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NOISE ANALYSIS IN THE ENGINE ROOM OF A RIVER SHIP ON THE DANUBE BY EIGHT METHODS

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ABSTRACT

In this paper was analysed the noise generated by 2 engines (with a sound level of 85.3dB and 96.1dB respectively) of a river vessel navigating on the Danube, by 8 methods divided into 4 categories: Part I - The 2 sources (engines) work simultaneously; Part II - The 2 sources (engines) work consecutively; Part III - Sonometry and Part IV - Dosimetry. In Part I noise was studied in 4 cases: Case 1) Estimation of the combined noise level of two acoustic sources; Case 2) Logarithmic addition of sound levels; Case 3) Combined noise source and distance calculator; Case 4) Multiple noise sources calculator - Point source model: In this case, the directivity of the noise source is also taken into account. The resulting cumulative noise (96dB) is unusual because it resembles cases 1, 2 and 3 when the distance was not taken into account. In Part II the noise was studied in 2 cases: Case 5) Noise exposure ready reckoner (daily and weekly exposure): the daily and weekly noise exposure is between 93 to 94dB, close to the other cases. Case 6) Daily Noise Exposure Calculator and Weekly Noise Exposure Calculator: the results are similar In Part III the noise was measured with the sound level meter Case 7) Graphic analysis of a complex sound: In this case, the sonogram has many more characteristics: sound level, frequency and time. In Part IV the noise was measured with the dosimeter Case 8) Noise dose calculation: This device is most useful in a workplace where the noise usually varies in duration and intensity and where the person changes locations, because it is connected to the person, giving continuous information right next to the point of interest: the ear.

KEYWORDS: *river vessel, Danube, noise, sound level, daily and weekly exposure*

INTRODUCTION

Noise is a tiring and annoying sound that bothers us; however, noise cannot be precisely defined. For example, what is noise for some can be music for others. Noise has several definitions, most of which are subjective. The most objective noise analysis can be done using measurable physical quantities (frequency, amplitude, sound pressure, time of action). In addition to these physical quantities, the person's reaction to a noise must also be studied: how well they know it, how necessary it is, how far / close they are to the source, how long they have to bear it, what they have to do during this time (to study, to sleep, etc.). Other factors that are particularly important in the perception of noise are: the person's age, health and education level [1].

DAILY AND WEEKLY PERSONAL NOISE EXPOSURE LEVELS

a) The daily personal noise exposure level, $L_{EP,d}$, which corresponds to $L_{EX,8h}$ defined in international standard ISO 1999:1990 [2] is:

$$L_{EP,d} = L_{Aeq,Te} + 10 \cdot lg\left(\frac{T_e}{T_0}\right) \text{ (dB)} \qquad (1)$$

where: T_e is the duration of the person’s work schedule (s), T_0 = 28,800 s (8 h); and $L_{Aeq,T}$ is the equivalent continuous A-weighted sound pressure level, to which the person is exposed for 8h.

b) If a person is exposed to noise of different levels for several periods during a day, then the daily personal noise exposure level is:

$$L_{EP,d} = 10 \cdot lg\left[\frac{1}{T_0}\sum_{i=1}^{n}\left(T_i \cdot 10^{0,1 \cdot (L_{Aeq,T})_i}\right)\right] \text{(dB)} \quad (2)$$

where: n is the number of individual periods in the working day; T_i is the duration of period i; $(L_{Aeq,T})_i$ is the equivalent continuous A-weighted sound pressure level that represents the sound the person is exposed to during period i; and $\sum_{i=1}^{n} T_i = T_e$, the duration of the person's working day.

c) The weekly personal noise exposure, $L_{EP,w}$, which corresponds to $L_{EX,8h}$ defined in international standard ISO 1999: 1990 for five working days is:

$$L_{EP,w} = 10 \cdot lg\left[\frac{1}{5}\sum_{i=1}^{m}\left(10^{0,1 \cdot (L_{EP,d})_i}\right)\right] \text{(dB)} \quad (3)$$

where: m is the number of working days on which the person is exposed to noise during a week; $(L_{EP,d})_i$ is the $L_{EP,d}$ for working day i.

d) Peak sound pressure level (L_{Cpeak}) is:

$$L_{Cpeak} = 20 \cdot lg\left(\frac{p_{Cpeak}}{p_0}\right) \text{(dB)} \quad (4)$$

where: p_{Cpeak} is the maximum value of the C-weighted sound pressure (Pa), to which a person is exposed during the working day; and p_0=20μPa [3].

MATERIALS AND METHODS

This paper analyses the noise produced in the engine room of a river vessel navigating on the Danube. The noise is generated by 2 engines. When measuring with the Blue Solo sound level meter, the values obtained for the 2 motors were 85.3dB and 96.1dB. The specific acoustic quantities will be calculated by 8 methods.

Part I - The 2 sources work simultaneously

Case 1) Estimation of the combined noise level of two acoustic sources

In order to estimate the noise level given by the 2 engines, it is considered that: sound levels are expressed in dB_{SPL} (sound pressure level), have the same frequency band and are out of phase [4].

$$dB_{SPL} = 20 \cdot lg\left(\frac{\text{sound pressure}}{20\mu Pa}\right) \quad (5)$$

where 20 μPa is the reference level.

