RESEARCH OF INFRASOUND NOISE IN HEAVY GOODS VEHICLE AND BUSSES

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The article refers to some problems of infrasound and infrasound noise and their influence on the behaviour of drivers of mechanical vehicles and machine operators. Infrasound waves act on the entire human organism. They induce resonance vibrations of the chest, abdominal membrane and digestive organs. That causes respiratory system problems, and with a prolonged exposure leads to the digestive system disorders. Furthermore infrasound causes feeling of tiredness, discomfort, and drowsiness; it decreases psychomotoric perception and eye sight clarity.

Motor Transport Institute has carried out research on infrasound noise. Measurements were taken using SVANTEK SVAN 945A register on correction curves A, Lin and G as well as dynamic characteristics Fast and Slow. Measurements were made only in the driver work place, recording level of sound pressure for 30 seconds. Tests were carried out on 5 buses (M3 category), 10 vehicles of N3 category (saddle tractors and HGV`s), 3 HGV`s N1 category and 2 vehicles of category M1. Research results confirm high infrasound noise levels in the case of M3 category vehicles. They would remain at about 110÷115 dB level, according to correction curve G with relatively low level of interior noise of about 66÷74 dB according to correction curve A, and at the speed range of 70 to 90 km/h. The level of infrasound noise reaches lower values of about 100 dB in the vehicles of N3 and N1 category. During the research, an importance of road surface condition was established, adding up to 7 dB, but in extreme cases even up to 10 dB, causing momentary increase of infrasound noise even to 125 dB.

Keywords: *infrasound, infrasound noise*

1. Introduction

Infrasound is acoustic energy with frequencies up to 20 Hertz (Hz), having wavelengths of 17 m or more. Some definitions give the upper limit of 16 Hz; others restrict infrasound to delivery by air transmission [9]. Infrasound is seldom generated at high sound pressure levels (SPL), usually measured in decibels [dB]) without accompanying audible sound [2]. However, hearing protection, e.g. ear muffs and ear plugs, offers little protection against infrasound exposure [22, 23].

In the recent years, the interest to the infrasounds very much increased, as in the contemporary man's environment, they constitute very significant nuisance factor. Infrasound sources can be divided into natural and artificial:

- natural: volcanoes, thunders, strong wind, earth quakes (seismic waves), big waterfalls,
- artificial: transport means (cars, buses, tramways, locomotives, aircraft, helicopters and others), road machines (road rollers), compressors (piston, centrifugal, impeller, screw type and others), blowers, ventilators.

Infrasound is generated by thunder, earthquakes, large waterfalls, ocean waves (< 1 Hz), wind (up to 135 dB at 100 km/h; up to 110 dB at 25 km/h), fluctuations in atmospheric pressure (< 1 Hz at 100 dB), and volcanoes. Running generates infrasound at frequencies below 2 Hz at levels up to 90 dB; swimming also generates infrasound below 2 Hz, but the pressure is more intense (up to 140 dB). Riding in automobiles exposes drivers and passengers to 1 to 20 Hz at up to 120 dB.

Infrasound contrary to common opinion about their inaudibility is received by our organism through a specific audible way (mainly through our hearing organ) and middle ear. Their audibility depends on the acoustic pressure level.

Great individual personal changeability was established however as far as hearing perception is concerned, particularly of the lowest frequencies. Infrasound hearing thresholds are so much the higher, the lower their frequency is and for example reach: for the frequency 6÷8 Hz about 100 dB, as for frequency 12÷16 Hz about 90 dB.

Beside the specific hearing way, the infrasounds are being received by the vibration reception sensors. The thresholds of this perception are 20÷30 dB higher than hearing thresholds.

2. Infrasounds and Infrasound Noise Characteristics

The term „infrasound" is interpreted as sounds or noise, whose spectrum is mainly contained within the frequency band of 1 Hz to 20 Hz [10]. Infrasound noise is understood as a noise, whose spectrum contains components of infrasound frequencies and low audible ones, up to 50 Hz [15].

