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VIBRATIONS STUDY OF A SHIP IN DIFFERENT OPERATING MODES

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Abstract: Based on the experimental measurements of vibrations transmitted to the staff from a ship during different operating modes on the Danube, this paper is focused on the technical aspects of the ISO 6954-2000 regulations. The measurements targeted were the staff's comfort both in the engines room and on the decks. The living conditions inside the cabins and inside the common areas were also taken into account. The parallel between the limit values (ISO 6954) and the mean value of the experimental results show that these limits were exceeded as follows: for common areas, acceleration increased almost 3 times, on the decks, almost 3.5 times and in the engines room, almost 2.15 times. Because of this, damping methods are required; these methods depend on the type of the area (passenger cabins, crew rooms, working area).
Keywords: whole body and hand-arm vibrations, ship vibrations, ISO 6954:2000, ISO 2631-1&2

1. INTRODUCTION

Over the past few years there is an increasing strain on the comfort of the military ship's crew members, on their work quality and mostly on their safety. In order to accomplish this challenge it is very important to determine the vibrations transmitted by the ship to the crew members, in all the cases. Because of this the shipbuilders must take into account all the international regulations for all the cases: running, idling, etc. The simulations carried out in order to establish comfort are not probative because during tests the crew members do not have the same emotional status as they have while actually working [2]. More than ever before it is of importance nowadays to determine, in the design stage, the vibration level of a ship. This enlarged urgency is caused by the ever increasing propulsion power (Fig. 1), [4].

It is considerable impetus was given to the experimental phase of ship vibration research by the manufacture of machines capable of vibrating entire hulls [6]. It is not possible to suffice with the calculation of the resonance frequencies, because in the blade frequency range at service speed the vibration modes are so complex and the resonances are so close to each other that it will always be impossible to calculate with sufficient accuracy the resonance frequencies (Fig. 2), [1].

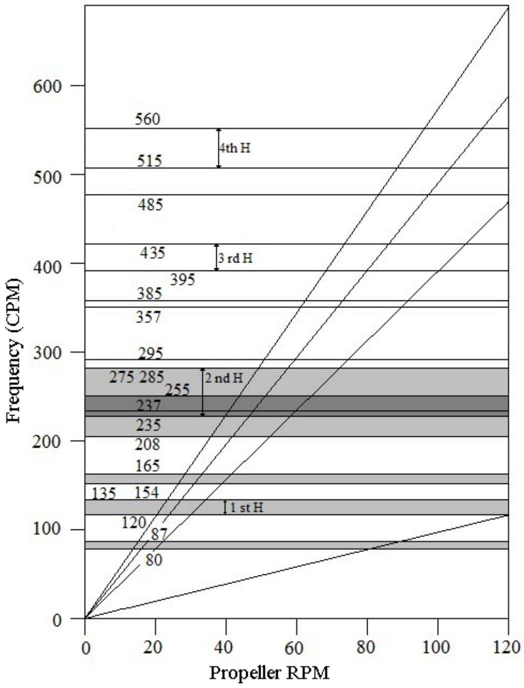

Fig. 1. Effect of load condition on the resonance frequencies

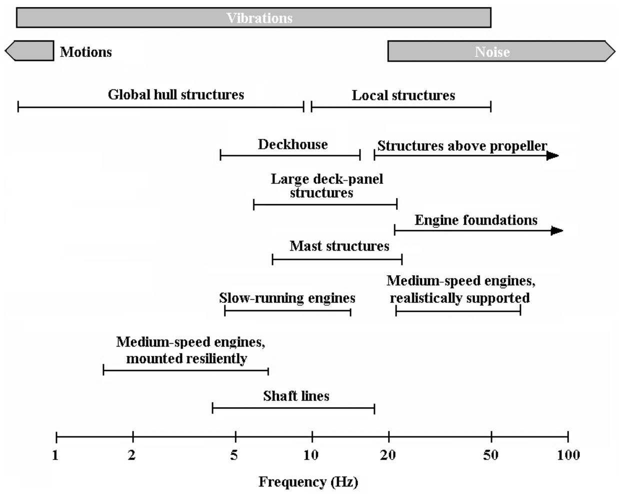

Fig. 2. Natural frequency ranges in ship building applications

In recent years the programme computers has contributed greatly to the development of ship vibration analysis, [5]. Simultaneously, experimental techniques have been devised to determine the vibratory response characteristics of the vibrations as well as the forces tending to excite vibration in the hull, [5]. So broad is the horizon that has been made visible by modern developments in computing techniques that methods of vibration analysis entirely independent of the beam theory of the hull are now under investigation.

