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STUDY OF ACOUSTIC PARAMETERS OF AUDIBLE AND VISUAL WARNING DEVICES USED BY THE POLICE OF THE CZECH REPUBLIC

In the article, the authors are concerned with acoustic parameters of audible and visual warning devices used by the Police of the Czech Republic. The objective of the article is, in context with the fundamental rules of sound and its propagation in environments and with associated health risks, to describe in accordance with valid legislative requirements the acoustic parameters of audible and visual warning devices used by the Police of the Czech Republic. Results of the acoustic study, their evaluation and recommendations for their field use will be presented.

Key words: *Police of the Czech Republic, acoustic quantities, noise, noise measurement, special audible and visual warning devices, sirens*

1. Introduction

Experience of road traffic shows clearly that vehicles having the right of way, have to be, as well as possible, equipped with an audible warning signalling device so that they could be distinguished in road traffic in sufficient advance. Then vehicles have to be equipped with a sufficient amount of efficient devices emitting pulses of warning light and devices generating warning sound with a variable tone pitch. Solving the problems of used audible and visual warning devices deserves individual attention. The reason is that using the audible and visual warning devices leads to a reduction in risk of traffic accident and a decrease in response time. When using the audible and visual warning devices, many kinds of acoustic signals exist, and it is of importance to other traffic participants to know how to behave [4]. That is why the authors of the article submit a comprehensive study and results of made measurements of acoustic parameters of audible and visual warning devices of the Police of the Czech Republic (henceforth referred to as PCR). The measurement as well as the evaluation of obtained results is carried out in conformity with the requirements of relevant valid legislation and international standards. In the framework of implementation of a joint project based on co-operation of Faculty of Safety Engineering of VSB – Technical University of Ostrava and the Regional Headquarters of Police of the Moravian-Silesian Region of PCR, both acoustic and photometric parameters of audible and visual warning devices of the PCR were compared and the results were the content of two Master's theses thematically focused like that; the authors being students in the field of Safety Engineering of Faculty of Safety Engineering of VSB – Technical University of Ostrava.

2. Properties of Acoustic Warning Signals

The auditory field (shape and size) is different for every individual. The shape and the size change depending on hearing defects. The greatest sensitivity of human ear ranges from 250 to 5000 Hz. The frequency of siren tones moves in the range of 540 Hz – 1500 Hz. [2] The frequency range of siren tones is set at the most sensitive range of auditory field. We can consider a change in frequency when a sound source and a detector are moving (Doppler effect). The worst case situation, leading to the greatest change in siren frequency of 1000 Hz, is the movement of the sound source Z and the detector D towards and away from each other. When moving towards each other at the velocity of 130 km/h, the frequency will be $f' = 1234$ Hz (increase by 234 Hz).[1] When moving away from each other, a frequency $f' = 810$ Hz (decrease by 190 Hz) will be recorded. The frequency range of siren tone is equal to the most sensitive range of human ear, which represents the worst level. If we want to determine the effects of noise on humans, we have to know above all the intensity and the frequency of the noise. Another essential factor is the time of noise exposure. The main adverse effect of noise is that on an auditory organ, when sound sensitive cilia in the organ of Corti die [8]. Subsequently, the mechanical transmission of waves in the middle ear is damaged. Noise affects negatively not only the auditory organ but also the quality of sleeping, compensation capacity for stress and the cardiovascular system. The adverse effects manifest themselves in hearing only at the intensity of more than 80 dB. At long-term exposure to the intensity of 85–90 dB, hearing impairment occurs. At long-term exposure to the intensity of more than 110 dB, a heavy impairment of the auditory organ up to deafness occurs. At the operation of

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sirens, individuals are exposed to the frequencies of about 1000 Hz and to the equivalent level of sound pressure of more than 105 dB and a significant adverse effect on the auditory organs of exposed persons can be expected. [5] At the assessment of noise risk to an employee of the Police of the CR, it is necessary to take into account the reasons for the use of audible and visual warning devices that are to be observed to avert the impending danger [7]. With reference to irreversible consequences that may appear after long-term exposure exceeding the hygienic limit values, it is also necessary to respect related preventive measures in the case of members of PČR.

