Mechanical Testing and Diagnosis
ISSN 2247 – 9635, 2017 (VII), Volume 1, pp. 28-35

WHOLE BODY VIBRATION OF A PUSHTOW BOAT CREW OPERATING ON THE DANUBE RIVER

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ABSTRACT

The purpose of this paper is to determine the Whole Body Vibration (WBV) of the workers operating on a pushtow boat on the Danube. Experiments were made on a Danube pushtow boat between Braila - Galati (a distance of about 20 km). The vibrations measurements were made with Maestro 01dB (to measure the vibrations transmitted to the people) and with Examiner (to measure the vibrations produced by the equipment). Measurements were made on the main deck. Six male subjects, aged of 25-48 years, weighting 68-95 kg, participated in this experiment. No subject drinks alcohol frequently, 4 of the subjects smoke. The accelerations transmitted to workers were measured on all three directions and the weighted acceleration, the vibrations dose and the estimated vibration were calculated for 2 situations: idling and with load. It is noted that, in case of load, all accelerations are higher than in the case of idling. The $A_{r.m.s.}$ *for both situations (idling and with load) are more than 18 times higher than the values above which adverse comments are probable. The dose value and the estimated vibration dose value are much higher than the limit value at which the action starts. In these situations, it would be better to replace the old engine with a new one. If this is not possible, it would be good to place the engine on vibro-absorbing materials.*

Keywords: Whole Body Vibration, weighted acceleration, vibrations dose, estimated vibration, pushtow boats

1. INTRODUCTION

The human body is, both physically and biologically, an extremely complex system. When considered as a mechanical system, it can be considered to be composed of linear and nonlinear elements, with quite different mechanical properties, from one person to another [2, 4]. From a biological point of view, the situation is more complicated, especially when psychological effects are included [3].

The human body is considered to be a mechanical system for which the distinctive resonance effect appears in the range 3 ÷ 6 Hz. It was also found that, in the range of 60 ÷ 90 Hz, disturbances are felt in the eyeball, suggesting resonance, and in the range 100 ÷ 200Hz, the resonance effect was observed in the lower part of the mandible / skull system (Fig. 1).

From the point of view of the vibrations impact, the low frequency domain is the most important. Some of the most interesting measurements were made by Rasmussen (1982) [4], who established the range of resonance frequencies for each part of the human body (Table 1).

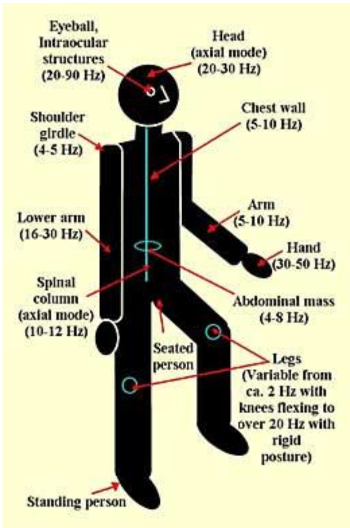

Fig. 1 The resonant frequencies of the human body

Vibrations at frequencies lower than 1 Hz occur in several types of transport vehicles and produce effects, such as kinetosis (motion sickness), which have completely different characteristics from those produced at higher frequencies.

These effects can not be easily correlated with the three motion parameters: intensity, duration and frequency, as it was possible in the range 1 ÷ 80 Hz. In addition, human reactions to vibrations below 1 Hz are extremely variable and appear to depend on a large number of external factors that have no connection with movement, e.g. age, gender, images, activity, odors [5].

Table 1. Symptoms due to whole-body vibration and the frequency range at which they usually occur (Rasmussen, 1982 [4]).

