ISSN : 2350-0743

www.ijramr.com

International Journal of Recent Advances in Multidisciplinary Research
Vol. 10, Issue 09, pp.8841-8845, September, 2023

RESEARCH ARTICLE

ANALYSIS OF THE EFFECTS OF VEHICLE VIBRATIONS AND NOISE ON THE HUMAN BODY

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ARTICLE INFO

Article History:
Received 08th June, 2023
Received in revised form
20th July, 2023
Accepted 16th August, 2023
Published online 30th September, 2023

Key Words:
Noise and vibrations, Level of comfort, Impact of noise and vibration, Interior of vehicles, Effects of noise and vibration.

ABSTRACT

At least 40% of the world's population spends their time in places where levels of noise and vibration harmful to health prevail, also the study on the interior of vehicles indicates a significant value of specific descriptors of discomfort induced by noise and vibration. These parameters must comply with the regulations in force, and which appeal to the concept of reliability in systems that ensure the living conditions of passengers. The present paper aims to analyze the specific descriptive factors of vibrations and noise in vehicles with the aim of preliminary cumulative estimation of the global impact due to them on the human body, together with the selection of the best available techniques, with the aim of making contributions to the further mitigation of the impact of noise and potential vibrations on passengers, as well as the implementation of a strategy to improve the level of comfort.

INTRODUCTION

According to the results present in the specialized literature according to tests carried out on 4 passengers about the influence of internal environmental factors, the temperature regime in the cabin (hot in summer, cold in winter) was evaluated negatively by 75% of the passengers, the presence of harmful substances (air pollution with exhaust gases) of 75%, vibration influence of 75% and noise of 75%. Also, a noise level between 35-70 dB, for a long time, to which the driver of a vehicle can be subjected, leads to the appearance of fatigue, weakening of vision, difficulty in understanding speech and even causing headaches for a noise level that exceeds the value of 70 dB (such a high sound level can occur, for example, when driving at a high speed of over 90 km/h on the highway) [Keren, 2020]. In this sense, the authorities responsible for regulating the noise inside the motor vehicle require the manufacturers of road vehicles to reduce noise emissions by establishing increasingly strict noise limits. In compliance with the ISO 362 international standard responsible for the permissible limit values of noise inside vehicles and which must be respected for approval starting from 2019, a downward trend is noted, in the direction of reducing noise levels from year to year, requiring that in 2026 the limit value of 68 dB for cars be respected. Where M1 represents cars, M2 minibuses and M3 buses, also N1 are pick-ups, van-type cars, N2 are medium-capacity trucks with a weight between 3.5 t - 12 t and N3 are high-capacity trucks with a total authorized weight greater than 12 t.

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The issue of noise can be approached from two perspectives, namely: noise perceived as high-level sounds generated by sources external to the structure and perceived high-level sounds generated by the structure. The sound generated by sources external to the vehicle structure propagates in the form of sound waves inside the vehicle through the holes in its structure (door seals, weld seams, etc.) and can be controlled by eliminating the noise source or by eliminating transfer between vehicle components. Sound pressure waves travel along the path of least resistance. Noise removal is currently done using passive and active noise reduction methods. Passive mitigation is achieved by using different levels of insulation or absorbent materials or by adopting acoustic baffles, using urethane-filled foams, and rubber plugs or gaskets. Active combat is achieved by direct action on prominent sources of noise, through noise cancellation systems [3.Cășeriu Bianca-Mihaela and Petruța Blaga, 2023]. The noise, having as its source the mechanical vibrations of the structure, propagates throughout its construction, causing local air movements. 1 cm3 volume of displaced air, obtained by 1 m^2 of vibrating surface with a displacement of 1 μm causes a sound intensity of 75 dB. Vehicle body vibration originates from tire-treadway interaction and roadway imperfections, high vehicle speed, suspension characteristics, etc [Badea, 2019]. The harmful action of vibrations on the human body is a current topic for NVH (Noise Vibration And Harshness) researchers, a fact due to the high complexity of the problem. In the specialized literature, it is presented until now that vibrations produce a series of harmful effects, both physiological and physical, the most important of which are the mechanical and thermal effects.

