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COMPUTATION IN NOISE REGULATION

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Abstract*. Noise is a harmful factor that poses a threat to the health of workers in many professions in the maritime industry. Domestic labour protection legislation provides effective tools for regulating the parameters of industrial noise [1]. At the same time, objective processes of globalization of the world economy, integration of Ukraine into the global system of labour division increasingly require knowledge and application of international standards in the field of occupational health. In particular, this becomes relevant in the course of training specialists to work on ships of foreign shipping companies.*

From a hygienic point of view, noise is any unwanted sound or sound that does not carry useful information. In turn, sound, as a physical phenomenon, is a fluctuation in the pressure or density of a continuous medium, in particular air.

Sound is characterized by the following physical parameters.

Sound frequency – the human auditory analyser perceives sound vibrations with a frequency ranging from 16 to 20 $\cdot 10^3$ Hz.

Sound intensity – the work performed by a sound wave per unit time, referred to a unit of surface area normal to the direction of propagation of the sound wave, W/m^2.

Sound pressure is the root-mean-square value of atmospheric pressure that changes as a result of the passage of a sound wave, Pa.

However, the use of absolute values of sound intensity or sound pressure in practical acoustics is unacceptable due to the action of the basic psychophysical law of Weber-Fechner, which forces the use of relative logarithmic parameters: logarithmic intensity level and logarithmic sound pressure level (SPL), which are measured in relative logarithmic units – decibels (dB). The latter parameter is the main standardized parameter of industrial noise in domestic legislation, and the main hygienic principle of standardization is the limitation of sound pressure levels for different categories of work.

Unlike domestic legislation, international legislation uses an approach that consists in standardizing the exposure dose, i.e. the sound pressure level in combination with the duration of exposure. In particular, this approach is the basis of the US Occupational Safety and Health Administration (OSHA) standard [2].

This standard establishes the relationship between the sound pressure level and the permissible noise exposure in tabular form and in the form of mathematical relationships containing exponential and logarithmic operands and are quite inconvenient for practical use – determining the admissibility of working conditions. The task is complicated in proportion to the number of periods with different noise levels during the work shift.

In view of this, it seems advisable to develop a computer program to automate calculations related to the application of the OSHA 29 CFR 1910.95 standard, what is the subject of this paper.

Key words: *industrial noise, standardization, noise exposure, calculation of permissible dose, calculation of time-weighted average sound pressure level.*

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ОБЧИСЛЕННЯ ПРИ НОРМУВАННІ ШУМУ

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Анотація. *Шум є шкідливим фактором, що становить загрозу здоров'ю працівників багатьох професій морської галузі. Вітчизняне законодавство з охорони праці передбачає ефективні інструменти нормування параметрів виробничого шуму [1]. В той же час об'єктивні процеси глобалізації світової економіки, інтеграція України в світову систему розподілення праці наполегливо вимагає знання і застосування міжнародних стандартів в галузі гігієни праці. Зокрема актуальним це стає в ході підготовки спеціалістів для роботи на суднах іноземних судноплавних компаній.*

З гігієнічної точки зору шумом є будь-який небажаний звук або звук, що не несе корисної інформації. В свою чергу звук, як фізичне явище представляє собою коливання тиску або густини суцільного середовища зокрема повітря.

Звук характеризується такими фізичними параметрами.

Частота звуку – слуховий аналізатор людини сприймає звукові коливання з частотою, що лежить в діапазоні від 16 до 20 · 103 Гц.

Інтенсивність звуку – робота, яку виконує звукова хвиля на одиницю часу, віднесену до одиниці площі поверхні, нормальної до напрямку розповсюдження звукової хвилі, Вт/м2.

Звуковий тиск – середньоквадратичне значення атмосферного тиску, що змінюється в наслідок проходження звукової хвилі, Па.

Проте використання абсолютних значень інтенсивності звуку або звукового тиску в практичній акустиці є неприйнятним через дію основного психофізичного закону Вебера-Фехнера, що змушує використовувати відносні логарифмічні параметри: логарифмічний рівень інтенсивності та логарифмічний рівень звукового тиску, які вимірюються у відносних логарифмічних одиницях – децибелах (дБ). Останній параметр є основним нормованим параметром виробничого шуму у вітчизняному законодавстві, а основним гігієнічним принципом нормування є обмеження рівня звукового тиску для різних категорій робіт.