Characteristic feature of the infrasound is considerable wave lengths (λ>17m), which, if lightly suppressed can radiate to a considerable distances from the source. Anti-noise protections used are not very effective. In some cases infrasounds can be amplified as a result of resonance of the premises, construction elements or the entire objects. The acoustic pressure levels may exceed then levels measured at the sources.

Infrasound levels, for health safety reasons and at the same time obligatory, are determined in the Regulation of the Polish Minister for Labour and Social Policies of the 29 November, 2002 on high admissible noise values – HANL [17]. Equivalent acoustic pressure level, corrected by frequency G curve, referred to 8-hours out of a 24–hours, or average, weekly working time **(**$L_{G\ eq,\ 8h)}$ is 102 dB, while the peek uncorrected acoustic pressure level, $L_{LIN,\ peak,}$ is 145 dB.

Admissible values of acoustic pressure levels for an 8-hour exposure, according to a Polish standard [16] are shown in the Table 1.

Table 1. Admissible values of acoustic pressure levels

No	Jobs position	Levels of sound pressure in dB in octave bands with geometric mean frequencies in Hz			
		4 Hz	8 Hz	16 Hz	31,5 Hz
1	Dispatcher, observatory and remote cabins	90	90	90	85
2	Administrative, office premises and project offices	85	85	85	80

In Russia, the admissible infrasound noise values have been defined in the standards: SN Nr. 2274-80 and SN 2.2.4/2.1.8.583-96 [20. 21] – Tables 2 and 3.

Table 2. Health standards for infrasound at the work places No. 2274-80

Levels of sound pressure in dB in octave bands with geometric mean frequencies in Hz					Overall level of sound pressure in dB Lin
2	4	8	16	31.5	
105	105	105	105	102	110

Table 3. Maximum Permissible Limits of Infrasound at the Work Places SN 2.2.4/2.1.8.583-96

Working activity	Levels of sound pressure in dB in octave bands with geometric mean frequencies in Hz				Overall level of sound pressure in dB Lin
	2	4	8	16	
Jobs with various degrees of laboriousness and intensity of working process in industrial premises and at territory of enterprise	100	95	90	85	100

As it can be seen from the Tables 2 and 3, the norms have become 2–3 times stricter. It is not easy to state to what extent they are substantiated, taking into account insufficient knowledge about effects of infrasonic radiation on a human being and what effects are more noticeable: frequency, intensity or duration.

Evidently, the levels of infrasound less than 110 dB are not very perceptible for a human being. At the same time, the levels of sound pressure in the tested vehicle interior (Table 2) that exceed the Sanitary Norms by 300 times, consequently can be injurious to health, create emergency situations on the road and so on.

Therefore setting the norms for levels of infrasound is undoubtedly important. But it can be clear seen that for introduction of rather strict requirements for infrasound levels, the comprehensive study is necessary.

It is estimated that, about 40÷60% people employed in transport are exposed to the infrasound noise. The recommendations for the infrasound measuring methods contain two international standards: ISO 7196 and ISO 9612 [10, 11]. Norm ISO 7196 determines frequency G curve to measure infrasounds, which is close to the infrasounds hearing perception threshold (direct).

The predominant effect of the influence of the infrasounds and infrasound noise on the human organism is their strenuous effect occurring with even a slightest breach of a hearing threshold. It is received by an organism through the subjectively determined states of an excessive tiredness, discomfort, drowsiness, and balance disruptions, disruptions of the physiological functions and decrease of the psychomotoric efficiency. The objective confirmation of those conditions are the changes in the central nervous system, characteristic to a lowered state of the alertness (which is particularly dangerous e.g. to the drivers of vehicles or machine operators). Human reaction time[1] is minimum 0,6 of a second, while a braking process always consists of two stages:

[1] Reaction time is a time necessary for making a single external reaction as an answer to a stimulus. The example can be pressing of a bake pedal as a reaction to the red light stimulus.

– Information received by an eye is conveyed to a brain, which composes an answer to the visual stimulus;
– The answer i.e. behavioural reaction is transferred to a lower limb, and manifests itself by pressing of the brake pedal.