Symptoms	Frequency (Hz)
General feeling of discomfort	4-9
Head symptoms	13-20
Lower jaw symptoms	6-8
Impact on speech	13-20
“Lump in throat”	12-16
Chest pains	5-7
Abdominal pains	4-10
Urge to urinate	10-18
Increased muscle tone	13-20
Influence on breathing movements	4-8
Muscle contractions	4-9

Human response to whole body vibration depends on vibration frequency, vibration acceleration, and exposure time [6]. Because of the difficult assessment of vibration response and inconsistency of research data, the International Standardization Organization, through ISO 2631/1:1997÷2631/5:2004 [7, 8, 9, 10], has established the Human Exposure Assessment of Whole Body Vibration. When using these criteria and limits, it is important to keep track of application restrictions.

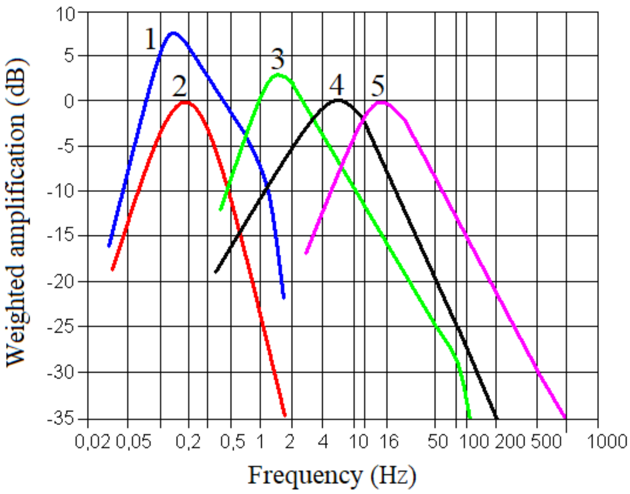

Fig. 2. Human body response to different vibrations: 1- Motion sickness / decreased comfort, 2 - Motion sickness / increased discomfort, 3 - Whole body / transverse vibrations a_x and a_y, 4 - Whole body / longitudinal vibrations a_z, 5 - Hand-arm

Some studies indicate that the standards are not low enough and that the diseases of the muscular and bone systems arise also from exposure to vibrations with values below the standard values [11]. The standard is only suitable for healthy people with a normal life routine, who are under the stress of a normal work day (Table 2). The standard provides numerical limits for exposure to vibrations transmitted from solid surfaces to the human body in the 1-80 Hz frequency range. The standard refers to three different levels of interest: decreased comfort, decreased dexterity due to fatigue and exposure limits.

Table 2. Daily exposure limit and action values for WBV, as specified in the EU Vibration Directive (2002/44)

The exposure value on which the action is triggered (EAV)	Exposure limit value (ELV)
0.5 m/s^2 A(8) r.m.s.	1.15 m/s^2 A(8) r.m.s.
9.1 $m/s^{1.75}$ VDV	21 $m/s^{1.75}$ VDV
15 $ms^{-1.75}$ e_{VDV}	17 $ms^{-1.75}$ e_{VDV}

2. VIBRATION EVALUATION

Results interpretation depend on the application field (health, comfort or perception) and it is made by comparing the obtained results to those given by ISO 2631-1 (Table 3).

Figure 2 shows the allowed exposure levels for 24 h vibrations [12, 13]. From a biological point of view, the situation is more complicated, especially when psychological effects are included [1].

Table 3. Comfort level depending on the value of the weighted vibration on the 3 axes

The value of the weighted vibration (total on the 3 axes)	Comfort level
< 0.315	Comfortable
0.315 – 0.63	Slightly uncomfortable
0.5 - 1	A little uncomfortable
0.8 – 1.6	Uncomfortable
1.25 – 2.5	Very uncomfortable
> 2	Extremely uncomfortable

3. MATHEMATICAL BACKGROUND

Vibration measurements are recommended to be made on multiple axes. For continuous or repetitive signals, consecutive measurements can be made on x, y and z axes to the maximum weighted effective value of aW acceleration obtained from:

$$a_w = \sqrt{a_{wx}^2 + a_{wy}^2 + a_{wz}^2} \tag{1}$$

where a_{wx}, a_{wy}, a_{wz} are the three-axis accelerations, frequency and time weighted. This relation leads to the maximum value of weighted effective value acceleration. The minimum value will be given by the highest value measured on a single axis [14].