3. Acoustic Requirements for Audible and Visual Warning Devices

In the Czech Republic, vehicles having the right of way are only vehicles equipped with a blue warning light supplemented by a special warning siren. The frequency of changes in pitch of a tone can be variable. Thus it is a case of lightbars, LED displays, supplemented by an electronic siren and a public address system. The most significant law regulating the use of audible and visual warning devices in the CR is the Act No. 361/2000 Coll. on road traffic (Road Traffic Act). In the CR, merely blue lights are allowed for all vehicles of rescue, safety and security services; combination with another colour is not allowed. Acoustic requirements are determined by legislation merely in general. A single technical parameter, which is stated in the Decree No. 341/2002 Coll., is the minimum sound pressure level determined at the value of 105 dB (A). In relation to the stated value it is necessary to apply the relevant provisions of the Regulation No. 28 of the Economic Commission for Europe (UN/ECE) – Uniform provisions concerning the approval of audible and visual warning devices and motor vehicles with regard to their acoustic signals and the Directive EEC/EC (70/388/EEC).

The maximum sound pressure level of audible and visual warning devices is not regulated by the Decree in any way but it demands keeping the sound pressure level, which must not damage the auditory organ of the individual who may be present in the vicinity of the siren. By the Regulation No. 28 of EC for Europe (EEC-ON) the maximum value of sound pressure level is determined at 118 dB (A), i.e. value smaller than the threshold of pain. This limit is in accordance with the standard CSN EN 981 (83 3593) Safety of machinery – System of auditory and visual danger and information signals.

4. PCR's Audible and Visual Warning Devices Selected for Acoustic Measurements

The basic configuration of the audible and visual warning devices and control units also includes a speaker with an amplifier. The power and the location of the speaker differ with various types of lightbars. The amplifier is located in the cabin of the car and is supplemented by control elements. In the text, attention is paid to the used audible and visual warning devices that are placed on measured police cars. In the Czech Republic, the manufacturer of audible and visual warning devices is the company Holomy Electronics.

For the evaluation of acoustic parameters, three types of lightbars mounted on three different types of vehicles were examined. The first one is a rotating warning lightbar VNK 530, which is dimensionally adapted from the point of view of maximum visibility and minimum aerodynamic resistance. The design of the lightbar enables the vehicle to drive at a speed of more than 200 km/h. The lightbar supplied for measurements can be seen in Fig. 1. On the bar blue beacons are mounted and in the central part a speaker of the power of 100 W is installed for transmitting siren tones and voice commands. The second lightbar selected for acoustic measurements is a flashing warning lightbar VSL 012LV. This lightbar has the most advanced design, LEDs of 3rd generation. The middle part of the lightbar is divided into two parts. The right one consists of a LED message board displaying red STOP. In the left part, a speaker of the power of 120 W is installed. The third lightbar is a flashing warning lightbar VSL 012FL. It is also a LED-based lightbar with a speaker of the power of 120 W, mounted usually at smaller heights; and is designed for vehicles with a manufacturer's maximum speed less than 300 km/h.

A warning device and a public address system enabling the control of executive elements of the lightbar are also part of the audible and visual warning device. Various types of audible and visual warning devices exist. These types differ from each other in the selection of elements in the set, which participate in the control of the lightbar and the speaker. Furthermore, they can differ in the number of possibilities of control and check of additional functions of lightbars, in the control of visual signals (displaying STOP, AMBULANCE, and others), the presence of a microphone socket, the presence of an amplifier in the control unit, etc. Warning lightbars were connected to various kinds of control units of type range AZD 530A. A control unit AZJ 530A makes it possible to control executive elements, light elements of the lightbar, to choose the siren tone and its loudness. During all measurements, the maximum level of produced siren tones was set on the control unit AZJ 530A [5].

The control unit made it possible to choose by switching from three preset warning siren types

Siren 1 (WAIL tone with a slow repetition frequency),
Siren 2 (YELP tone with a fast repetition frequency),
Siren 3 (Hi-LO tone with fast repetition frequencies of two tones).