Only after 0,6 sec. it is possible to activate any „electronic braking assistant". If the person has a lowered reaction as a result of an exposure to infrasounds (effects of tiredness similar to those after consuming high quantity of alcohol) the reaction time gets extended. It is worth realising, that at a speed of 50 km/h, and during 0, 6 of a second, the vehicle will cover 8, 3 metre.

Infrasound also restricts a field of vision, just like after alcohol consumption. For the fit man the field of vision is:

– at a standstill is 180 degree,
– at 40 km/h is limited to 100 degree,
– at 70 km/h is limited to 75 degree,
– at 100 km/h is limited to 45 degree,
– at 130 km/h is limited to 30 degree.

Infrasounds also affect the internal human organs causing their vibration of a resonance character, which subsequently can lead to serious and permanent damages.

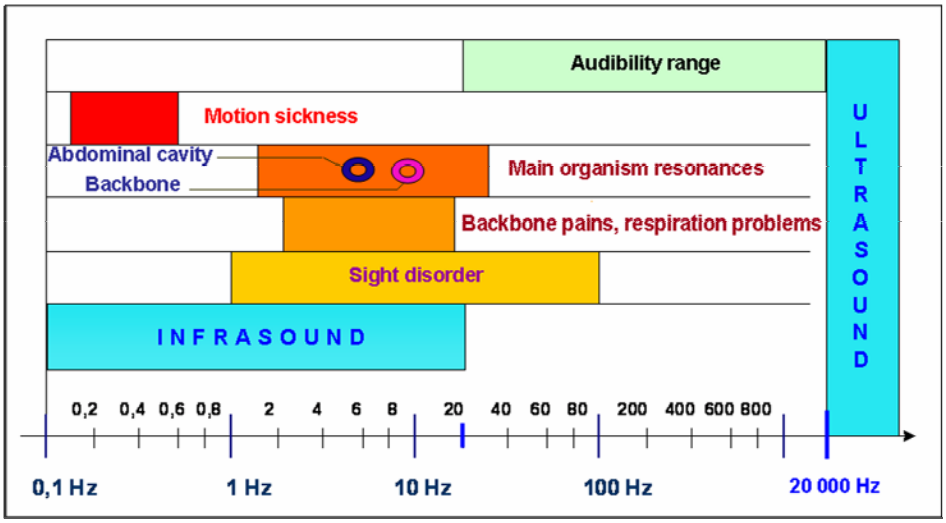

Fig. 1. Infrasound influence on human body

British scientists established that infrasound can have an effect on disorganising nervous activities in a similar manner to the effects of alcohol and the typical symptoms of their activity are unjustified feeling of fear, anxiety, headaches, nausea like sea sickness, eye ball bounce with a blurred vision, balance disruptions and tiredness.

Exposure to infrasound of a level below 120 dB does not cause unpleasant sensations and is harmless. Exposure to the infrasound field of 120 –140 dB can cause slight disruption of a physiological functions and a feeling of an excessive tiredness. But infrasound of 140–160 dB, even at a short exposure 2 min cause unpleasant physiological, sensations (sense of balance disruptions, vomiting). Long exposure can cause permanent damages to the organism. During the research conducted on animals it was established that the exposure to infrasound above 170 dB is lethal, usually through blood-shot lungs.

3. The Results of the Researches into Infrasound Noise

The researches, on the infrasound noise, have been conducted by the Motor Transport Institute. Measurements of the sound level have been taken using SVANTEK SVAN 945A register on correction curves A, Lin and G as well as dynamic characteristics Fast and Slow. Measurements were made only in the driver work place, recording acoustic pressure level for 30 seconds. Tests were carried out on 5 buses (M3 category), 10 vehicles of N3 category (saddle tractors and HGV`s), 3 HGV`s N1 category and 2 vehicles of category M1[2]. Results are presented in the Tables 4 and 5.