2. MEASUREMENTS

2.1 Vibration standards

The standards from which any analysis starts are: Det Norske Veritas (DNV) comfort class (1994), the vibration level was expressed through a peak value [mm/s] defined as the r.m.s. value multiplied by 2; Lloyd's Register of Shipping (LR) comfort class (1998), the same vibration level was expressed through a peak value [mm/s] defined as the r.m.s. value multiplied by 2 and by a crest factor CF equal to 1.8 and Bureau Veritas comfort class (1999), the same vibration level was expressed through a peak value [mm/s] defined as the maximum repetitive value corresponding to the "peak hold" value.
In 2000, the ISO 6954 has been revised and the criteria were based on an integrated weighted overall r.m.s. level, [2].
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.
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. Besides the ones presented here, there are other important regulations regarding the ship's vibrations: American Bureau of Shipping (ABS), Bureau Veritas, Germanischer Lloyd's (GL), Lloyd's Register and the Italian Classification Society RINA.

2.2 Materials and method

Measurements were made taking into account Directive 2002/44/EC, Annex A, which provides:
● For Hand-Arm Vibration (HAV) - Assessment of exposure: The assessment of the level of exposure to hand-arm vibration is based on the calculation of the daily exposure value normalised to an eight-hour reference period A(8), expressed as the square root of the sum of the squares (r.m.s.) (total value) of the frequency-weighted acceleration values, determined on the orthogonal axes a_{hwx}, a_{hwy}, a_{hwz} as defined in Chapters 4 and 5 and Annex A to ISO standard 5349-1(2001).
● For Whole-Body Vibration (WBV) - Assessment of exposure: The assessment of the level of exposure to vibration is based on the calculation of daily exposure A(8) expressed as equivalent continuous acceleration over an eight-hour period, calculated as the highest (r.m.s.) value, or the highest vibration dose value (VDV) of the frequency-weighted accelerations, determined on three orthogonal axes ($1.4a_{wx}$, $1.4a_{wy}$, a_{wz} for a seated or standing worker) in accordance with


Fig. 3. HAV - main deck


Fig. 4. WBV - main deck

Fig. 5. Vibrations transmitted to the manrope - main deck


Fig. 6. Vibrations transmitted to the floor - main deck


Fig. 7. WBV - engines room

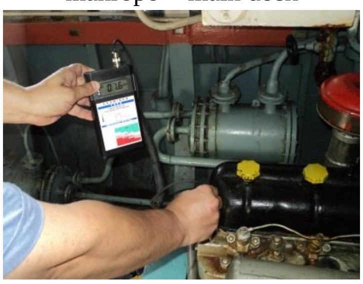
Fig. 8. Vibrations transmitted by the generator engine

Chapters 5, 6 and 7, Annex A and Annex B to ISO standard 2631-1(1997). In the case of maritime shipping, Member States may consider only vibrations of a frequency exceeding 1 Hz.
In this paper the measurements were made on a patrol ship on the Danube, over a distance of 50 km. The measuring conditions on human were different: the start from the shore, running, idling with generator engine, mooring manoeuvre (Fig. 3, 4 and 7). In order to determine the ship's vibrations, measurements were made in different spots on the ship: on the navigating bridge, on the command cabin, on the main deck, in the engines room, in the rest area (Fig. 5, 6 and 8).
The vibrations measurements were made with Maestro 01dB Metravib (to measure the vibrations transmitted to the people) and with Examiner 1000 (to measure the vibrations produced by the equipment).

3. RESULTS AND DISCUSSIONS

After these experimental measurements the following results were obtained:

3.1 Measurements made on the navigation bridge

3.1.1 Measurements made on the navigation bridge while the ship starts from the shore

During the measurements of the HAV transmitted to the person standing on the navigating bridge (hand placed on the manrope) while the ship is starting from the shore the mean value of the acceleration root mean square ($\bar{a}_{r.m.s.}$=0.9856 m/s^2) is higher than the acceleration value for which the adverse comments are probable (0.286 m/s^2) with 244.633 % (Fig. 9).

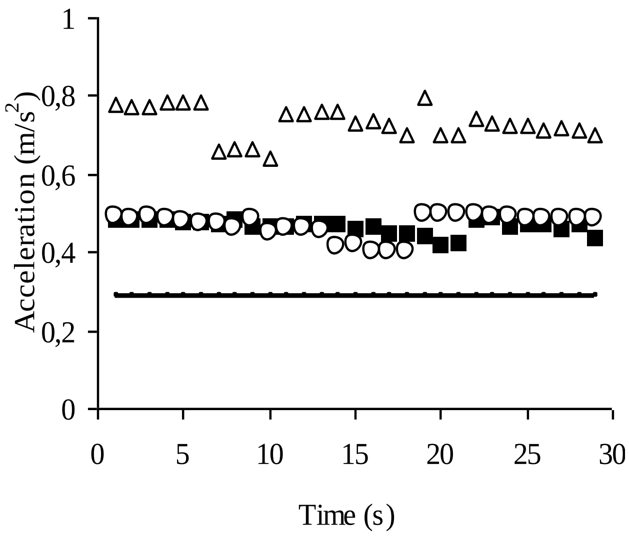

Fig. 9. HAV transmitted to a person who stands on the navigation bridge (hand placed on the manrope) while the ship starts from the shore; (■)-a_x; (○)-a_y; (Δ)-a_z; (▬) - Value above which adverse comments are probable (0.286 m/s^2)