На відміну від вітчизняного міжнародне законодавство використовує підхід, що полягає в нормуванні дози впливу, тобто рівня звукового тиску в комбінації з тривалістю впливу. Зокрема такий підхід лежить в основі стандарту Адміністрації з виробничої безпеки та гігієни США (OSHA) [2].

Цей стандарт встановлює залежність між рівнем звукового тиску і допустимою експозицією шуму (тривалістю впливу) в табличній формі та у вигляді математичних залежностей, що містять експоненціальні та логарифмічні операнди і є досить незручними для практичного використання – визначення допустимості умов роботи. Задача ускладнюється пропорційно кількості періодів з різним рівнем шуму протягом робочої зміни.

З огляду на це видається доцільною розробка комп'ютерної програми для автоматизації розрахунків, пов'язаних із застосуванням стандарту OSHA 29 CFR 1910.95, ознайомленню з якою присвячена пропонована робота.

Ключові слова: *виробничий шум, нормування, експозиція шуму, розрахунок допустимої дози, розрахунок середньозваженого рівня звукового тиску.*

Introduction. *Noise is a harmful factor that poses a threat to the health of workers in many professions in the maritime industry. Domestic labour protection legislation provides effective tools for regulating the parameters of industrial noise [1]. At the same time, objective processes of globalization of the world economy, integration of Ukraine into the global system of labour division increasingly require knowledge and application of international standards in the field of occupational health. In particular, this becomes relevant in the course of training specialists to work on ships of foreign shipping companies.*

Main part of the article. From a hygienic point of view, noise is any unwanted sound or sound that does not carry useful information. In turn, sound, as a physical phenomenon, is a fluctuation in the pressure or density of a continuous medium, in particular air.

As a physical phenomenon, sound is characterized by the following parameters [3; 4; 5; 6].

Frequency f [Hz] – a person perceives sound vibrations with a frequency whose value lies in the range of 16-20,000 Hz.

Intensity (power) of sound I [W/m^2] – the operation of the sound wave per unit of time, referred to the unit of surface area normal to the direction of sound propagation.

Sound intensity is defined as a function of sound pressure p [Pa]

$$I = p^2/(\rho v),$$

where p – the measured root-mean-square (rms) sound pressure;

ρ – medium density of air, kg / m^3;

v – speed of sound in air, m / s.

The use of absolute values of sound intensity and sound pressure is inconvenient due to the effect of Weber-Fechner's basic psychophysical law. The Weber-Fechner law states that intensity of our sensations depends on the intensity of the stimulus, not linearly, but according to the logarithmic law, as shown in figure 1. That is, as the intensity of the stimulus increases, our sensitivity decreases. For the auditory analysers, the base of the logarithm is 10. And if the point corresponding to the hearing threshold is here (at the figure), then the point corresponding to the pain threshold will be somewhere in the street.

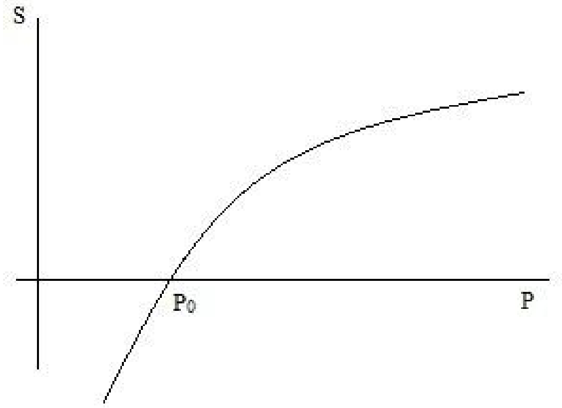

Fig. 1. The dependence of human`s auditory sensitivity on sound pressure

The way out of this situation is quite simple - to replace the absolute values of the sound intensity and sound pressure by relative logarithmic values [dB] (decibel).

As a result, we obtain a linear dependence of the sensitivity of the hearing organ on the intensity of the stimulus (figure 2).