[2] Category M1 – vehicles designed and manufactured for carrying passengers, with not more than eight seats apart from the driver seat. Category M3 – vehicles designed for carrying passengers, with not more than 9 seats with a driver and of a max mass more 5 tons. Category N1 – vehicles designed for carrying loads of a max mass not more than 3,5 tons. Category N2 – vehicles designed for carrying loads of a max mass more than 3,5 tons, but less than 12 tons. Category N3 - vehicles designed for carrying loads of a max mass more than 12 tons.

Table 4. Research results for category M1 passenger cars

Vehicle	Category	LEQ sound level in dB in speed about 140 km/h	
		According to weighing curve A	According to weighing curve G
Personal car 1	M1	68	100
Personal car 2	M1	72	97

Table 5. Research results of M3, N3, N1 category vehicles

Vehicle	Category	LEQ sound level in dB in speed 70 – 90 km/h	
		According to weighing curve A	According to weighing curve G
Bus 1	M3	74	110
Bus 2	- „ -	73	115
Bus 3	- „ -	66	110
Bus 4	- „ -	74	115
Bus 5	- „ -	67	110
Tractor - semitrailer 1	N3	70	100
Tractor - semitrailer 2	N3	70	100
Tractor - semitrailer 3	N3	70	100
Tractor - semitrailer 4	N3	70	100
HGV 1	N3	73	100
HGV 2	N3	72	100
HGV 3	N3	70	98
HGV 4	N3	70	97
Vehicle chassis 1	N3	70	100
Vehicle chassis 2	N3	70	100
HGV 1	N1	72	100
HGV 2	N1	72	103
HGV 3	N1	75	100

Research results confirm high infrasound noise levels in the case of M3 category vehicles, remaining in the speed range of between 70 to about 90 km/h at a constant level, i.e. about 110÷115 dB acc. to correction curve G with relatively low level of interior noise of about 66÷74 dB according to correction curve A.

The level of infrasound noise reaches lower values of about 100 dB in the vehicles of N3 and N1 category. During the research, an importance of road surface condition was established, adding up to 7 dB, but in extreme cases even up to 10 dB, causing momentary increase of infrasound noise even up to 125 dB (maximum value).

The conclusion of the above analysis is that high infrasound levels are common in all motor vehicles, particularly in busses. This problem is being discussed on the forum of the EU European Economic Commission working group, dedicated to vehicles design.

Russian experts established [16], that the windows' position significantly influences the infrasound level inside the vehicle (Table 6). The differences are on average from 10-17 decibels. If the rear, side window is opened, it can cause an acoustic resonance (effect similar to the Helmholtz resonator). At the resonance frequency, there is an amplification of the vibrations intensity, very well audible. The tests conducted indicate, that in majority of cases, the resonator works no 8–16 Hz. frequency.

Table 6. Infrasound levels in the interior of a passenger car

Speed Km/h	Position of side windows	Levels of sound pressure in octave band 16 Hz	Overall sound pressure level, dB Lin.
70	All windows closed.	74	95.7
70	Rear right window is ⅓ open, the rest are closed.	117.9	118
70	Rear right window is ½ open, the rest are closed.	129.1	129.1
70	Rear right window is fully open, the rest are closed.	130.5	130.5
70	Rear left window is fully open, the rest are closed.	125.8	125.8
70	Front left window is fully open, the rest are closed.	122.5	122.5
80	All windows closed.	76.1	117.4
80	Rear right window is fully open, the rest are closed.	132.2	132.2
90	All windows closed.	77.6	112.9
90	Rear right window is fully open, the rest are closed.	133.1	133.2

During the research conducted in Russia, it was established that the acoustic pressure levels inside the tested passenger vehicle (Table 6), exceeded acceptable values, even 300 times[3] and are very harmful to humans, creating very dangerous situations on the roads. That is why it is imperative to pay a particular attention to setting acceptable values of infrasound for individual work places.

Infrasound waves can also affect bioelectrical signals known as (EEG) of the human brain. In the human, brain the alfa waves were discovered by Berger in 1929. Their rhythm consists of waves with a frequency 7-14 Hz. The rhythm of beta waves is in a range between 14-30 Hz. The rhythm of theta waves is of 4-7 Hz. frequency. Below 4 Hz are delta waves. Signals of 6, 6 Hz cause depression, signals 7, 83 Hz – wonderful feeling, while signals 10, 80 Hz – big annoyance, fury.