Thus, vibrations have a complex harmful effect on life, affecting: the health of the human body, the quality of human work, the resistance of vehicle components, the quality of operations and products made by different types of tools and devices, etc. If the human body is subjected to the prolonged action of vibrations, a general illness of the body occurs, called vibration disease. The harmful nature of vibrations is amplified if they are accompanied by noises, just as the harmfulness of noises increases when they are accompanied by vibrations.

REQUIREMENTS FOR ENSURING THE OPTIMAL LEVEL OF NOISE AND VIBRATION IN VEHICLES: Spending time in an upward trend, in the sense of growth in transport systems, leads to the fact that the study of noise and vibration constitutes determining factors not only on productivity and quality in the process of driving vehicles, as well as safety, but, perhaps to a much greater extent, also on exposure to accidents and the health of the human operator. In the case of vehicles, vibrations and noises transmitted in the passenger compartment are perceived by the body indifferently, from person to person, but much more intense than those parts of the body that are in direct contact with the component elements of the vehicles thatare in vibratory motion or as close as possible to them (positioning the engine unit with the solution in front) [5]. The problem of vibrations and noises in vehicles is studied from the perspective of transmission the human body as follows:

- On the whole body through the common contact surface, in the human-vehicle relationship. This mode of transmission of vibrations is achieved when the operator is in an orthostatic position or sitting, in the process of operating the vehicles;
- On the constituent elements of the vehicle causing wear over time, technological games in operation.

Mechanical noises and vibrations transmitted to humans have a harmful effect complex, affecting his health through physiopathological effects and embarrassing carrying out the process of driving and operating the vehicle until the loss of the ability to drive. The most important effects produced by the action of noises and vibrations are physiological, mechanical and thermal nature, the last two being predominant [Titu, 2022].

Establishing noise and vibration limit values is an operation complex, based on experimental determinations and analysis of the vehicle operation process, in vibration and noise conditions, as well as on the corresponding experience the explored field. In this context, it is emphasized that the permissible limits of vibrations and noises transmitted to the human body must be determined according to the following specific descriptors and different units of measurement in assessment of sound and vibration levels of the impact generated by noise and vibrations [Florian, 2022]:

- Kinematic parameters of vibrations (acceleration, speed, displacement);
- Frequency of vibration and acoustic wave;
- duration of exposure to vibrations and noise during vehicle operation;
- The direction of operation of vibration and sound waves in relation to the human body;
- The noxiousness criterion (subjective human response);
- Perception threshold, fatigue threshold, tolerance limit.

The limitation of the level of vibrations and noise transmitted to the human body is based on many criteria, namely: the medical criterion (for establishing their limit values in relation to the harmful effects on the human factor), the professional criterion (takes into account the concentration and skills in the exploitation process) and the technical-economic criterion (related to their effects on vehicle reliability) [Deubel, 2023].

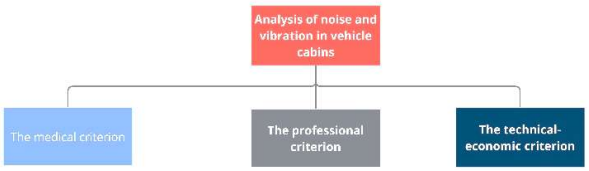

Figure 1. Criteria for the analysis of noise and vibration limit values in vehicles

In the specialized literature there are recommendations and rules that specify the admissible limit by the harmfulness threshold (tolerance, exposure). Appreciation of the limitation character of vibrations and noises according to these recommendations and norms is not always the case complete and edifying, because the mode is not always taken into account transmission of vibrations and noise from sources to the human factor, body position to the vibrating or acoustic source, as the case may be, nor to the exposure time by specifying duration intervals. The synthesis of the influence of these factors led to the elaboration of some permissible limit values for the exposure of the human body to the action of vibrations. Values established by exposure limit curves at vibrations and noises, on the basis of which the exposure assessment criteria are established, are expressed according to frequency, amplitude of accelerations, exposure time and transmission direction [Zhehao Huang, 2023].

The limits of exposure to vibrations and noise are:

- The reduced comfort limits corresponding to the maintenance situation a comfort, or occurrence of discomfort. Maintenance of specific descriptors for a certain period of time, below the permissible limit values leads in compliance with the comfort criterion;
- The limit of capacity reduced by fatigue corresponds to the situation of maintaining efficiency in the vehicle operation Process.
- The exposure limit corresponding to the conservation criterion a health.

