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Comparative study of vibration-absorbing materials to improve the comfort of the crew on a river ship

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Abstract. The purpose of this paper is to find a damping material for the vibrations generated by the equipment of a ship. That will improve the working and resting conditions of seafaring personnel on a pusher boat that travels over long distances. The experiments were made upstream the Danube. The convoy was made up of a self-propelled vessel and four barges. The water flow rate was 0.76 m/s and there were good visibility conditions and light wind. The accelerations transmitted to man were measured with Seat PAD 01dB triaxial accelerometers mounted on the floor of the ship and connected to the NetdB-Complex system for analysis and measurement. The working frequencies were 0÷100 Hz. Subjects were placed directly on the ship's deck, then on neoprene and rigid foam. It was found that for longitudinal vibrations, the r.m.s. accelerations are 9 times higher than standard if there is no attenuator, 4.8 times higher than standard for neoprene and 2.4 times higher in the case of rigid foam. For transverse vibrations, r.m.s. accelerations are 10.8 times higher than standard when there is no attenuator, 6.4 times higher in the neoprene case and 2.7 times higher for rigid foam. For vertical vibrations, accelerations r.m.s is 5.9 times higher than standard if there is no attenuator, 3.4 times higher for neoprene and 1.7 times higher for rigid foam. The results are similar in the case of transmissibility determination. It was shown the importance of a vibration attenuator for the health, comfort and implicitly for labour productivity of river sailing personnel.

1. Introduction
The mechanical vibrations generated by equipment during work lead to the occurrence of occupational diseases. The admissible vibrations limits depend on their physical characteristics: frequency, amplitude, acceleration, speed. Vibration generation can be: desirable (vibratory tools and machines) and undesirable (technical failures, means of transport).

Vibrations are transmitted directly to the worker's body in two main ways:

a) Action on the whole body (Whole Body Vibrations) through the lower limbs (if the worker stands in orthostatic position on the surface that vibrates: ground, floor, platform, etc.) or through the part of the body that is sitting on a chair that vibrates and through the lower limbs of pedals, etc. (if the worker is in the sitting position) with a frequency of 0÷20 Hz.

b) The action on the hand-arm system (Hand-Arm Vibrations), a system that supports, pushes, guides the vibratory (pneumatic) tools with a frequency of 20÷200 Hz.

Vibrations act on: vibration-sensitive receptors; internal organs in the abdominal and pelvic cavity; the osteoarticular system (mainly on the spine); directly on the muscles, tendons, etc. [1-6]:

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a) Occupational diseases due to professional vibration with a frequency of 0÷2 Hz (motion sickness) occur in the personnel who work in aeronautical or maritime transport, etc. Linear movements are transformed into elliptical movements at head due to reflex reactions of the head, causing vestibular stimulation, responsible for clinical manifestations.

b) Occupational diseases due to professional vibrations with 2÷20 Hz frequency (general vibration illness) occur in the following professions: trucks, tractors, excavators, bulldozers drivers, etc. These vibrations lead to rhythmic movements of the organs in the abdominal and pelvic cavity, as well as to the displacements of the vertebra.

c) Occupational diseases due to professional vibrations with 20÷1000 Hz occur in all professions that use vibratory tools and machines that act on the hand-arm system: miners (due to pneumatic equipment), workers in the machine-building industry used for riveting, moulding casting etc.

For example, American sailors are exposed to a very high number of risks due to mechanical vibrations; pneumatic tools are one of the potential exposure hazards for HAV [7], but WBV is a negative factor [8].

Another example is given by Netudykhata Oiu [9], which presents the connections between social, psychological, economic, physiological and hygienic factors, between age and occupation. Navigation for longer than 6 months, continuity, vibration, air temperature, noise, chemical factor, ship's diet, atmospheric humidity and motion air lead to deterioration of the seamen's physical and mental state: excessive fatigue, low working capacity, restless sleep, abnormal irritability, depressive state.