The vibration evaluation must include measurements of the weighted mean square acceleration (r.m.s). It is expressed in [m/s^2] for translational vibrations and in [rad/s^2] for rotation vibrations (SR ISO 2631-1).

$$a_w = \sqrt{\frac{1}{T}\int_0^T a_w^2(t)dt} \tag{2}$$

where a_w is the weighted mean acceleration, $a_w(t)$ is the weighted acceleration over time, T the measurement duration [s].

Weighted r.m.s. acceleration must be determined for each axis of translational vibrations. The assessment of the vibrations effect on health must be carried out independently on each axis (ISO 2631-1).

Section 6 of ISO 2631-1 [7] specifies the r.m.s averaging of the acceleration based on the comfort assessment method during movement. Weighted acceleration r.m.s. [m/s^2] on a discrete time domain is given by:

$$a_{r.m.s.} = \sqrt{\frac{1}{N}\sum_{n=0}^{N-1} a_w(n)^2} \tag{3}$$

where $a_w(n)$ is the n^{th} value of the weighted acceleration and N is the total number of measurements.

Also, it is extremely useful to calculate the VDV vibrations dose. The VDV method uses the fourth power of the vibrations magnitude, which is more shock-sensitive than using the second power in the r.m.s. acceleration calculation. The VDV measurement unit is $m/s^{1.75}$ and the VDV is given by:

$$VDV = \sqrt[4]{\frac{1}{\nu_s}\sum_{n=0}^{N-1} a_w(n)^4} \tag{4}$$

where $a_w(n)$ is the current weighted acceleration, ν_s the frequency of the measurement and N the total number of measurements.

The values on each axis are summed, giving the total weighted acceleration r.m.s.:

$$A_{r.m.s.} = \sqrt{\left(k_x^2 \cdot a_{wx}^2\right) + \left(k_y^2 \cdot a_{wy}^2\right) + \left(k_z^2 \cdot a_{wz}^2\right)} \tag{5}$$

where $a_{wx/y/z}$ are r.m.s. accelerations, weighted on the axes x/y/z, and k is the multiplication factor given in ISO 2631-4:2001.

Estimated Vibration Dose Value (eVDV). It is possible to estimate the vibration dose value using an alternative formulae.

$$eVDV = k \cdot a_{rms} \cdot t^{0.25} \tag{6}$$

where k is nominally 1.4 for Crest Factors below 6 (For Crest Factors above 6, the eVDV equation may be inaccurate and this estimate should not be used); a_{rms} is weighted RMS acceleration (m/s^2) and t is total cumulative time (seconds) of the vibration events(s) or period(s) of vibration.

The purpose of this paper is to determine the WBV for workers on a pushtow boats on the Danube.

4. MATERIALS AND METHODS

Experiments were done on a Danube pushtow boat between Braila - Galati (a distance of 20 km).

Pushtow boats have become indispensable in the river transport. During their use, the mechanics are exposed to whole body vibrations [15]. Because of these vibrations, the mechanics suffer from different vascular and neurological disorders, skeletal and muscle disorders [16]; the most often outcomes appear at 8–1000 Hz frequencies [17]. The human body is subjected to the action of vibration, when the worker is in the engine room or other areas with vibrating equipment on a boat. It turned out that the vibrations lead to a disorder of the muscle and bone systems, both of hand and arm, neck and back [18, 19].

In 2000, the ISO 6954 [20] has been revised and the criteria were based on an integrated weighted overall r.m.s. level [21]. A complete approach was made with ISO 6954:2000; this regulation introduced the concept of „habitability”, which refers to the living conditions of the people on board, clearly giving the limit values of the r.m.s. accelerations for each case (Table 4).