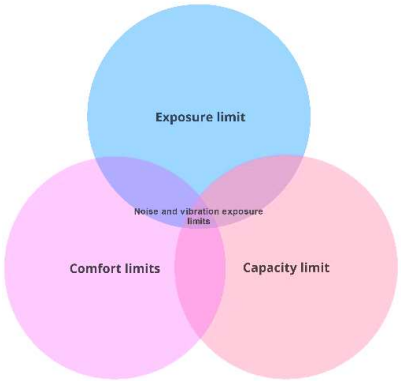

Figure 2. Noise and vibration exposure limits

These limits are established on a practical experimental basis and in laboratory conditions regarding the behavior of the human body to vibrations and noises of certain levels.

Table 1. Limits of the noise level in the passenger compartment of vehicles [2]

Category	Vehicles used to transport people	Limit values[dB]		
		Test 1	Test 2	Test 3
		2016	2020	2024
M1	PMR ≤ 120	72	70	68
	120 < PMR ≤ 160	73	71	69
	PMR >160	75	74	71
	PMR>200, no.places≤ 4	75	74	72
M2	M ≤ 2.5 t	72	70	69
	2.5 t < M ≤ 3.5 t	74	72	71
	M > 3.5 t; Pn ≤ 135 kW	75	73	72
	M > 3.5 t; Pn> 135 kW	75	73	72
M3	Pn ≤ 150 kW	76	74	73
	150 kW <Pn ≤ 250 kW	78	77	76
	Pn> 250 kW	80	78	77

Table 2. Limits of the noise level in the passenger compartment of vehicles until 2026 [2]

Category	Vehicles used to transport materials	Limit values [dB] - 2026		
		Test 1	Test 2	Test 3
N1	M ≤ 2.5 t	72	70	69
	M > 2.5 t	74	73	71
N2	Pn≤ 135 kW	77	75	74
	Pn> 150 kW	78	76	75
N3	Pn ≤ 150 kW	79	77	76
	150 kW <Pn ≤ 250 kW	81	79	77
	Pn> 250 kW	82	81	79

On these grounds, the values of the descriptive indicators of vibrations and noise transmitted to the human factor, were adopted as norms (the form of recommendations to be standardized), and these represent exposure limit. In this situation, the values of the descriptive parameters aimeasured vibrations and noises effective and which are transmitted to man, are compared with the admissible values of curves at the limit of exposure to vibrations and noise [Orit Taubman-Ben-Ari, 2004].

ANALYSIS OF NOISE AND VIBRATION IN VEHICLE CABINS

For the analysis of noise and vibrations inside the vehicles, experimental determinations were made on a bus, for people transportation, with 51+1 seats, from M3 category. The experimental tests were carried out taking into account the prominent sources of noise and vibration and the specific descriptors, in a test range in the radius of which there were no obstacles (vehicles, buildings, large opaque objects) at a distance of at least 20 m, which could influence the propagation of sound and vibrating waves.

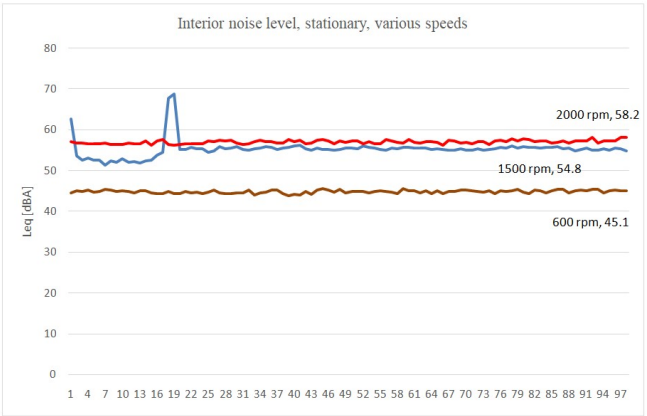

Figure 3. The graph of the interior noise level, stationary at different speeds

The tests to determine the interior noise level were carried out with the vehicle in motion and stationary, using a class 1 precision sound level meter, weighted in the A scale and data acquisition and processing software. Before each measurement the measuring devices were calibrated and the background noise was measured [Hanna Bellem, 2016]. The average value for the noise level at n=600 rpm is: 44.81dB(A). The average value for the noise level at n=1500 rpm is: 55.34dB (A). The average value for the noise level at n=2000 rpm is: 57.05 dB(A).