5. Acoustic Measurements in Real Conditions

The issue of measurement of acoustic parameters is, with regard to the nonexistence of any specific regulation or standard, very complicated. The Regulation No. 28 of the Economic Commission for Europe (UN/ECE) and the Directive No. 70/388/EEC, prescribe requirements for the procedure of measurement of sound pressure levels of audible warning devices. These regulations *do*

Fig. 1 Lightbar VNK 530

Fig. 2 Lightbar VSL 012LV

Fig. 3 Control unit AZD 530A

Fig. 4 Lightbar VSL 012FL

not relate to special audible warning devices. In the course of measurements, calculations and also evaluations, we proceeded in accordance with relevant valid international standards for acoustic measurements and evaluation of machinery.

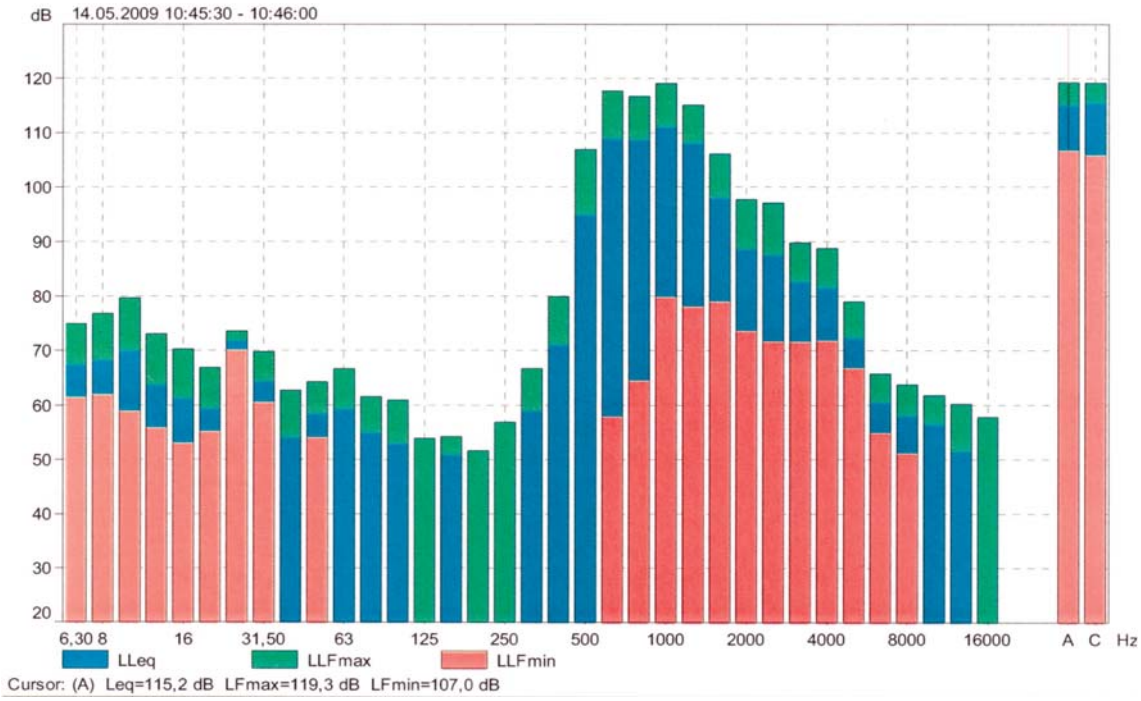
All measurements were taken in a D1 motorway segment closed to the traffic near Ostrava. In this place, three measurements were carried out. The first one served as a pilot measurement. The objective of this measurement was to find possible problems of the measurement of acoustic parameters of the audible and visual warning devices and to determine whether chosen methods can be used in real conditions. The second and third measurements were live measurements of acoustic parameters. It was the measurement of sound pressure level and power of the audible and visual warning device, its directional operation, the measurement of the frequency ranges of siren tones and of the sound pressure level in the cabin of the car in the course of operation of the audible and visual warning device.