Table 4. Acceleration limit values for different areas (Guidelines for the habitability)

	A - type areas may be applicable to passenger cabins	B - type areas to crew accommodation areas	C - type areas to working areas
Values above which adverse comments are probable	0.143	0.214	0.286
Values below which adverse comments are not probable	0.0715	0.107	0.143

Fig. 3. WBV - main deck

Fig. 4. Vibrations transmitted to the floor - main deck

The vibrations measurements were done with Maestro 01dB (to measure the vibrations transmitted to the people) and with Examiner (to measure the vibrations produced by the equipment) (Figs. 3 and 4).

Measurements were done on the main deck. WBV determinations are in accordance with ISO 2631-1/1997 and compared to its provisions.

However, it is a well-known fact that people respond differently to the same type of external stress. Because of this, equal response human curves, also known as sensitivity curves, are different in ISO 2631 - 1/2 as opposed to those from ISO 6954.

Another important factor is the weather; if there is a strong wind [22], this significantly influences the measurements. Also, the wave conditions are usually significant and strong currents induced there by the Danube river outflow lead to interactions between waves and currents [23, 24]; this fact increases the acceleration transmitted to the crew.

In addition to those shown here, there are other important rules in the vibrations of the ship: Det Norske Veritas (DNV) (1994), Lloyd’s Register (LR) (1998), Bureau Veritas (BV) (1999), American Bureau of Shipping (ABS), Germanischer Lloyd (GL) and Italian Classification Society (RINA).

Six male subjects, aged of 25-48 years and weighting 68-95 kg, participated in this experiment. No subject drinks alcohol frequently, 4 of the subjects smoke (Table 5). The accelerations transmitted to workers were measured on all three directions and the weighted acceleration, the vibrations dose and the estimated vibration were calculated for 2 situations: idling and with load (Table 6).

Table 5. Anthropometric data of test subjects

Subject	**Age (years)**	**Weight (kg)**	**Height (m)**	**Work experience (years)**	**Pain of spine**
Subject 1	39	71	1.68	11	X
Subject 2	48	89	1.82	26	X
Subject 3	35	68	1.56	14	X
Subject 4	25	95	1.86	17	-
Subject 5	41	92	1,75	15	X
Subject 6	46	88	1,84	10	X

Table 6. Measurement duration

Subject	**Sub. 1**	**Sub. 2**	**Sub. 3**	**Sub. 4**	**Sub. 5**	**Sub. 6**
t (s) idling	1500	1800	1800	2100	1200	1500
t (s) with load	3600	3600	3600	3600	3600	3600

5. RESULTS AND DISCUSSIONS

The results are shown in Figures 5÷10. These figures clearly show the action value (║) and limit value (█) for each calculated parameter, according to health care guidelines.

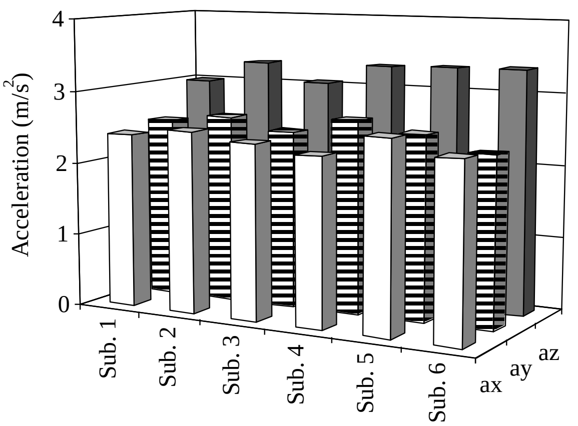

Fig. 5. Average of accelerations ax, ay, az for subjects on main deck - idling case

