Analysis and evaluation of the tram vibrations to human body

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Abstract – **The current paper discusses the impact of the rail motor carriage vibrations over the standing human comfort in the tram. The three axis accelerometer is installed on the tram floor at the wheel set center. The acceleration data are frequency weighted to model the human reaction to the different frequencies. The most commonly used weightings are Wk, Wd, Wb. The main characteristic which is used to evaluate the vibration impact is an effective acceleration value. Sometimes the sudden shock and the high amplitude accelerations are also included in the evaluation with the maximum transient vibration value (MTVV) and the vibration dose value (VDV) according to ISO 2631-1:1997 standard and the human health risk is valuated according to Directive 2002/44/EC. Some criteria are defined to interpret the results. According to these criteria the test shows that the tram accelerations are comfortable for the standing human.**

Keywords – **Human body, comfort, accelerations, vibrations**

I. INTRODUCTION

The rail transport hold out the more comfortable travelling towards other transport types. The travel comfort depends from lots of factors such as temperature, noise, seats, etc., but the accelerations have the main impact over the comfort. Their main parameters are recognized as an amplitude and frequency distribution and they depend from the vehicle construction, its technical condition, railway status, driver qualification, etc. The acceleration impact is valuated according to the ISO 2631-1:1997 standard - Mechanical vibration and shock - evaluation of human exposure to whole body vibration [1], national standards such as BS 6841 in UK [2], EU Directive 2002/44/EC about the safe and health conditions [3] and international standard ISO 8041:2005 [4] Human response to vibration — measuring instrumentation. A summary of the standards is made in the book [5]. The specificity of the vibrations in the rail transport is described in the UIC513 standard and the valuation methods are developed as Sperling's ride index.

The current paper describes a method to specify the vibration level on the tram floor and to evaluate the standing human comfort.

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II. SYSTEM DESCRIPTION

The 3D acceleration measurement consists of EK3LV02DL evaluation system from STMicroelectronics [6] and personal computer. The system includes the 3D MEMS linear accelerometer LIS3LV02D. It is able to measure accelerations in three axes in the range ± 2g, ± 6g, with a frequency from 40 to 2560 Hz and the sensitivity is equal to 1mg. The measurement system is installed on the rail motor carriage floor at the wheel set center, which axes are orientated according to the requirements of ISO 2631-1:1997 standard (Figure 1).

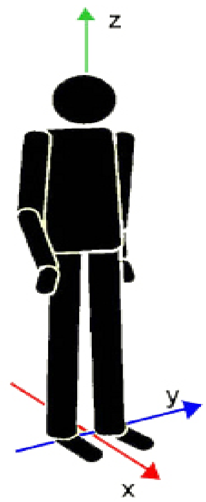

Figure 1. Basic axes of the standing human body

III. DATA ANALYSIS BASICS

The measured accelerations are processed according to the algorithm shown at Figure 2. The vibrations with equal amplitudes and different frequencies are perceived in a different way by humans, because the human body is very sensitive to the frequency equal to 5Hz. The equalized sensitivity is obtained by the filtration of the data by specially designed filters [1]. This standard defines the filter curves for different human body positions and different frequencies. The Figure 3 shows three of these curves. The Wk filter is used for filtration of the z data direction and for vertical recumbent direction (except head) while Wd filter is used for the x and y directions and for horizontal recumbent direction.

The main characteristic which is used for the valuation of the human comfort is recognized as an effective value of the weighted acceleration. Its value is estimated according to the following equation for each axis [1]:

$$a_{wj}rms = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(a_{wj}(n)\right)^2} \quad (1)$$

where N is sample number and j is the acceleration of the corresponding axis.

When some sudden shock appears then the crest factor is used to evaluate the human comfort. Its value is calculated according to the equation:

$$CF = \left|\frac{\max(a_w)}{a_{wj}rms}\right| \quad (2)$$

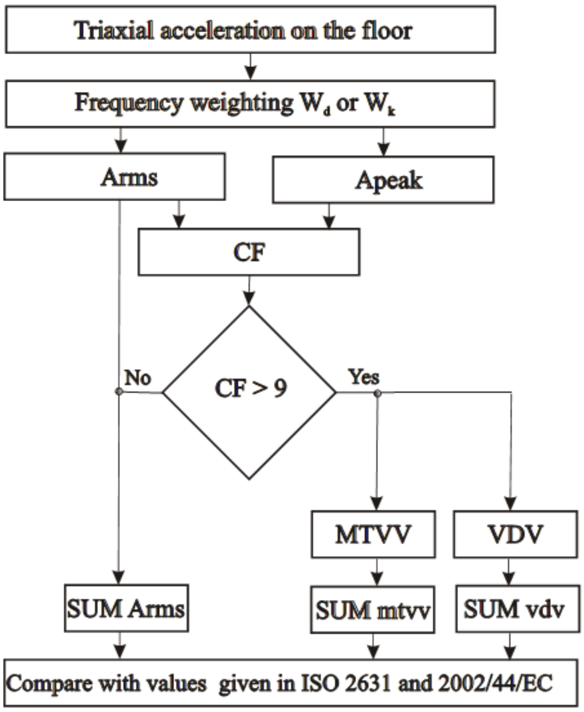

Figure 2. Algorithm of evaluation and assessment of whole-body vibration

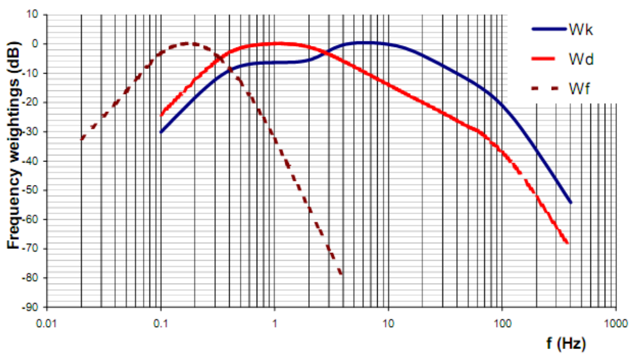

Figure 3. Frequency weighting curves for principal weightings

The crest factor is equal to 1 for the square wave signal, 1.4 for the sinusoidal signal and 1.7 for the Gaussian distributed vibrations. Its value is changed significantly when the sudden shock appears while the effective value remains unchanged. When the crest factor value exceeds 9 it is recommended to use the additional characteristics to evaluate the human comfort. The first characteristic is recognized as a maximum value of the vibrations. The moment vibrations and shocks are obtained by the data integration for a short time. The standard recommendations at [1] set this time to 1s. The maximum transient vibration value is calculated as:

$$MTVV_j = \max\left(\sqrt{\frac{1}{fs}\sum_{n=n_0}^{n_0+fs}\left(a_{wj}(n)\right)^2}\right) \quad (3)$$

where fs is the sampling frequency, n_0=0,1,2….N-fs-1.

The second characteristic is recognized as a vibration dose value (VDV). This characteristic is more sensitive to the peak values than the MTVV value. The vibration dose value is calculated as:

$$VTV_j = \sqrt[4]{\frac{1}{fs}\sum_{n=0}^{N}\left(a_{wj}(n)\right)^4} \quad (4)$$

The additional characteristics are important for the final valuation when the following thresholds are exceeded:

$$\frac{MTVV_j}{a_{wj}rms} = 1.5 \quad (5)$$

and

$$\frac{VDV_j}{a_{wj}rmsT^{1/4}} = 1.75 \quad (6)$$

The total effective value is calculated from the effective values of each axis as follows:

$$a_v = \sqrt{\left(k_x^2 a_{wx}rms\right)^2 + \left(k_y^2 a_{wy}rms\right)^2 + \left(k_z^2 a_{wz}rms\right)^2} \quad (7)$$

where $k_x, \_k_y\_k_z$ are coefficients which values depends from the human position and vibration direction.

When the human body is standing then the coefficients are equal to 1. The weighted vibration magnitude (total of three axes) is compared with the standard values (Table 1) and the final valuation is established.

TABLE 1 [1]

Weighted vibration magnitude (total of three axes) [m/s^2]	Likely reaction in public transport
Less than 0.315	Not uncomfortable
0.315 to 0.63	Little uncomfortable
0.5 to 1	Fairly uncomfortable
0.8 to 1.6	Uncomfortable
1.25 to 2.5	Very uncomfortable
Greater than 2	Extremely uncomfortable

The Directive 2002/44/EC defines the top values of these characteristics regarding the exposure of workers to the risks arising from physical agents (vibrations).. These values are shown at Table 2.

TABLE 2

Exposure action value	$a_w$rms [m/s^2]	VDV [m/s$^{1.75}$]
A daily exposure action value	0.5	9.1
A daily exposure limit value	1.15	21

The daily vibration dose which is obtained during the 8 hour working day is calculated as follows:

$$A_{wj}(8) = k_j a_{wj} rms \sqrt{\frac{T_{\exp}}{8}} \qquad (8)$$

where k_j is equal to 1.4 for x and y axes and 1 for z axis and T_{exp} is the exposing time.

In this case the maximum exposing time may be calculated to reach the maximum values from Table 2. The equation also may be used to calculate the vibration dose as follows:

$$VDV_{\exp j} = k_j VDV_j \sqrt[4]{\frac{T_{\exp}}{T_{meas}}} \qquad (9)$$

where T_{meas} is a recording time, VDV_j is measured value for the time period equal to T_{meas}.