During normal functioning (being awake) and everyday activities, the dominating frequency is a beta type frequency. Alfa cycle generally appears in the state of deep relaxation and just before falling asleep and just after awakening. Theta frequency appears on the brink of awakening. Delta frequencies characterise deep sleep. The key to utilising fully the capabilities of our mind is the ability to self lowering the dominating frequency of our mind from the beta level to that of alfa and theta with retaining full consciousness.

The researches of the influence of the infrasound on the bioelectrical brain signals were conducted by AGH [5, 6]. The effects of infrasound on the changes of morphology of the spectral power density function of EEG signals were studied as a part of the research program covering two test conditions: f=7 Hz Lp= 120 dB and f=7 Hz Lp=120 dB. The research program involved 66 experiments; there were 33 participants–volunteers. A quantitative analysis was conducted of the driving response effect for the fundamental frequency and its harmonics to find the frequency of the driving response effect occurrence depending on the sex of participants. Studies were made for the low frequency acoustic wave of an acoustic pressure level 110dB on the population of 33 people. EEG signal was presented directly in the time domain, as a Higuchi Fractal Dimension changes curve, calculated for short time windows [8]. Higuchi algorithm is an effective and relatively simple method of calculating fractal dimension of the registered human brain biopotencials. Laboratory tests supported by statistical analysis of experimental data approved the following considerations:

- the intensity of the driving response with the fundamental frequency is an increasing function of frequency, the fraction of the effect occurrence increases with frequency of the applied excitation,
- the intensity of the driving response with the harmonic frequency is a decreasing function of frequency, the fraction of the effect occurrence decreases with frequency of the applied excitation,
- the fraction of the driving response with the fundamental frequency is larger for men than women,
- the fraction of the driving response with the fundamental frequency is an increasing function of frequency, both for men and women,
- for men, the fraction of the driving response with the harmonic frequency is a decreasing function of frequency.

Tests carried out proved, that infrasound noise affects human central nervous system, causes feeling of an excessive tiredness, drowsiness and decrease of the psychomotoric efficiency.

National Swedish Road and Traffic Research Institute has tested the influence of noise, infrasound and temperature on performance and wakefulness of drivers performing realistic driving tasks in a simulator, where they were exposed to realistic and controlled environmental as well as driving conditions. Forty-eight young, healthy individuals "drove" the VTI driving simulator for about four hours [14]. They were exposed to different combinations of noise, infrasound and temperature. Two levels of each of these variables, representing low and high levels measured in traffic were used. The experimental design thus included eight different experimental conditions (combinations) with six drivers exposed to each condition. As dependent measures of driving performance were used steering precision, speed holding and stimuli-induced reaction time, while EEG, ECG and EOG[4] were recorded for the assessment of wakefulness. Audiometer was carried out, before and after exposure, to observe possible temporary hearing threshold shifts.

U. Sandberg [18, 19] has carried out studies of the infrasound noise influence on the drivers and concluded, that the noise of 20 Hz dominating frequency and acoustic pressure level 90-115 dB, causes onset of the feeling of tiredness, drowsiness and decrease of the psychomotoric efficiency. Furthermore he presents the results of experiments conducted to investigate infrasound generation in a bus. The bus was driven on a smooth road, both upwind and downwind, and with and without damping of window vibrations. It was also run on an uneven road for comparison. The results show that by damping the window vibrations it was possible to reduce the infrasound levels significantly.

[3] According to a logarithmic scale and Weber-Fechner law, audible impressions are proportional to the logarithm of a stimulus. Two–fold increase of a sound intensity means the increase of the loudness level by about 3 dB, 10 - times increase of a sound intensity produces an increase of the loudness level by about 10 dB, 100 - times increase of a sound intensity produces an increase of the loudness level by about 20 dB, 1000 - times increase of a sound intensity produces an increase of the loudness level by about 30 dB.