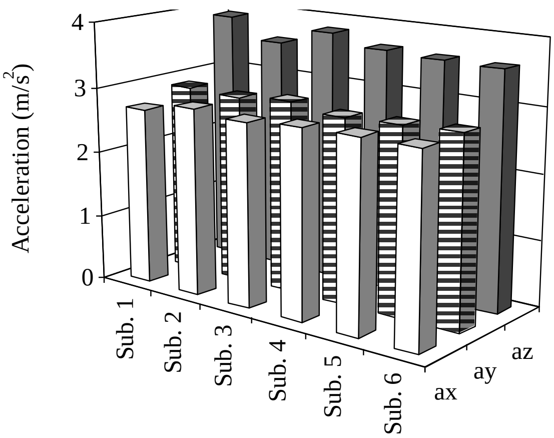

Fig. 6. Average of accelerations ax, ay, az for subjects on main deck - with load

Figures 5 and 6 show that, for the Ox and Oy axes, the accelerations have very close values: for idling: $\bar{a}_X$ =2.4333 m/s^2 and $\bar{a}_Y$ =2.5116 m/s^2; for Oz axis: $\bar{a}_Z$ =3.2266 m/s^2 (0.7 - 1.3 times higher than on Ox or Oy).

In the case with load: $\bar{a}_X$ =2.8151 m/s^2 şi $\bar{a}_Y$ =2.8683 m/s^2 for Oz axis, $\bar{a}_Z$ =3.6883 m/s^2 (1.28-1.31 times higher than on Ox or Oy).

It is noted that in case of load all accelerations are higher than in the case of idling. Also, for subjects 1 and 3 (that are weaker), the accelerations are higher than for the rest of the subjects.

For working areas, the value above, which adverse comments are probable, is 0.286 m/s^2 and the value below which adverse comments are not probable is 0.143 m/s^2.

Figures 7 and 8 show that $A_{r.m.s.}$ for both situations (idling and with load) are more than 18 times higher than the values above which adverse comments are probable.

Figures 9 and 10 show that the dose value and the estimated vibration dose value are much higher than the limit value at which the action starts.

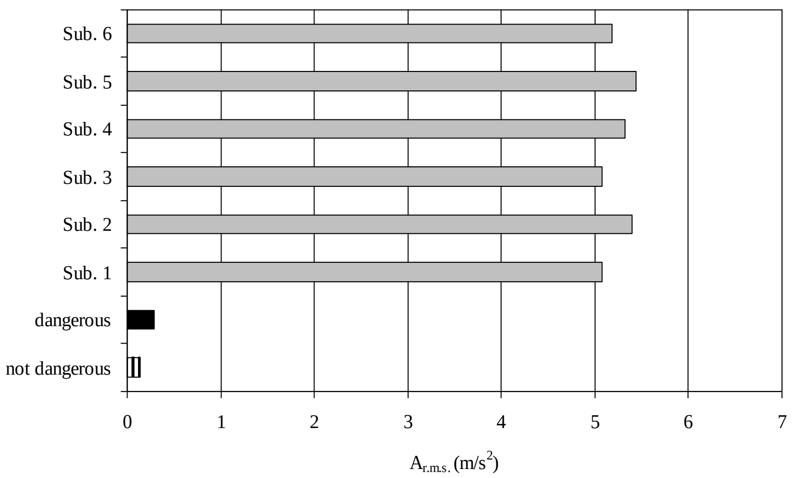

Fig. 7. Average of accelerations $A_{r.m.s.}$ for subjects on main deck - idling case (‖) - action value; (▌) - limit value