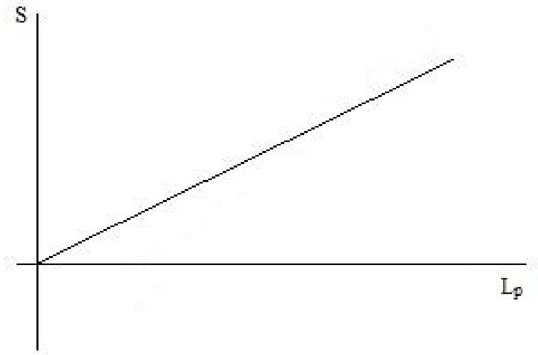

Fig. 2. The dependence of human`s auditory sensitivity on SPL

Because of this, in practical acoustics, not absolute but relative logarithmic values are used: the sound intensity level

$$L_I = 10 \cdot \log_{10}(I / I_0) \text{ [dB]},$$

where $I_0 = 10^{-12}$ W/m^2 is the sound intensity corresponding to the sensitivity threshold at a frequency of 1000 Hz; and sound pressure level

$$L_p = 20 \log_{10}(p / p_0) \text{ [dB]},$$

where $p_0 = 2 \cdot 10^{-5}$ Pa, sound pressure corresponding to the sensitivity threshold at 1000 Hz.

The human ear does not sense each frequency in the audible range with the same sensitivity. To take that into account the instruments designed for measuring of sound pressure level have a special measuring scale named A scale. In that scale the instrument operates like human hearing modelling its sensitivity to several frequencies and summarizing them in one value. Therefore, a sound pressure level measured in that special scale has unit of measuring dB A.

Rather authoritative and widespread regulation of industrial harmful factors are OSHA Standards. OSHA (Occupational Safety and Health Administration), a federal agency of the United States that regulates workplace safety and health.

Table 1 lists the OSHA permissible exposures depending on corresponding sound pressure level.

Table 1

OSHA exposure limits

Sound Level (dB A)	**Permissible Duration of Exposure (hr)**
90	8,00
92	6,00
95	4,00
97	3,00
100	2,00
102	1,50
105	1,00
110	0,50
115	0,25 or less
140 peak level	Impulse or impact noise

When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each.

If the sum of the following fractions: $t_1/T_1 + t_2/T_2 + ... + t_n/T_n$ exceeds unity, then, the mixed exposure should be considered to exceed the limit value. Here ti is the total time of exposure at a specified sound pressure level and Ti is the total time of exposure permitted at the specified level.

For example, a worker is exposed as presented in table 2.

Table 2

Noise exposure during a workday

Noise Level (dB A)	Duration (hr)
110	0,25
100	0,5
90	1,5

Is the OSHA limit exceeded?

From the preceding exposure data, allowable exposure times in table 1, and following equation we have

$$t_1/T_1 + t_2/T_2 + t_3/T_3 = 0{,}25/0{,}5 + 0{,}5/2 + 1{,}5/8 = 0{,}938.$$

Because 0,938 is less than l.0, the exposure is allowable.

The way of dosimetry may be used as well.

If the noise exposure is constant during a job assignment. Noise dose in percent is

$$D = 100 \cdot t / T,$$

where t – the total length of the job assignment in hours, and

T – the reference duration in hours for a measured A-weighted sound level, Lt, in dB A, in other words T is a permissible duration of exposure to Lt.

If T isn't present in table 1 exactly it can be derived from an expansion of the OSHA exposure limits (table 1) and computed as

$$T = \frac{8}{2^{\frac{L-90}{5}}}.$$

That is just an interpolation formula for calculating allowable time responding to some sound level (Lp).

When noise exposure for a work shift consists of 2 or more periods of noise at different levels, the total noise dose over the workday is given by

$$D = 100 \cdot (t_1/T_1 + t_2/T_2 + ... + t_n/T_n).$$

For example, a worker is exposed to a 107 dB A constant noise source during a 7-hr shift. What is the noise dose?

The corresponding duration is

$$T = \frac{8}{2^{\frac{107-90}{5}}} = \frac{8}{2^{3,4}} = 0,758h$$

The dose is

$$D = 100 \cdot (t/T) = 100 \cdot (7 / 0,758) = 924 \%.$$

Thus, the allowable dose is significantly exceeded.