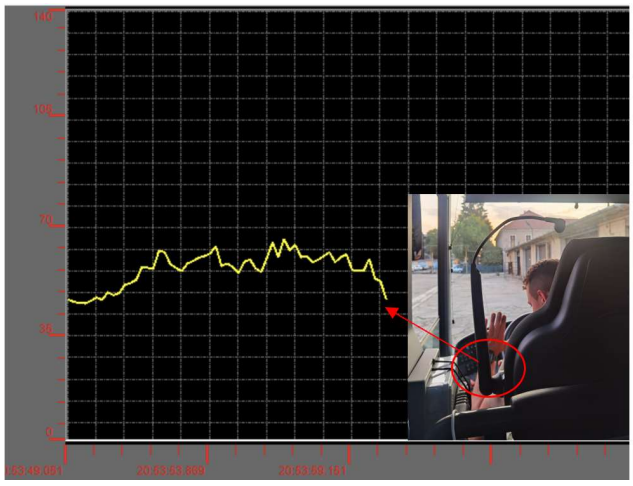

Figure 4. The graph of the interior noise level, in motion at 45 km/h

The average value for the noise level at 45 km/h is: 56.51 dB (A).

The vibration analysis in the vehicle subjected to experimental determinations took into account the kinematic factors: acceleration and frequency. Depending on the frequency and energy of the vibrations, they can produce a multitude of mechanical effects: relative displacements of different organs, rupture of less resistant ligaments and tissues, pulmonary

hemorrhages (in the case of low-frequency vibrations (5...15 Hz) and high accelerations (5...15) xg, g – gravitational acceleration), diseases of the hands of those who work with vibrating tools.

DISCUSSION

EFFECTS OF NOISE AND VIBRATION ON THE BODY IN VEHICLES

Scientific studies on the vibrations that occur in transport systems and comfort have been carried out since the 1940s, determining since then that the vibrations and shocks to which the human body in a transport system can be subjected can lead to health problems and may alter driving performance. Vibrations occur along all three axes, both linear and rotational. It has been determined that those manifested along the vertical axis are taken up entirely by the suspension and the seat. Also, at that time a method for estimating discomfort perception was standardized by ISO 2631 in 1974. Noise is the source of producing a series of health problems, such as: communication and concentration difficulties; stress and irritability; sleep disorders; cardiovascular problems and negative effects on the endocrine system, on performance, work capacity and social behavior. Officially, in many European countries hearing loss at work is considered an occupational disease. The following figure shows the scale of reference values for the effects of noise on the human body. By correlating the information regarding the noise and vibration level, a concise and complete formulation of noise and vibration pollution dose in vehicles.