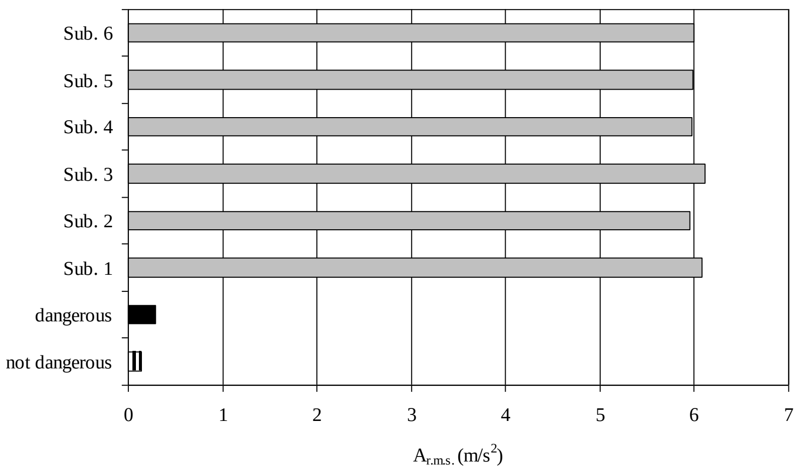

Fig. 8. Average of accelerations $A_{r.m.s.}$ for subjects on main deck - with load (‖) - action value; (▌) - limit value

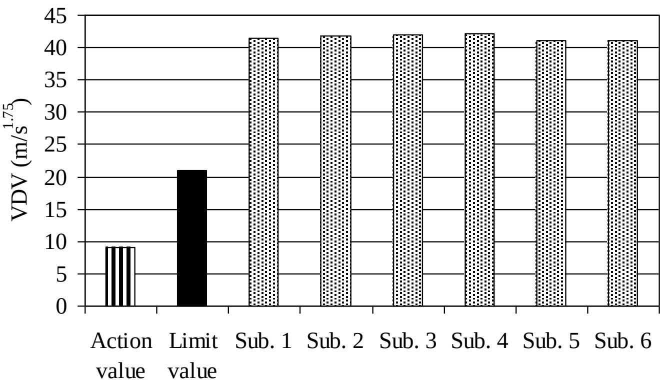

Fig. 9. Average of dose value VDV for subjects on main deck - for both cases: idling and with load (‖) - action value; (▌) - limit value

6. CONCLUSIONS

It is a well-known fact that people respond differently to the same type of external stress. Because of this, equal response human curves, also known as sensitivity curves, are different in ISO 2631-1/2 as opposed to those from ISO 6954.

From this perspective, it was found in the present work that, with the increasing power from idling to rolling with load, the vibrations increase.

The acceleration values measured for all the subjects are only slightly different.

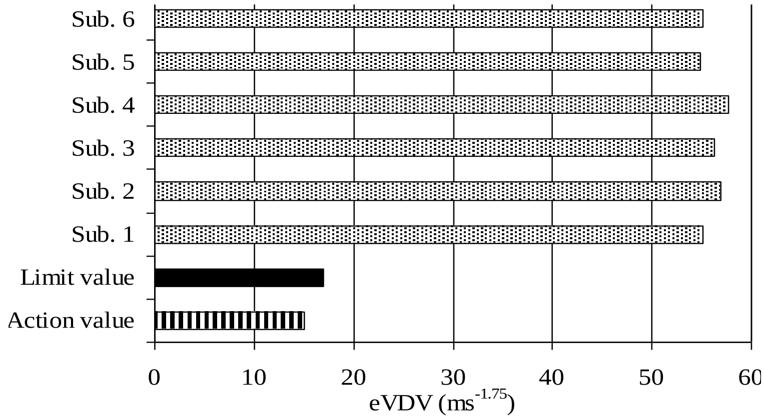

Fig. 10. Average of estimated vibration dose value (eVDV) for subjects on main deck - for both cases: idling and with load (‖) - action value; (▌) - limit value

Knowing that in the river transport, the work is carried out usually by-stages, the activities with a high level of vibrations do not influence the mechanics the whole year, so the risk of occurrence of diseases due to vibrations is diminished, but it still remains.

In these situations, it would be better to replace the old engine with a new one. If this is not possible, it would be good to place the engine on vibro-absorbing materials.

AKNOWLEDGEMENT

This work was carried out in the framework of the project proposal REMARC, submitted under the number PN-III-P4-IDPCE-2016-0017 to the Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding, UEFISCDI.

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