Or, if a daily noise exposure is composed of three periods with deferent levels as presented in table 3

Table 3

Noise exposure during a workday

Noise Level (dB A)	Duration (hr)
112	1.0
98	3.0
93	4.0

the dose is:

$$T = \frac{8}{2^{\frac{112-90}{5}}} = \frac{8}{2^{4,4}} = 0,379h$$

$$T = \frac{8}{2^{\frac{98-90}{5}}} = \frac{8}{2^{1,6}} = 2,639h$$

$$T = \frac{8}{2^{\frac{93-90}{5}}} = \frac{8}{2^{0,6}} = 5,278h$$

$$D = 100 \cdot (t_1/T_1 + t_2/T_2 + t_3/T_3) = 100 \cdot (1 / 0,379 + 3 / 2,639 + 4 / 5,278) =$$
$$= 100 \cdot (2,64 + 1,14 + 0,76) = 454 \%.$$

It is desirable in some situations to know not only the dose of noise but as well the 8-hour time-weighted average sound pressure level (TWA) or equivalent sound pressure level ($L_{p\ eqv}$). Equivalent SPL is a normative parameter of our domestic noise regulation so it is necessary to know the correlation between international and Ukrainian norms.

The notion of $L_{p\ eqv}$ (TWA) can be illustrated by the figure 3.

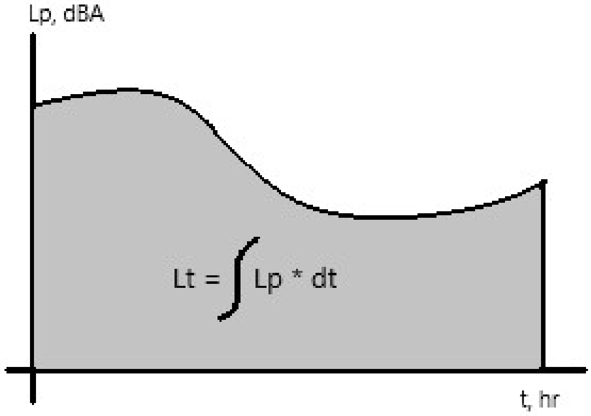

Fig. 3. Depending of SPL from time during a workday

On the figure L_p is the SPL (dB A), L_t – integral of SPL over time (t) and τ – duration of the work shift.

Then

$$L_{p.eqv.} = \frac{\int_t Lp \cdot dt}{\tau} = \frac{\sum_{i=1}^{N} L_{pi} \cdot \Delta t}{\tau}.$$

And for the above example it is

$$L_{p\ eqv}\ (TWA) = (112 \cdot 1 + 98 \cdot 3 + 93 \cdot 4) / 8 = 97{,}25 \text{ dB A}.$$

For defining of this value, the approximating formula is offered by the OSHA standard

$$TWA = 16{,}61 \cdot \log_{10}(D/100) + 90 = 16{,}61 \cdot \log_{10}(453/100) + 90 = 101 \text{ dB A}.$$

As we see the last expression causes a rather significant error in comparison with the precise formula.

So, as we can see, defining of noise dose and TWA connected with the necessity of making rather large quantity of calculations and thus the development of a computer program is desirable.

The interface of such a program, developed in the environment of Microsoft Visual Foxpro, presented at the figure 4.