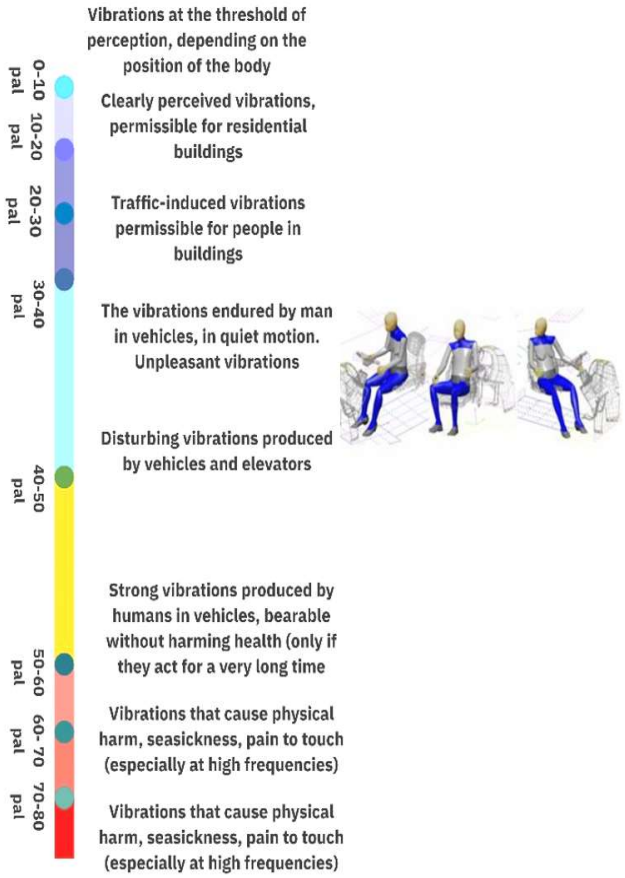

Figure 5. Scale of reference values for vibrational effects on the human body

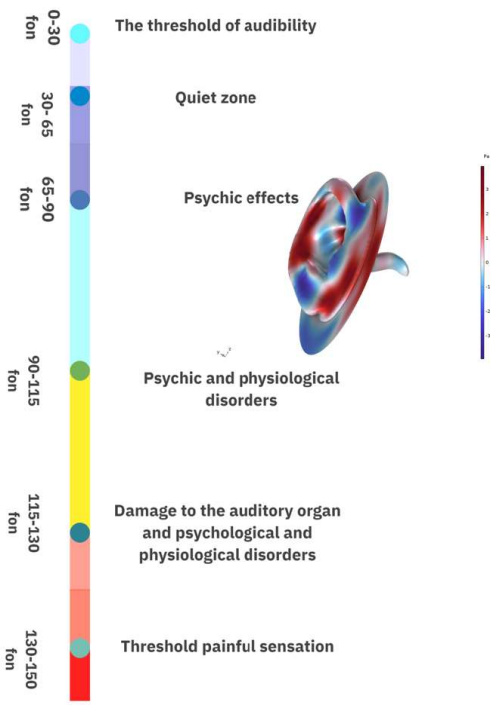

Figure 6. Scale of reference values for noise effects on the human body

The variations in the characteristic parameters of the noise and vibrations determined as a result of the experimental measurements and the investigation of the specialized literature, in the passenger compartment of the vehicle lead to the appearance of the state of discomfort and bring harmful effects on the passengers. A noise level between 35-70 dB, compared to that obtained experimentally while stationary and in motion during the operation of the vehicle, for a long time, to which the driver of a vehicle can be subjected leads to the appearance of fatigue, weakening of vision, difficulty in understanding speech even and causing headaches for a noise level exceeding 70 dB. The approach to the results obtained according to the previously presented methodologies can be carried out in two ways: 1) separate analysis of the two aspects related to noise, respectively to vibrations or 2) global, simultaneous and intercorrelative analysis of the two components – noise and vibrations. Taking into account the fact that the second situation contains essential aspects in the definition and the use of the "pollution dose" through the simultaneous action and the combined effect of vibrations and noise, it is obvious that it was adopted as a global method of evaluation, analysis and characterization of the experimental results presented in the study. The partial conclusions outlined following both individual and comparative data analysis experimental results obtained and presented in this chapter are listed below:

- An experimental verification of the concept of "pollution dose" through the simultaneous effect and combination of vibrations and noise;
- Highlighting the polluting factors in the driving process: noise and vibrations, produced by vehicles, as well as those in which the generation of vibrations and noise are secondary processes, useless in performing specific operations the management process;
- Evaluation of noise and vibration parameters for the passenger compartment of motor vehicles;

- Experimental determinations regarding the level of vibrations highlighted the special importance of the duration of action on humans;
- Highlighting the psychosensory effects of vibrations and noise on the human factor in the operation of vehicles.

CONCLUSION

The present paper presents a model of experimental acoustic determinations and vibration analysis, moreover, the analysis of their effects in the operation of vehicles, based on standardized acoustic and vibration emission factors. This study presents a cumulative preliminary estimate for the effects of noise and vibrations in the vehicle cabin, in order to obtain an initial picture of the cumulative impact due to noise and vibrations generated by acoustic and vibrational sources from the operation of vehicles. A monitoring and analysis strategy is presented as well as important data on noise and vibration in the vehicle cabin, together with the selection of the best available techniques, with the aim of contributing to the further mitigation of the potential sound impact on passengers, as well as the implementation of a strategy which lead to the improvement of the level of acoustic and vibrational comfort in vehicles.

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