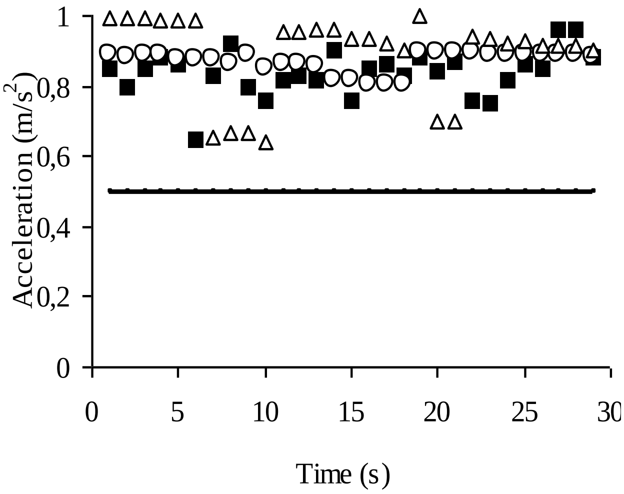

Fig. 10. WBV transmitted to a person who stands on the navigation bridge (hand placed on the manrope) while the ship starts from the shore;
(■)-a_x; (○)-a_y; (Δ)-a_z; (▬) - The daily exposure action value standardised to an 8h reference (0.5 m/s^2)

During the measurements of the WBV transmitted to the person standing on the navigating bridge while the ship is starting from the shore the mean value of the acceleration root mean square ($\bar{a}_{r.m.s.}$=1.5006 m/s^2) is higher than the daily exposure action value standardised to an 8h reference (0.5 m/s^2) with 66.682 % (Fig. 10).

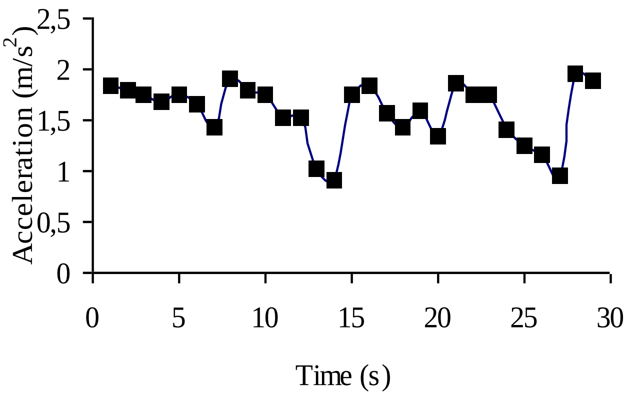

Fig. 11. Vibrations transmitted to the manrope of the navigation bridge while the ship starts from the shore

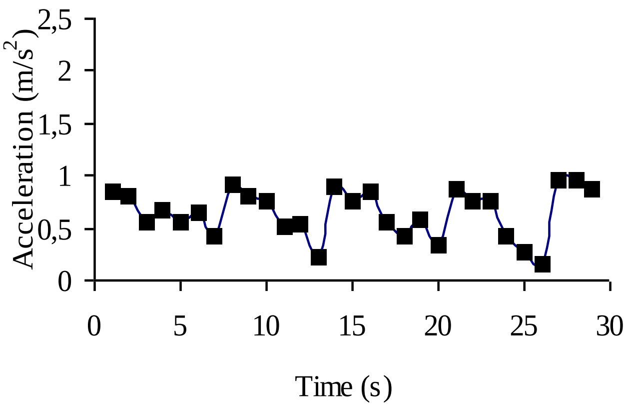

Fig. 12. Vibrations transmitted to the floor of the navigation bridge while the ship starts from the shore

Figures 11 and 12 shows the vibrations transmitted to the manrope (the average of the obtained values was 1.592 m/s^2) and to the floor (the average of the obtained values was 0.652 m/s^2) of the navigation bridge while the ship starts from the shore.

3.1.2 Measurements made on the navigation bridge while the ship performs the mooring manoeuvre

During the measurements of the HAV transmitted to the person standing on the navigating bridge (hand placed on the manrope) while the ship performs the mooring manoeuvre, the mean value of the acceleration root mean square ($\bar{a}_{r.m.s.}$=0.8788 m/s^2) is higher than the acceleration value for which the adverse comments are probable (0.286 m/s^2) with 207.276 % (Fig. 13).