[4] EEG (Electroencephalography) is the measurement of electrical activity produced by the brain as recorded from electrode placed on the scalp. ECG (An electrocardiogram), is a graphic produced by an electrocardiograph, which records the electrical activity of the heart over time. EOG (Electrooculography) is a technique for measuring the resting potential of the retina. The resulting signal is called the electrooculogram. The main applications are in ophthalmological diagnosis and in recording eye movements.

U. Landström [12, 13] concluded that for the frequency 2-20 Hz, and acoustic pressure level 115-120 dB, the reaction time in the psychomotoric efficiency test gets extended by 30-40 %. Drivers exposed to simulated industrial infrasound of 5 and 10 Hz and levels of 100 and 135 dB for 15 minutes reported feelings of fatigue, apathy, and depression, pressure in the ears, loss of concentration, drowsiness, and vibration of internal organs. In addition, effects were found in the central nervous, cardiovascular, and respiratory systems.

S. Benton [1] stresses that infrasound noise may cause stress. Stresses may be grouped into three broad types: cataclysmic stress, personal stress and background stress. Cataclysmic stress includes widespread and devastating physical events. Personal stress includes bereavements and similar personal tragedies. Background stresses are persistent events, which may become routine elements of human life. Infrasound noise has been classified as a background stressor. In this way, chronic psycho physiological damage may result from long-term exposure to infrasound noise.

P. N. Dorosenko [7] tested infrasound noise of 12 Hz frequency with acoustic pressure level equal to 140 dB. He concluded that, 63% cases tested complained of irritation, headache, periodical dizziness, humming noise in the ears and difficulties with breathing. He proved, that the loss of hearing, manifested by lasting lifting of the hearing threshold, progressed with the period of years at work. At 30% of people tested, he observed balance and movement co-ordination disruptions.

Conclusions

The problem of infrasounds and infrasound noise influence on drivers is not recognised in detail, because vehicles type approval tests, conducted according to the UN European Economic Commission Regulations [3, 4]; encompass only testing of the vehicle external noise.

Based on the analysis conducted, it is possible to say that prolonged exposure to the infrasound noise of a low acoustic pressure 90 dB causes symptoms of strenuousness. The most often reported symptoms of strenuousness are: drowsiness, excessive tiredness, sluggishness, headaches, and irritations, extension of the reaction time, decrease of the psychomotoric efficiency, increase of the psychological tension and loss of hearing.

Infrasound waves are also strenuous for the values admissible by Polish Standards. E.g. infrasound waves for the levels: 90 and 120 dB, with a dominating frequency 5 Hz, cause symptoms of strenuousness, characteristic to a lowered state of the alertness of the central nervous system, in which the vehicle drivers have disrupted attention, disrupted perception of surrounding activities and diminished sharpness and field of vision. There is certain analogy and cumulative effect of infrasound and alcohol, manifesting itself by lowering speed of the nervous reactions.

Even a short exposure to infrasound noise can bring on symptoms of strenuousness like drowsiness, irritation, headaches, pressure in the ears, being short of breath and heart action disruptions. Additionally infrasound waves can induce resonance vibrations of the chest, abdominal membrane and digestive organs. That causes respiratory system problems, and with a prolonged exposure leads to the digestive system disorders.

Research conducted by ITS, AGH and Russian experts indicate that excessive levels of NDN values of the infrasound noise are common occurrence ($L_{G,\ eq\ 8h}$ = 102 dB) in various domestically and abroad manufactured vehicles, which creates significant nuisance in the driver working environment, and can have an effect on lowering psychomotoric effectiveness of the drivers, cause attention disruptions, bring about tiredness and drowsiness, which can be a cause for the road accidents.

There is a possibility to control the level of infrasound noise in the vehicle. It appears that, the noise can be caused by the working engine, pulsating air, or the road surface. It is necessary to conduct further research in order to recognise the fact of endangering drivers by their exposure to the infrasound noise in the working environment and formulate the appropriate countermeasures.

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