IV. EXPERIMENTAL RESULTS

The experimental data are measured by two transitions of the tram on the same road. The sampling frequency is equal to 640Hz and the accelerometer dynamic range is set to ±6g. The recorded time is equal to 25 minutes so the data are statistically representative for the railway section. The recorded data are processed according to the algorithm shown at Figure 2 and it is integrated in the MATLAB environment. The weighted value of the Z acceleration, the maximum transient vibration value (MTVV) and the vibration dose value (VDV) are shown at Figure 4. The Figure 5 represents the data during the time interval between 840 and 1200 s.

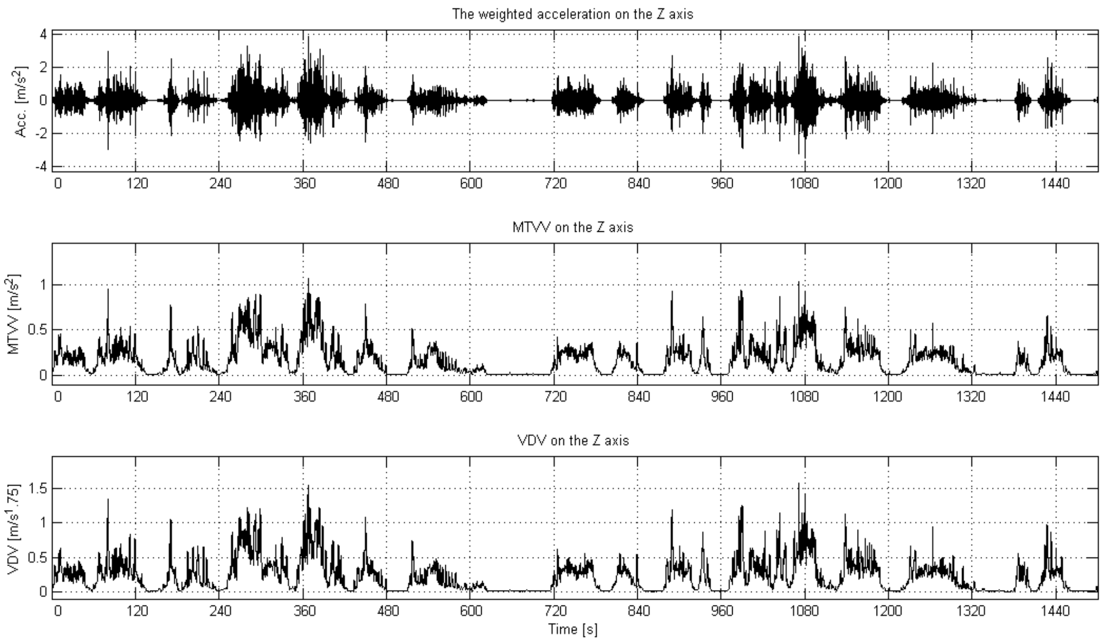

Figure 4. A_{wz}rms, MTVV and VDV

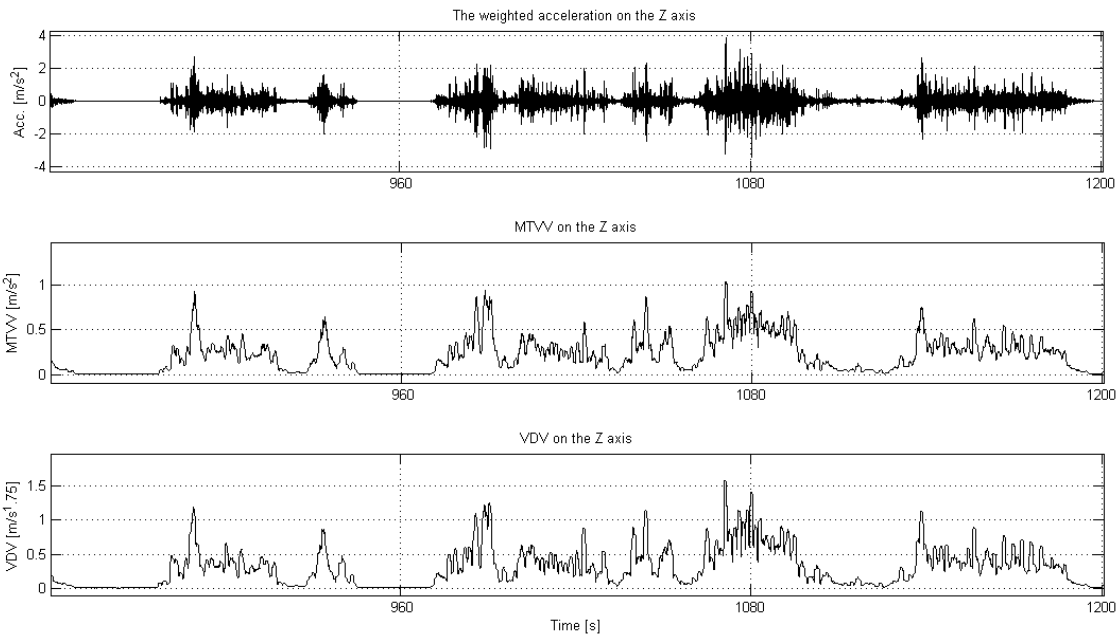

Figure 5. A_{wz}rms, MTVV and VDV during the time interval 840-1200s

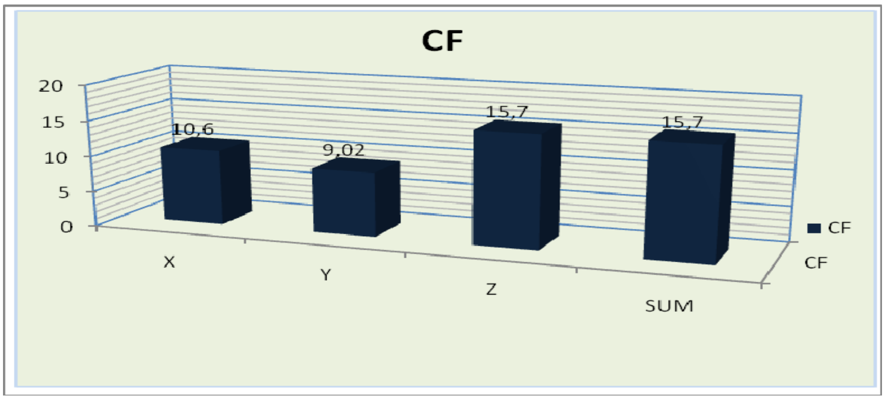

Figure 6. Crest factor

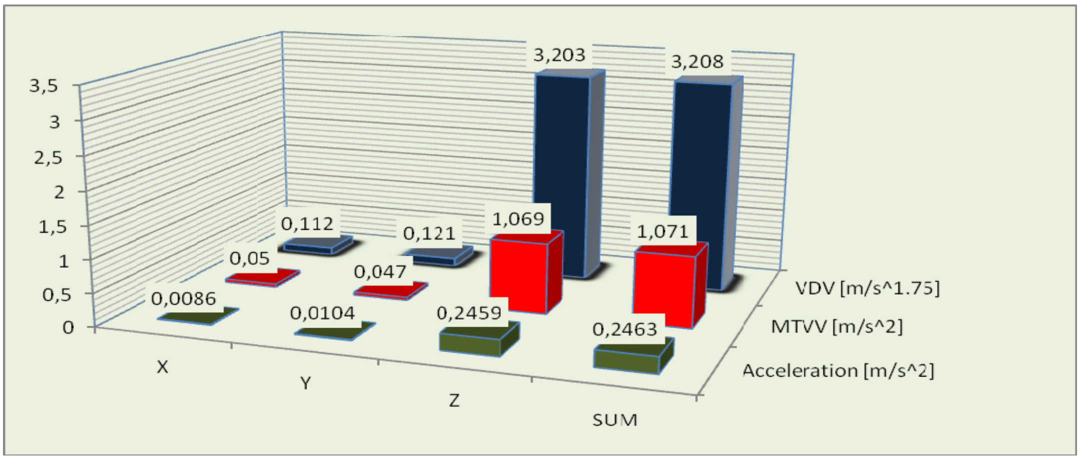

Figure 7. Values of the A_{wj}rms, MTVV and VDV

The calculated values of the crest factor exceed 9 for all three axes (Figure 6). The conditions (5) and (6) are also fulfilled which require the calculation of the additional characteristics. The measurements results for the effective value of the weighted acceleration, the maximum transient vibration value (MTVV) and the vibration dose value (VDV) for each axis are shown at Figure 7.

The calculated values do not exceed the threshold values described at Table 1 and Table 2 which defines the valuation of the human comfort as not uncomfortable and the vibration values as safe for the human health.

V. Conclusion

The current paper discusses a method for standing human comfort valuation according to standards ISO 2631-1:1997 and EU Directive 2002/44/EC. Also the algorithm for calculation of the main characteristics is developed and studied which may be also used for valuation of the vibration influence to the sitting human. The obtained results show that the vibrations are not uncomfortable and the vibration values are safe for the human health.

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