The measurement was made using measuring devices designed for the professional measurement of acoustic quantities, namely a device B&K Observer and a device Acoustilizer A1. The processing of results was carried out electronically using relevant software products supplied with the devices, and in accordance with relevant international standards the uncertainty of measurement was evaluated as well.

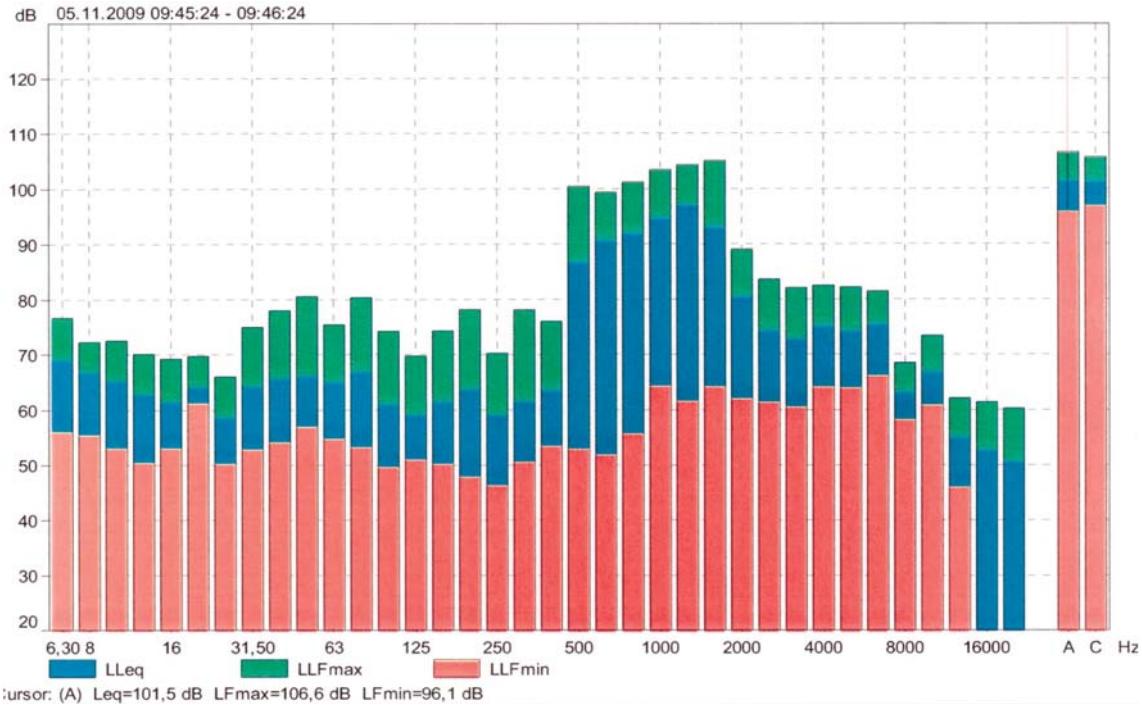
6. Results and Discussion

For the determination of acoustic parameters, three ranges of the above-mentioned types of measurements describing sufficiently the characteristics of the audible and visual warning devices were proposed. After determination of equivalent sound pressure levels of the audible and visual warning devices, the calculation of recommended duration of presence in the surroundings and in the cabin in the course of operation of the siren was executed to avoid the exceeding the determined eight-hours' hygienic limit [6]. The executed calculations should be a basis for detailed assessing compliance with the hygienic limit values at work near audible and visual warning devices.

In all three types of evaluated lightbars, comprehensive measurements with partial outputs were repeatedly done. In the following graphs, results of measurements of sound pressure of the lightbar VNK 530 – see Graph 1 and the lightbar VSL 012FL – see Graph 2 at the first of three siren types (WAIL) are plotted.