Chan et al., 2006 [10] shows that, in addition to all these presented factors, smoking and drink (outside the ship) contribute to the deterioration of the crew’s health.

In this paper we will refer to the vibrations transmitted to the navigational staff of a riverboat (a pusher). In this case, things are different from on land workers because the sailing personnel besides working on the ship they are also living there for several weeks. In other words, their activities are divided into several categories: surveillance, maintenance, training, meeting, sleeping, free & personal time [11]. These
categories do not comply with the periods indicated by the legislation in force [12], mostly to the
detriment of sleep and personal time (Figures 1.a) and 1.b)). This is caused by the lack of personnel.

Figure 1.c) illustrates the deviation of sailor from the Navy Standard Workweek (NSW). The
deviation was calculated using the following formula:

\[
\text{Deviation} = \frac{(\text{Reported} - \text{Allocated})^2}{\text{Allocated}}
\]  
(1)

Sailor shows the greatest deviation from the Navy Standard Workweek (NSW) in the categories of
standing watch and training [13].

The purpose of this paper is to find an attenuating material for the vibrations generated by a ship's
equipment to improve the working and resting conditions of seafaring personnel on a long-distance
Danube pushing ship.

2. Materials and methods

The experimental determinations took place in August 2018 on the upstream Danube, between Orșova
(km 954) and Baziaș (km 1072), Romania (Figure 2), on certain segments of approximately 1 km long.

Figure 2. The distance over where measurements were made on the Danube:
Orșova (km 954) and Baziaș (km 1072)

The convoy was made up of a propelled vessel and four barges coupled in front of the pusher
(Figure 3). The characteristics of the vessel are: length 20.73 m, width 7.78 m, total height to the main
deck is 3.30 m at the bow and 3.70 m at the stern; maximum draft 1.50 m; fresh water displacement of
152 tons and MP 2x500 hp. The propulsion system of the ship consists of propellers in modern nozzles
with rounded rear edges. Barges have a length of 70.05 m, width of 11.60 m, a useful weight of 1398 t.

The characteristics of the convoy are: length 160.83 m, width 23.20 m, draft 2.42 m, maximum
load capacity 5512 t, real load 4614 t (83.71% - including pusher), maximum displacement maximum
6844 t, real displacement 5900 t. Speed of the water flow was 0.76 m/s, with good visibility and light
wind (0-5 m/s). Measurements were made over a distance of 118 km, over certain segments of
approximately 1 km long. The time corresponding to each analyzed segment was 7-8 min. The speed
over the ground was approximately 7.92 km/h and over water approximately 10.66 km/h.
The accelerations transmitted to man were measured with Seat PAD 01dB triaxial accelerometers mounted on the floor of the vessel and connected to the NetdB - Complex system for the analysis and measurement of vibration to the human body. Data was processed with the dBFA Suite - 01dB Control Software for data acquisition and post-processing. The working frequencies were 0÷100 Hz. Subjects were placed directly on the ship's main deck, then on neoprene and rigid foam (Figure 4), making comparisons according to the legislation in force. The elastic features of neoprene and rigid foam have been analyzed in a previous paper [14].

3. Results and discussions

The experiments took place on the Danube, upstream, during a 118 km trip, on certain sections of approximately 1 km. These sections were completed in 7 min and 40 s; the shore speed was 7.4 km/h, water speed 2.7 km/h and the engine revolution was 1800 rpm.

Longitudinal, transverse and vertical vibrations transmitted to the subjects by the ship's equipment were measured in 3 cases: the subject placed directly on the deck (Figure 4), the subject placed on neoprene and on rigid foam.

Were measured the amplitude of the output vibration frequency for the materials studied. Also, the transmissibility was determined according to the relationship [15]:

$$T = \frac{a_{\text{out}}}{a_{\text{in}}}$$

(2)

where $a_{\text{in}}$ is the maximum acceleration input and $a_{\text{out}}$ is the maximum acceleration output.