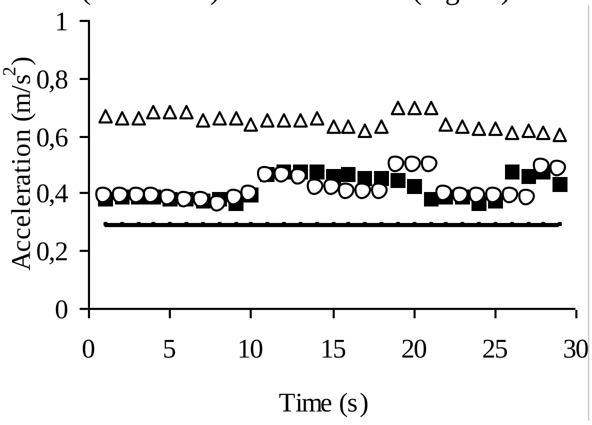

Fig. 13. HAV transmitted to a person who stands on the navigation bridge (hand placed on the manrope) while the ship performs the mooring manoeuvre; (■)-a_x; (○)-a_y; (Δ)-a_z; (▬) - Value above which adverse comments are probable (0.286 m/s^2)

During the measurements of the WBV transmitted to the person standing on the navigating bridge while the ship performs the mooring manoeuvre, the mean value of the acceleration root mean square ($\bar{a}_{r.m.s.}$=1.6014 m/s^2) is higher than the daily exposure action value standardised to an 8h reference (0.5 m/s^2) with 220.282 % (Fig. 14).

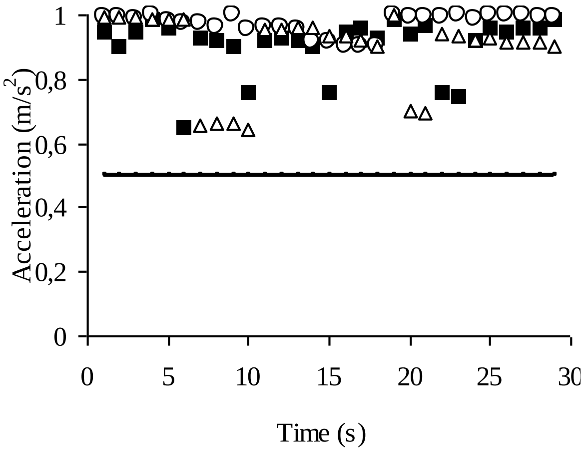

Fig. 14. WBV transmitted to a person who stands on the navigation bridge while the ship performs the mooring manoeuvre; (■)-a_x; (○)-a_y; (Δ)-a_z;
(▬) - The daily exposure action value standardised to an 8h reference (0.5m/s^2)

Figure 15 and figure 16 show the vibrations transmitted to the manrope (the average of the obtained values was 1.390 m/s^2) and to the floor (the average of the obtained values was 0.748 m/s^2) of the navigation bridge while the ship performs the mooring manoeuvre.

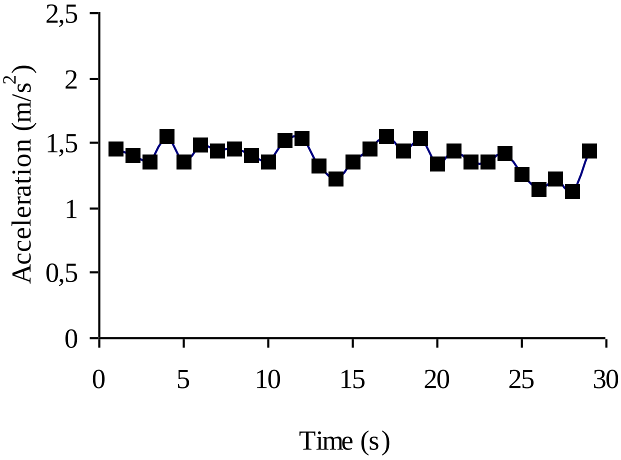

Fig. 15. Vibrations transmitted to the manrope of the navigation bridge while the ship performs the mooring manoeuvre

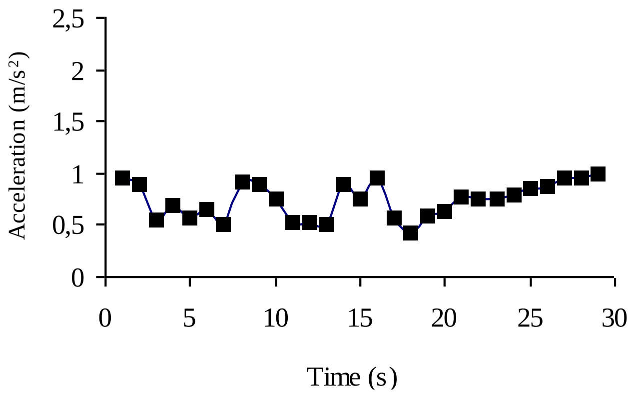

Fig. 16. Vibrations transmitted to the floor of the navigation bridge while the ship performs the mooring manoeuvre

3.2 Measurements made on the main deck

3.2.1 Measurements made on the main deck while the ship is running

During the measurements of the HAV transmitted to the person standing on the main deck (hand placed on the manrope) while the ship is running, the mean value of the acceleration root mean square ($\bar{a}_{r.m.s.}$=0.9493 m/s^2) is higher than the acceleration value for which the adverse comments are probable (0.286 m/s^2) with 231.926 % (Fig. 17).

During the measurements of the WBV transmitted to the person standing on the main deck while the ship is running, the mean value of the acceleration root mean square ($\bar{a}_{r.m.s.}$=1.3049 m/s^2) is higher than the daily exposure action value standardised to an 8h reference (0.5 m/s^2) with 260.992 % (Fig. 18).