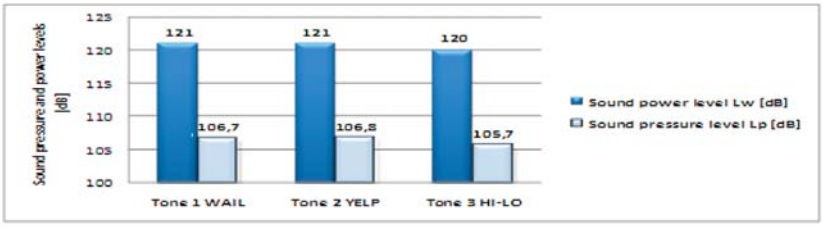


Graph 1 Level of sound pressure of VNK 530 with WAIL tone of siren 1

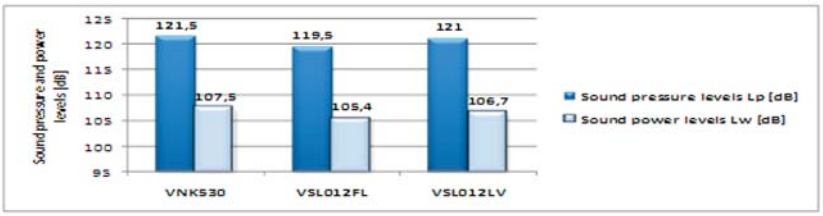


Graph 2 Level of sound pressure of VSL 012F with WAIL tone of siren 1

The following Graph 3 shows the comparison of results of acoustic measurements of all three siren types of the lightbar VSL 012LV. For the calculation of average level of surface sound pressure of the siren, a formula given in the standard CSN ISO 3744 was used. For the calculation, measured values of sound pressure levels were used.



Graph 3 Calculated levels of sound pressure and power of warning lightbar VSL 012LV



Graph 4 Calculated values of levels of sound pressure and power of warning lightbars

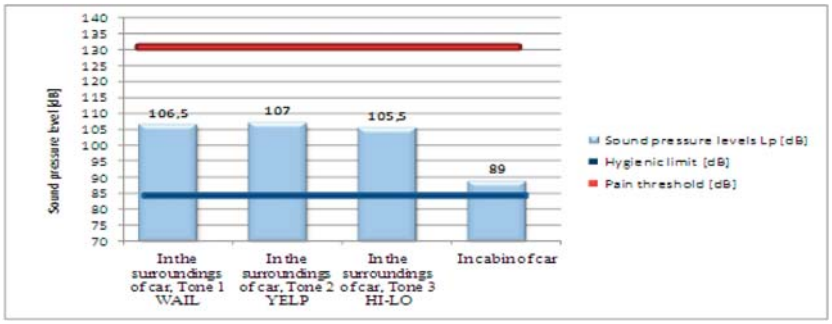
Recalculated levels of sound pressure and power for all siren tones in the case of three measured lightbars are plotted in Graph 4.

The comprehensive results of measurement in the framework of the study confirm that *there are not any significant acoustic differences between the measured audible and visual warning devices.* The majority of advanced sirens are controlled by a microprocessor; a certain standardization of tone has occurred. For this reason, measurement results could be used for the evaluation of frequency ranges of siren tones. In addition to the measurement of sound pressure level, percentile levels were another measured parameter. For the evaluation of frequency range of tones of the three siren types, results of measurements made at a distance of 3 m from the lightbar were used. Switching between the tones was possible thanks to the control unit [3].

