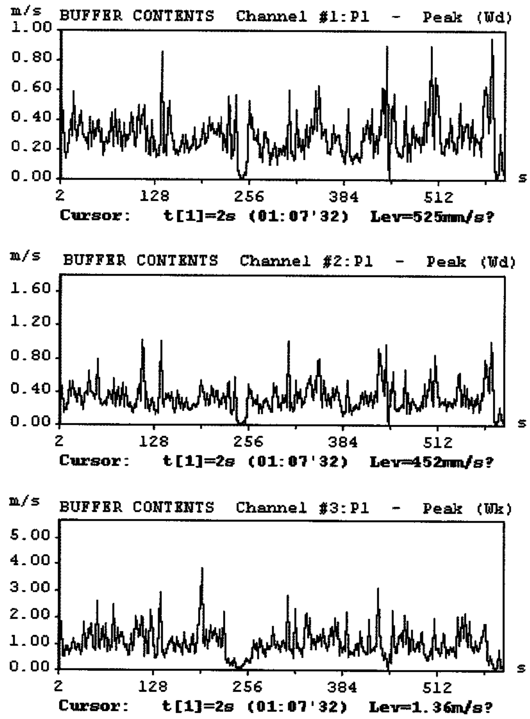
**Fig. 3.** Measurement vehicle

## 4. Experimental Result

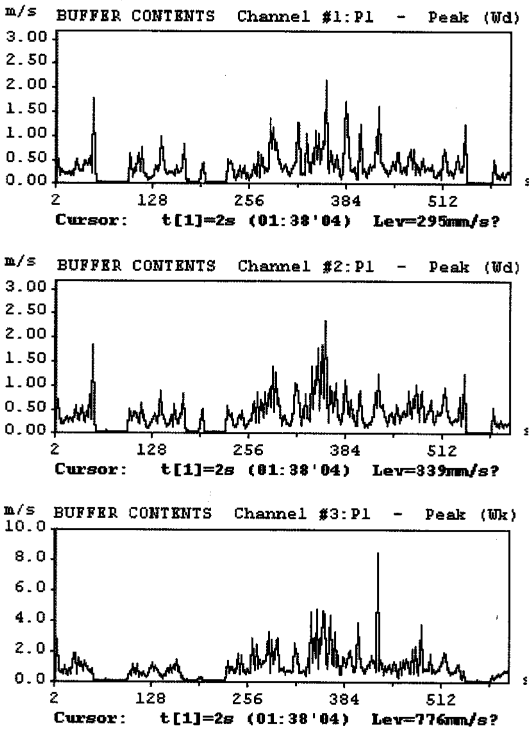
The three road surfaces (asphalt, cement, off-road) have the same characteristics. The similar RMS values are shown for the x, y axis. On the other hand, z axis values are about 2~3 times. As a result, it is expected that the horizontal vibration has less effect than vertical vibration on the driver's body.

When evaluate measurement values by the different

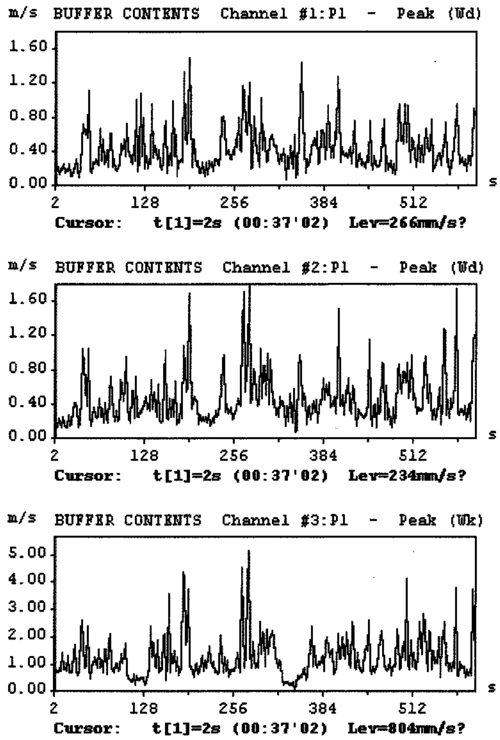
**Fig. 4.** Measuring devices



(a) Graph of measurement value at asphalt



(b) Graph of measurement value at cement



(c) Graph of measurement value at off-road

**Fig. 5**. The characteristic x,y,z axes values

road surfaces, RMS value of off-road is higher than others. The next is cement, and then asphalt.

Total evaluation is taken from the vector sum. The vector sum is the sum of the vectors for vibration exposure on the 3 axes. It is defined as;

$$a_{vs} = \sqrt{(1.4 \cdot a_{\omega x})^2 + (1.4 \cdot a_{\omega y})^2 + (a_{\omega z})^2} \quad \ldots\ldots (4)$$

Where, $a_{wx}$ , $a_{wy}$ , $a_{wz}$ are virtual values that apply to frequency weighted function (RMS).

By ISO 2631-1, It is not over 5.6 m/s$^2$ RMS for 10 minutes. ISO 2631-1 gives a vibration exposure limit of

**Table 2.** RMS values for different road surfaces (unit: m/s$^2$ RMS)

| Road surface | NO. | X-axis | Y-axis | Z-axis | Vector sum |
|---|---|---|---|---|---|
| Asphalt | 1 | 0.135 | 0.147 | 0.357 | 0.453 |
| | 2 | 0.177 | 0.183 | 0.370 | 0.514 |
| | 3 | 0.134 | 0.152 | 0.335 | 0.439 |
| Cement | 4 | 0.200 | 0.209 | 0.457 | 0.611 |
| | 5 | 0.169 | 0.178 | 0.440 | 0.558 |
| | 6 | 0.190 | 0.197 | 0.410 | 0.561 |
| Off-road | 7 | 0.368 | 0.374 | 0.650 | 0.981 |
| | 8 | 0.444 | 0.459 | 0.830 | 1.220 |
| | 9 | 0.507 | 0.513 | 0.850 | 1.320 |

not more than 10 minutes; $a_L = 5.6\ (t_0/t)^{1/2}\ (t_0=10\ \text{min})$.

All measurement values are not over the 5.6 $m/s^2$ RMS (exposure limit at 10 minutes). So, we think the three road surfaces are safe for the 10 minutes. The minimum time of duration of Asphalt is 19.78hour, cement is about 14 hours, off-road is about 3 hours. When the vector sum values are applied to the "health guidance caution zones", we conclude that the "health effects have not been clearly documented and/or objectively observed".

## 5. Conclusions

This study evaluates the whole-body vibration for different road surfaces given by ISO 2631-1. The results are as follows:

1) When we compare the measurement values along x,y,z axes, the z axis is higher than the x,y axes by 2~3 times.

2) The result of experiment show that the RMS values for off-road are the highest, with cement coming in next, and then asphalt.

3) Measurement vector sum ranges from 0.453$m/s^2$ to 1.320 $m/s^2$. It is not less than 5.6 $m/s^2$ (exposure limit) within first 10 minutes.

4) It is concluded that health effects have not been clearly documented and/or objectively assessed .

5) If the measurement values are within the safety zone, we need to know the duration of the limit.

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