Figure 19 and Figure 20 show the vibrations transmitted to the manrope (the average of the obtained values was 1.546 m/s^2) and to the floor (the average of the obtained values was 0.677 m/s^2) of the main deck while the ship is running.

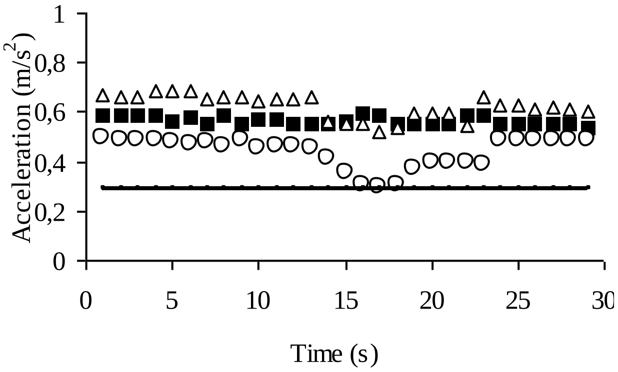

Fig. 17. HAV transmitted to a person who stands on the main deck (hand placed on the manrope) while the ship is running; (■)-a_x; (○)-a_y; (Δ)-a_z; (▬) - Value above which adverse comments are probable (0.286 m/s^2)

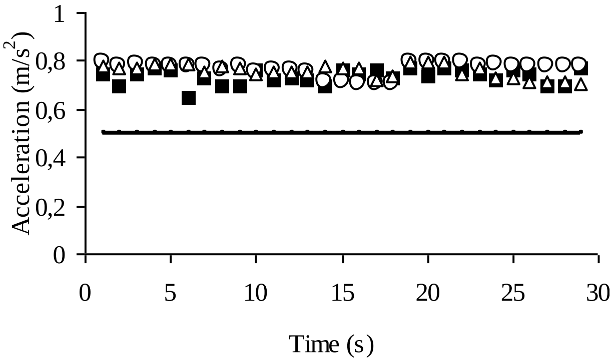

Fig. 18. WBV transmitted to a person who stands on the main deck while the ship is running; (■)-a_x; (○)-a_y; (Δ)-a_z; (▬) - The daily exposure action value standardised to an 8h reference (0.5 m/s^2)

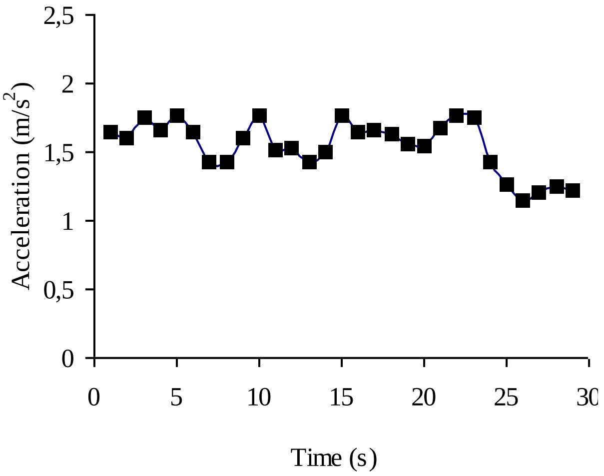

Fig. 19. Vibrations transmitted to the manrope of the main deck while the ship is running

3.2.2 Measurements made on the main deck while the ship performs the mooring manoeuvre

During the measurements of the HAV transmitted to the person standing on the main deck (hand placed on the manrope) while the ship performs the mooring manoeuvre, the mean value of the acceleration root mean square ($\bar{a}_{r.m.s.}$=1.2167 m/s^2) is higher than the acceleration value for which the adverse comments are probable (0.286 m/s^2) with 325.444 % (Fig. 21).

During the measurements of the WBV transmitted to the person standing on main deck while the ship performs the mooring manoeuvre, the mean value of the acceleration root mean square ($\bar{a}_{r.m.s.}$=1.3086 m/s^2) is higher than the daily exposure action value standardised to an 8h reference (0.5 m/s^2) with 161.738 % (Fig. 22).

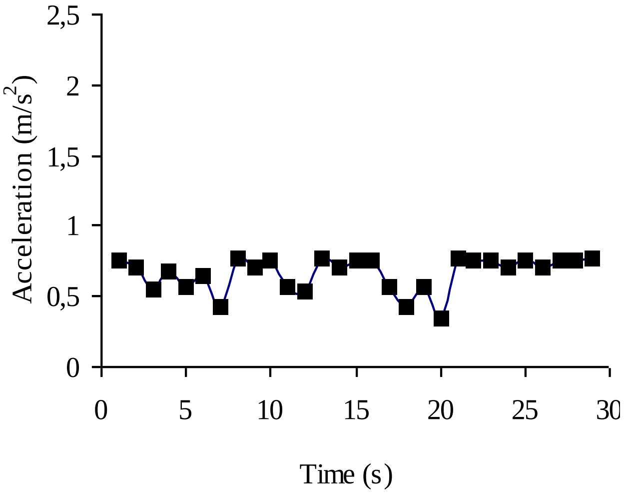

Fig. 20. Vibrations transmitted to the floor of the main deck while the ship is running