WAIL is a continuously variable tone, which imitates the sound of a motor siren. The frequency range of tones of sirens 1 and 2 is 540 – 1500 Hz. The frequency range of tone of siren 3 is 780/1040 Hz. The greatest sound transmission loss occurs in the siren tones at a frequency of 1600 Hz. This frequency will be, in contrast to the other frequencies, least audible over long distances. The least sound transmission loss occurs in the siren tones at a frequency of 500 Hz. To be able to distinguish safely a siren tone a person has to hear all its frequency components. Furthermore, a sufficient difference between the sound pressure level and that of the background has to exist. In accordance with technical standards, the difference of 10 dB can be taken as sufficient. From the legislative requirements follows that the minimum value of sound pressure level of the audible and visual warning devices is *105 dB*. From the previous measurements it follows that the sound pressure level of background of *70 dB*. The highest joint frequency of the tones of sirens 1 and 2 is the frequency of 1500 Hz. For this value any tabular value of sound transmission loss does not exist, and for this reason, the closest possible value, i.e. 1600 Hz was selected. If we take the frequency from the greatest transmission loss (1600 Hz), a distance over which the siren tone will be audible can be calculated in a simplified way. A difference between the sound pressure level of the siren and that of background is $\Delta L = 35$ dB. A similar situation is there with the HI-LO tone of siren 3. The highest frequency of the tone of siren 3 is the frequency of 1040 Hz. For the WAIL and YELP tones, the range of audibility is theoretically 5 km, for the HI-LO tone about 7 km. The determined range depends considerably on atmospheric conditions and operating environment. In the course of application of warning siren tones in a town, all the siren tones cannot be recommended wholly without fear. This fear is caused by a long repetition period of the WAIL tone. The repetition period of the WAIL siren tone is 4 s. Other road users need not notice any warning signal before an increase in maximum sound pressure level. A situation may occur when the other road users do not yield the right of way to a police car. This risk increases especially in the course of crossing junctions in high-density built-up areas of towns. Acoustic shadows caused by buildings may occur. There is a risk of tragic events and a recommendation is to select a tone with a rather short repetition period of siren tone, e.g. YELP, HI-LO, before passing the junction. In a free space, all siren tones of the audible and visual warning device concerned can be used.

All the types of measured lightbars satisfied the legislative requirement for the lower level of sound intensity of these devices. The legislative requirement determines the value of 105 dB (A) as a minimum and a hemispherical surface of a radius $r = 2$ m surrounding the audible and visual warning device fulfils it. From the resultant calculated values of sound power, only negligible differences on the level of measurement uncertainties were found between the audible and visual warning devices.

In the framework of the study, the evaluation of effects of sound of the audible and visual warning devices used on persons



Graph 5 Average levels of sound pressure of VSL 012VL

in the close vicinity of the audible and visual warning devices was carried out. The average value of sound pressure level at a distance of 3 m from the car is 99.7 dB (A). The average value of sound pressure level in these measuring points is 96 dB (A). The measured value at a distance of 3 m is smaller than the threshold of pain; however it is necessary to emphasise cumulative effects of noise on the auditory organ. A decrease in acuity of hearing takes place after long-term exposure to noise the values of which exceed the hygienic limit of 85 dB (A) per shift. [6] Measurements and evaluations of sound pressure level in the closed cabin of the car at switched on audible and visual warning devices were carried out; subsequently, the sound pressure level at the switched on audible and visual warning devices is up to 25 dB (A), which indicates a high level of sound insulation of vehicles used. The achieved decrease is however on the level exceeding the hygienic limit per shift. In Graph 5 an overview of values of sound pressure level determined at various siren tones in the case of lightbar VSL 012LV is presented

Although we do not expect that a member of the Police of the CR is subject to such exposure for the whole shift, it is necessary to be concerned with the duration of the exposure per average characteristic shift, because the use of adequate hearing protection as e.g. in industrial conditions is out of the question. What is a solution is the determination of recommended time of work in the cabin and also outside the cabin at the switch on audible and visual warning devices. The calculated recommended time of working in the surroundings (within the distance of 3 m) at the switched on audible and visual warning devices is *3.4 min as a maximum*. The calculated recommended time of work in the cabin of the car at the switched on audible and visual warning devices is *186 min as a maximum*. This time represents the maximum allowable time at everyday use of the siren to avoid the exceeding of hygienic limits. [3]

7. Conclusion

The study in real conditions has verified acoustic characteristics and parameters of audible and visual warning devices used commonly on vehicles of the Police of the CR. The obtained results can be the basis for further verification of other both used and new audible and visual warning devices in various conditions of use, e.g. in high-density built-up areas. When evaluating the effects of noise on members of the PCR, the amount and the severity of noise exposure as well as the reasons for the use of audible and visual warning devices designed for application in the interests of averting the impending hazard are to be considered.

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