The working frequencies are shown in Table 1 (small frequencies of interest to the human body). 1/3 octave bands were used to provide a further in-depth outlook on vibration levels across the frequency composition.
Table 1. The frequency spectrum (Hz) which was used

| Octave | Lower band limit | Middle of the band | Top band limit |
|--------|------------------|--------------------|---------------|
|        | 11               | 16                 | 22            |
|        | 22               | 31.5               | 44            |
|        | 44               | 63                 | 88            |

| The 1/3 octave | Lower band limit | Middle of the band | Top band limit |
|----------------|------------------|--------------------|---------------|
|                | 14.1             | 16                 | 17.8          |
|                | 17.8             | 20                 | 22.4          |
|                | 22.4             | 25                 | 28.2          |
|                | 28.2             | 31.5               | 35.5          |
|                | 35.5             | 40                 | 44.7          |
|                | 44.7             | 50                 | 56.2          |
|                | 56.2             | 63                 | 70.8          |
|                | 70.8             | 80                 | 89.1          |
|                | 89.1             | 100                | 112           |

Figure 5. Determination of the vibratory properties

Figure 6. Experimental assembly to determine the vibration damping through different mediums (1) exciter, (2) contact sheets, (3) damper medium, (4) accelerometer for the final vibrations, (5) accelerometer for the initial excitation, (6) acquisition system NetdB

Figure 7. Variation $a_{r.m.s.}$ for the three situations: without damper, neoprene and rigid foam versus legislation ($r.m.s. = \text{root mean square}$)
The determination of the accelerations and transmissibility for the neoprene analysis (Figure 5.b) and rigid foam (Figure 5.a) was made with the equipment in Figure 6.

When determining transmissibility, the results are similar: for small frequencies (of interest to the human body), rigid foam proved to be better than neoprene (Figure 7).

**Figure 8.** Variation of $a_{r.m.s.}$ according with legislation: (■) – Longitudinal; (o) – Transversal; (▲) – Vertical

**Figure 9.** Variation of $a_{r.m.s.}$ without damper: (■) – Longitudinal; (o) – Transversal; (▲) – Vertical

**Figure 10.** Variation of $a_{r.m.s.}$ with neoprene: (■) – Longitudinal; (o) – Transverse; (▲) – Vertical

**Figure 11.** Variation of $a_{r.m.s.}$ with rigid foam: (■) – Longitudinal; (o) – Transverse; (▲) – Vertical

Following the determinations, it was found that:

a) for **longitudinal** vibrations, accelerations r.m.s. are 9 times higher than the standard (Fig. 8) if there is no attenuator (Fig. 9), 4.8 times higher when we use neoprene (Fig. 10) and 2.4 times higher than the standard for rigid foam (Fig. 11);
b) for transverse vibrations, accelerations r.m.s. are 10.8 times higher than standard when there is no attenuator (Fig. 9), 6.4 times higher for neoprene (Fig. 10) and 2.7 times higher for rigid foam (Fig. 11);

c) for vertical vibrations, accelerations r.m.s. are 5.9 times higher than standard if there is no attenuator (Fig. 9), 3.4 times higher for neoprene (Fig. 10) and 1.7 times higher for rigid foam (Fig. 11).

“Using the resonant method the natural frequency will be determined for an oscillating system with one degree of freedom (where the spring is made up from the material to be studied), also it will be determined the bandwidth of the frequency that corresponds to certain level decreases near the resonance area and amplitude oscillatory motion speed decrease.” [14]

Abbreviation with $f_0$ the resonance frequency of the respective material and with $f$ the working frequency, then transmissibility will be represented the as a function of the ratio $r = f/f_0$.