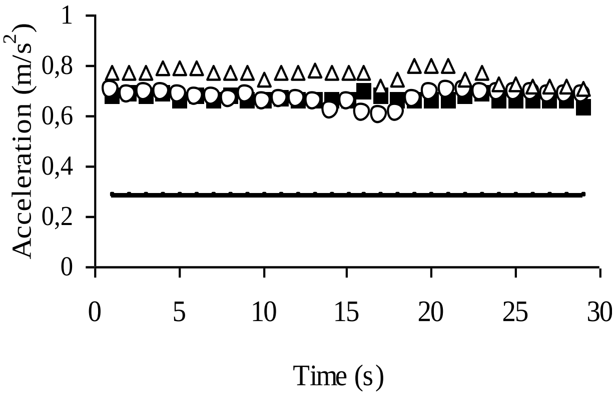

Fig. 21. HAV transmitted to a person who stands on the main deck (hand placed on the manrope) while the ship performs the mooring manoeuvre; (■)-a_x; (○)-a_y; (Δ)-a_z; (▬) - Value above which adverse comments are probable (0.286 m/s^2)

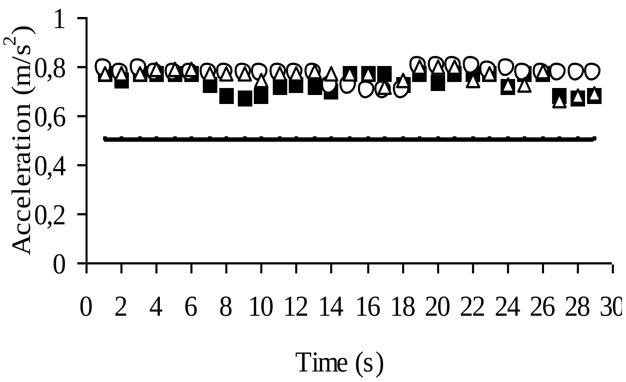

Fig. 22. WBV transmitted to a person who stands on the main deck while the ship performs the mooring manoeuvre; (■)-a_x; (○)-a_y; (Δ)-a_z; (▬) - The daily exposure action value standardised to an 8h reference (0.5 m/s^2)

3.3 Measurements made inside the engines room

3.3.1 Measurements made inside the engines room (idling with generator engine)

During the measurements of the WBV transmitted to the person in the engines room (idling with generator engine), the mean value of the acceleration root mean square ($\bar{a}_{r.m.s.}$=7.2408 m/s^2) is higher than the daily exposure action value standardised to an 8h reference (0.5 m/s^2) with 1348.165 % (Fig. 23).

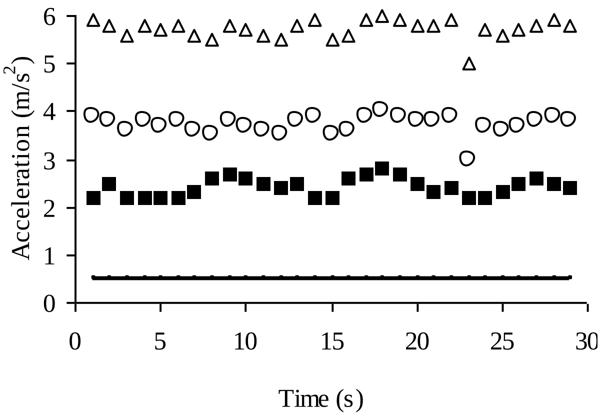

Fig. 23. WBV transmitted to a person who stands in the engines room while the ship is running; (■)-a_x; (○)-a_y; (Δ)-a_z; (▬) - The daily exposure action value standardised to an 8h reference (0.5 m/s^2)

Figure 24 show the vibrations transmitted to the floor of the engines room (idling with generator engine) (the average of the obtained values was 5.501 m/s^2) and Figure 25 show the vibrations transmitted by the generator engine (idling with generator engine) (the average of the obtained values was 6.567 m/s^2)

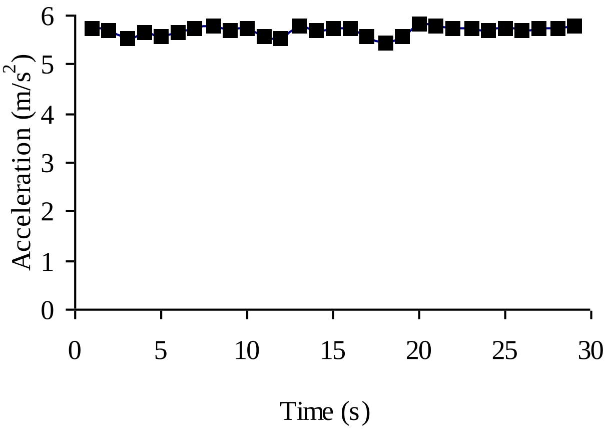

Fig. 24. Vibrations transmitted to the floor of the engines room (idling with generator engine)

3.4 Measurements made in the command cabin (idling with generator engine)

During the measurements of the HAV transmitted to the person standing in the command cabin (idling with generator engine) the mean value of the acceleration root mean square ($\bar{a}_{r.m.s.}$=1.1560 m/s^2) is higher than the acceleration value for which the adverse comments are probable (0.286 m/s^2) with 304.220 % (Fig. 26).