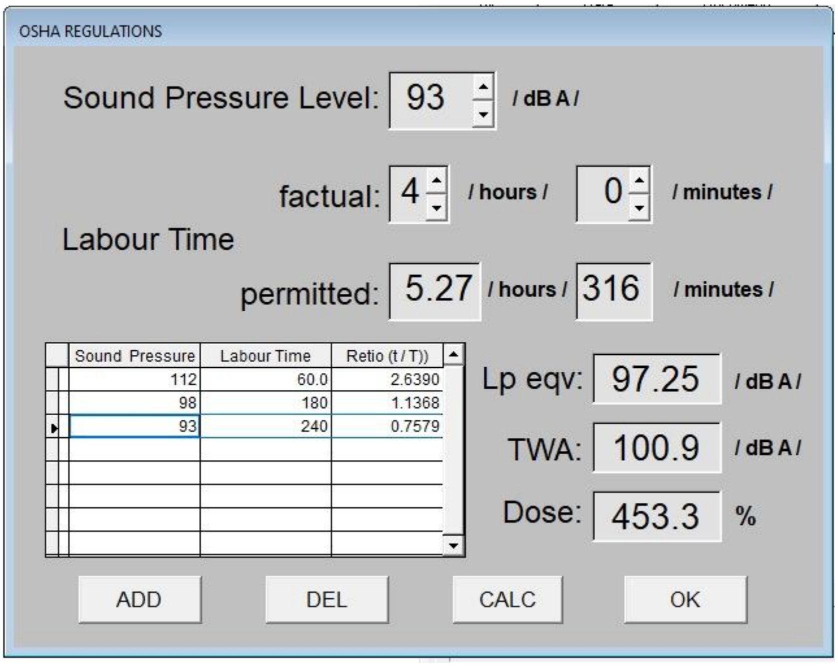

Fig. 4. The interface of the program

Sound pressure level and factual labour time are assigned by corresponding spinners. Then permitted labour time calculated automatically and displayed on screen as soon as SPL or factual time is changed. Press of the button «CALC» evokes calculating and displaying equivalent pressure level, TWA and dose.

If the work shift consists of 2 or more periods, then ich set of values (SPL, factual labour time and ratio – t/T) are saved in a database as a individual record. The records can be added and deleted by corresponding buttons. Computation is triggered by the same button «CALC».

At the figure 4 is represented the example considered above.

Conclusions: 1 Automation of computation in industrial noise regulation is highly desirable.

2 A computer program for such an automation will ease the practical use of noise regulation provided by the OSHA standard 29 CFR 1910.95.

3 The computer program will contribute to better understanding of the nature of industrial noise and hygienic requirements to it by students in the case of using the program in studying.

The code of the main module of the program is given below.

```
**************************************************
* Noise exposure, the main program
* 23.12.24. Palahuta Vitalii
**************************************************
zoom window 'Microsoft Visual FoxPro' max
*modify window screen title "INDUSTRIAL NOISE"
*modify window screen icon file 'c:\student\TWA\factory.ico'
_screen.MaxButton = .t.
_screen.MinButton = .t.
_screen.Closable = .t.

set date to german
set century off
set sysmenu off
set ANSI off
set exact on
set cursor off

set path to c:\student\TWAN; C:\foxpro\PROJ_VFP6\TWAN

public vSPL, vDrtn, vPwr, sPwr, sInt, sDec, vInt, vDec
public vT_p, T_p_mnt, vT_p_1, vT_p_2, vT_f, vT_f_h, vT_f_m, vRatio
vSPL = 90                        && Sound Pressa Level
vDrtn = 8,00                     && Duration of exposition
vPwr = (vSPL - 90) / 5           && Power of the rising
sPwr = "123"                     && init of the string of vPwr
sInt = "123"                     && init of the string of integer part of
vPwr
sDec = "123"                     && init of the string of decimal part of
vPwr
vInt = 0                         && init of the floating of integer part of
vPwr
vDec = 0                         && init of the floating of decimal part of
vPwr
vT_p = 0                         && init of the time permitted
vT_p_mnt = 0                     && init of the time permitted in minutes
vT_p_1 = 0
vT_p_2 = 0
vT_f = 0                                 && init of the time factual
vT_f_h = 0
vT_f_m = 0                       && init of the time factual in minutes
```

```
select 1
use c:\student\TWAN\tSpells

do form fNorma
read events
* Процедура обчислення допустимої експозиції

sPwr = str(vPwr,3,1)                  && визначення цілої та дробної частини ступеня (t – 90) / 5
sInt = substr(sPwr,1,1)
sDec = substr(sPwr,3,1)
vInt = VAL(sInt)
vDec = VAL(sDec)
vT_p_1 = 1
vT_p_2 = 1
vT_p = 1

if vInt = 0 then
    vT_p_1 = 1
    else vT_p_1 = 1
    for I = 1 to vInt
        vT_p_1 = vT_p_1 * 2
    next
endif

if vDec = 0 then
    vT_p_2 = 1
    else vT_p_2 = 1
    for I = 1 to vDec
        vT_p_2 = vT_p_2 * 1.071773
    next
endif

vT_p = vT_p_1 * vT_p_2

vT_p = 8 / vT_p
vT_p_mnt = vT_p * 60

return
```

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