For $r \in (0;1)$:

- in the case of neoprene: $T = 2.8244 \cdot \ln(r) + 11.533$  \hspace{1cm} ($R^2 = 0.9087$) (3)
- in the case of rigid foam: $T = 2.877 \cdot \ln(r) + 8.9578$ \hspace{1cm} ($R^2 = 0.9406$) (4)

If $r \in (1;10)$:

- for neoprene: $T = 0.5888 \cdot \ln(r) - 0.2568$ \hspace{1cm} ($R^2 = 0.9225$) (5)
- for rigid foam: $T = 0.5507 \cdot \ln(r) - 0.2913$ \hspace{1cm} ($R^2 = 0.8263$) (6)

Figures 12 and 13 show that the transmissibility is greater for neoprene than for rigid foam (so rigid foam is better insulator for vibrations transmitted by the ship than neoprene).

4. Conclusions

From the studies conducted, it was easy to see that the vibrations transmitted by the ship's working equipment far exceed the limits indicated by the legislation in force. These vibrations, along with long ship stays, air temperature, noise, atmospheric humidity, and diet on the ship, can lead to irritability, depression, etc. All these inevitably lead to fatigue, to the change in circadian rhythm and implicitly to sleep problems.

These results have shown the importance of a vibration attenuator (especially for low frequencies) for the health, comfort, and implicitly work productivity of inland waterway sailors working and living
on the ship 3-4 weeks. As a result, it was observed that the use of rigid foam carpets (where possible) can lead to an improvement in the quality of life of this type of worker.

The difference between transmissibility through neoprene, or rigid foam is more pronounced for low frequencies \( r \in (0\div1) \), where the neoprene transmissibility reaches up to 10 and rigid foam up to 9. It also results from the difference in free terms from equations (3) and (4), where for neoprene is 11.533, and 8.9578 in the case of rigid foam.

As for the range \( r \in (1\div10) \), the situations are similar for neoprene and rigid foam; in this case, the difference comes from the logarithm coefficient which is 0.5888 for neoprene and 0.5507 in the case of rigid foam (see equations (5) and (6)).

References
[1] Picu C L 2018 Proc. 11th Eur. Cong. and Exp. on Noise Contr. Eng. (Hersonissos, Crete) 2663-68
[2] Picu M E and Picu C L 2018 MATEC Web Conf. 148 09005
[3] Picu M E and Picu C L 2017 Springer Proc. in Phys. 198 389-95
[4] Bezyukov O K and Afanaseva O V 2014 Life Sci J 11(5) 483-86
[5] Praetorius G, Österman C and Hult Carl 2018 TransNav: Int J Mar Navig Saf Sea Transp 12(3) 587-95
[6] Picu C L and Rusu EVC 2017 Whole body vibrations of a pushtow boat crew on the Danube Mechal Testing and Diagnosis VII(1) 28-35
[7] Dunn S E 2006 Vibration level characterization from a needle gun used on U.S. naval vessels Graduate Thesis
[8] Wilhite C R 2007 Pneumatic tool hand-arm vibration and posture characterization involving U.S. navy shipboard personnel Graduate Thesis
[9] Netudykhkhata O 1999 The age-related characteristics of the psychophysiological indices of sailors Likars'ka Sprava (Medical report) 1 131-34
[10] Chan G, Moochhala S M, Zhao B, Tan D and Wong J 2006 A comparison of motion sickness prevalence between seafarers and non-seafarers onboard naval platforms Int Marit Health 57(1-4) 56-65.
[11] Hursh S R, Redmond D P, Johnson M L, Thorne D R, Beleny G, Balkin T J, Storm W F, Miller J C and Eddy D R 2004 Fatigue models for applied research in warfighting Aviat Space Environ Med 75 (3 suppl.) A44-53
[12] Ministry of Labour and Social Solidarity 2002 General Labour Protection Norms
[13] Haynes L E 2007 A comparison between the Navy standard workweek and the actual work and rest patterns of U.S. Navy Sailors Graduate Thesis
[14] Picu A 2011 A study on improving minibus travel comfort by using vibrations attenuator material Carpath J Earth Env 6 119-28
[15] Picu M E 2015 From exploratory research and monitoring mechanical noise and vibrations to the development of models of the human response under the action of stress caused by these factors Habilitation Thesis