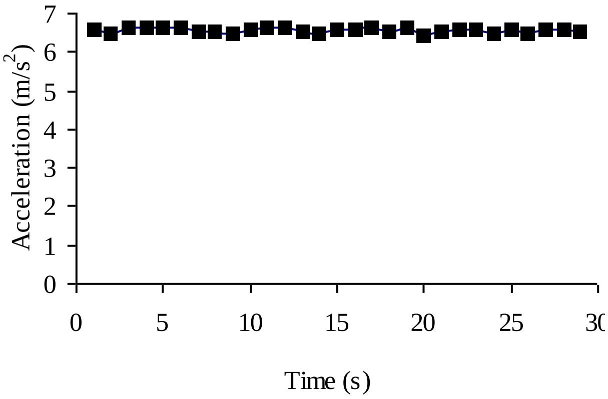

Fig. 25. Vibrations transmitted by the generator engine (idling with generator engine)

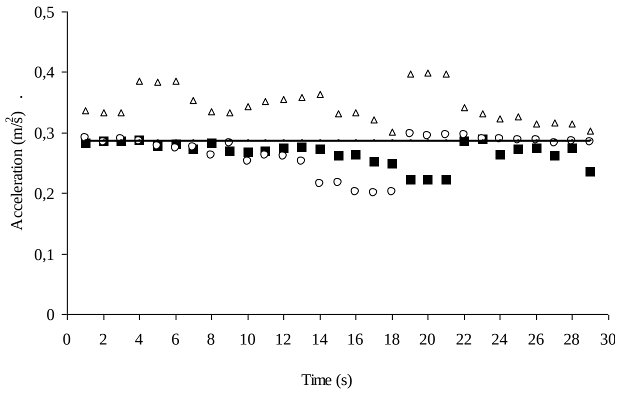

Fig. 26 HAV transmitted to a person who stands in the command cabin (hand placed on the helm) while the ship is idling with generator engine; (■)-a_x; (○)-a_y; (Δ)-a_z; (▬)-Value above which adverse comments are probable (0.286 m/s^2)

3.5 Measurements made in the rest area

3.5.1 Measurements made in the rest area while the ship is running

During the measurements of the WBV transmitted to the person standing in the rest area while the ship is running the mean value of the acceleration root mean square ($\bar{a}_{r.m.s.}$=1.1283 m/s^2) is higher than the daily exposure action value standardised to an 8h reference (0.5 m/s^2) with 125.671 % (Fig. 27).

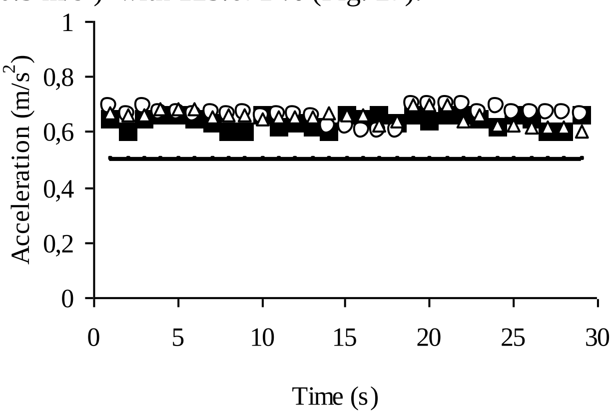

Fig. 27. WBV transmitted to a person who stands in the rest area while the ship is running; (■)-a_x; (○)-a_y; (Δ)-a_z; (▬) - The daily exposure action value standardised to an 8h reference (0.5 m/s^2)

3.5.2 Measurements made in the rest area while the ship performs the mooring manoeuvre

During the measurements of the WBV transmitted to the person standing in the rest area while ship is performing the mooring manoeuvre the mean value of the acceleration root mean square ($\bar{a}_{r.m.s.}$=1.2644 m/s^2) is higher than the daily exposure action value standardised to an 8h reference (0.5 m/s^2) with 152.898 % (Fig. 28).

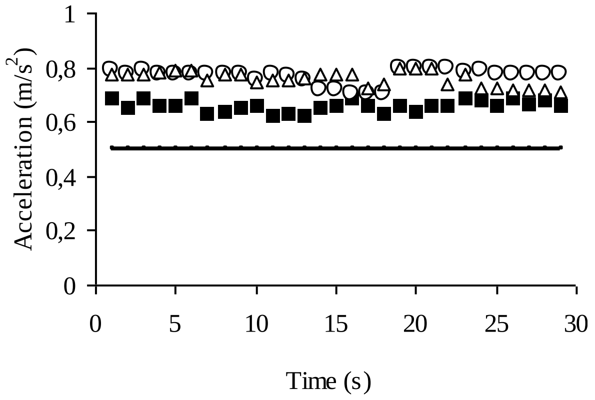

Fig. 28. WBV transmitted to a person who stands in the rest area while the performs the mooring manoeuvre; (■)-a_x; (○)-a_y; (Δ)-a_z; (▬) - The daily exposure action value standardised to an 8h reference (0.5 m/s^2)

4. CONCLUSIONS

It has to be emphasized that for this last averaging it was not taken into consideration the value 1348.1652 %, which represents the exceeding of the limit value for the WBV transmitted to the person who stands in the engines room (idling with generator engine). Otherwise, the transmitted vibrations would have had extraordinary high value, hence, the average acceleration on the Ox axis is a_x=2.4206 m/s^2, on the Oy axis is a_y=3.7206 m/s^2 and on the Oz axis is a_z=5.7206 m/s^2.

Figure 29 shows that the average excess for $a_{r.m.s.}$ mediated in relation to the limit value (0.286 m/s^2) for the HAV is 262.7 %, in other words, there were measured accelerations that exceed 3.5-4 times the accepted limit value for these cases.

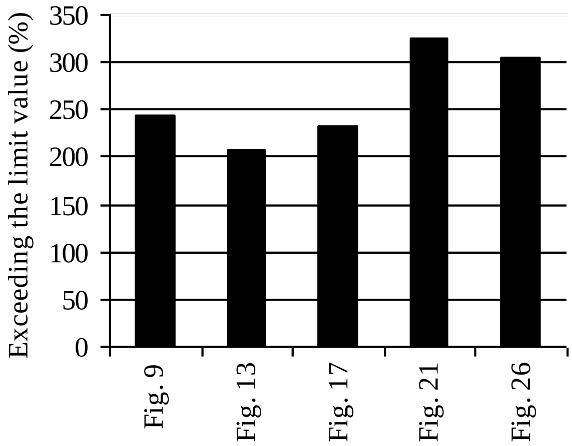

Fig. 29. The excess percentage of $a_{r.m.s.}$ mediated in relation to the limit value (0.286 m/s^2) for the HAV

Figure 30 shows that the average excess for $a_{r.m.s.}$ mediated in relation to the limit value (0.5 m/s^2) for the WBV is de 167 %, in other words, there were measured accelerations that exceed 2.5-3 times the accepted limit value for these cases.

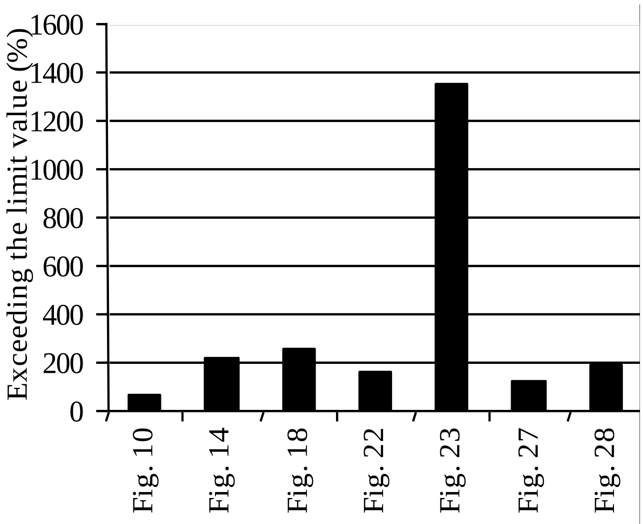

Fig. 30. The excess percentage of $a_{r.m.s.}$ mediated in relation to the limit value (0.5 m/s^2) for the WBV

In order to determine the habitability level, ISO 6954 divides the ship in 3 areas: passenger cabins, crew rooms and working areas and establishes for each one the limit values of vibrations. If we make a comparison between the limit values (ISO 6954) and the average value of the experimental results we can see that those limits were exceeded as follows: for the common areas the acceleration increased almost 3 times, on the decks almost 3.5 times and in the engines room almost 2.15 times (see Table 1).

Table 1. Limit values $a_{w,\,H}$ (m/s^2) for different areas (Guidelines for the habitability)

Limit values (ISO 6954) for $a_{w,H}$ (m/s^2)	Passenger cabins	Crew rooms	Working area
Values at which complaints are likely	0.143	0.214	0.286
Values below which complaints are unlikely	0.071	0.107	0.143
Measured values a_w (m/s^2)	0.427	0.748	0.614

where $a_{w,H}$ represents the limit value recommended by the Rule for working and living conditions.

For these reasons, a reassessment of the working conditions of the ship's crew is necessary because the engines generate extremely high vibrations by motors, which are transmitted through the ship's structure, to the people. These engines should be replaced by new and efficient ones, or, if this is not possible, the engines should be placed on vibroabsorbant materials. If the situation will not improve, the ship's crew may suffer a variety of disorders due to vibrations.

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