To calculate this, we first need to convert from dB_{SPL} levels to raw pressure:

Figure 1. Experimental determinations with the Blue Solo sonometer in the engine room of the river ship

$$\text{Sound pressure} = 20 \cdot 10^{\frac{dB_{SPL}}{20}} \ \mu\text{Pa} \quad (6)$$

$$\text{Pressure}_1 = 20 \cdot 10^{\frac{85.3}{20}} = 368154.4002 \ \mu\text{Pa} \quad (7)$$

$$\text{Pressure}_2 = 20 \cdot 10^{\frac{96.1}{20}} = 1\,276\,526.\,9723 \ \mu\text{Pa} \quad (8)$$

Then the conversion is made from raw pressure to power values (i.e., square them); then do the sum of the resulting power values, and finally, this is converted back to a pressure amplitude value (via a square-root operation).

$$RMS_{pressure} = \sqrt{(\text{pressure}_1)^2 + (\text{pressure}_2)^2} \quad (9)$$

$$RMS_{pressure} = \sqrt{(368154.4002)^2 + (1276526.9723)^2} = 1328555.1451 \ \mu\text{Pa} \quad (10)$$

Now back to dB_{SPL} using Eq. 5:

$$dB_{SPL} = 20 \cdot lg\left(\frac{1328555.1451}{20\mu Pa}\right) = 96.4469 \quad (11)$$

In other words, the result of summing the 2 sound pressure levels (85.3 dB and 96.1 dB) is 96.4469 dB.

Case 2) Logarithmic addition of sound levels

It is well known that the sum of sound levels is done logarithmically (Eq 12); this calculation assumes that the SPL of each source is known at a certain measurement point.

$$\text{Total SPL} = 10 \cdot lg\left\{\sum 10^{(SPL1+SPL2+SPL.../10)}\right\} \quad (12)$$

Unfortunately, this software does not allow the entry of decimals data; for this reason, source 1 is considered to have 85dB, and the second 96dB (fig. 2). The cumulation result is 96.33dB (almost identical to that in case 1). It should be noted that, neither in this case nor in case 1, were the distances taken into account.

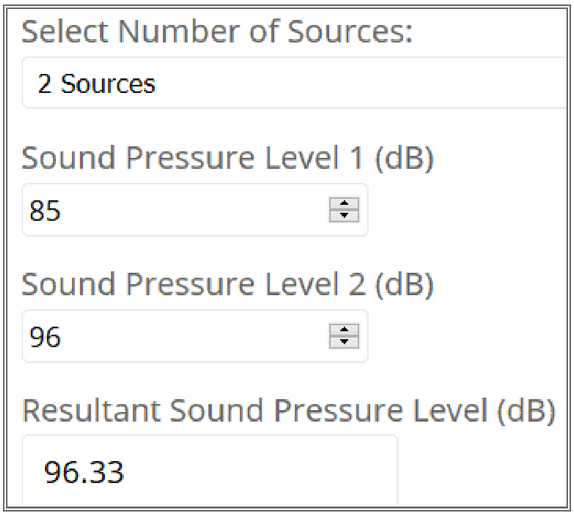

Figure 2. The result of the sound pressure level cumulation for the 2 sources [5]

Case 3) Combined noise source and distance calculator

A-weighted decibels are based on a logarithmic scale. In our case, the 2 sources have 85.3 dB and 96.1 dB, but the first is 1m away from the navigator's workstation, and the second, at 1.5m. These distances must be considered when calculating the combined noise level.

It will be used a software that combines the 2 individual noise sources and will result the perceived sound level at a distance D from the nearest noise source (fig. 3).

Figure 3 shows that the result obtained when the distance was not taken into account is identical to that in case 1 (96.45dB compared to 96.4469dB), because neither in case 1 the distance was not taken into account. When this physical quantity is considered, the result differs by 10.7% (86.13dB).

Case 4) Multiple noise sources calculator - Point source model

Another type of software takes into account not only the combined noise level and distance, but also the directivity of the noise source. There are 4 situations:

1=whole (e.g. above soft ground);
2=half (e.g. above hard ground);
4=quarter (e.g. above hard ground on a wall)
8=eighth space (e.g. in the corner of a room)

In fig. 4 and 5 are presented the sound pressure level and the sound power level for sources 1 and 2.

Figure 6 shows the cumulative noise; the result (96dB) is surprising because it resembles cases 1, 2, 3 when the distance was not taken into account.

If situation 2 (=half) had been chosen, then 3dB would have had to be added. (fig. 8). For the next situations

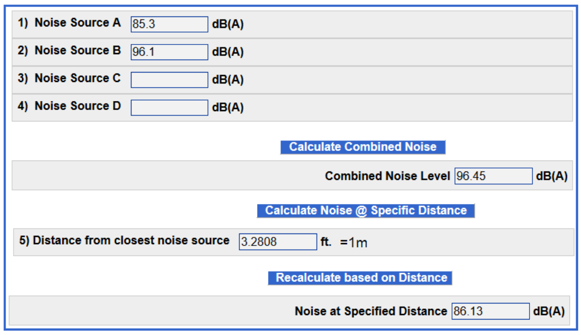

Figure 3. Combined noise source and distance calculator [6]

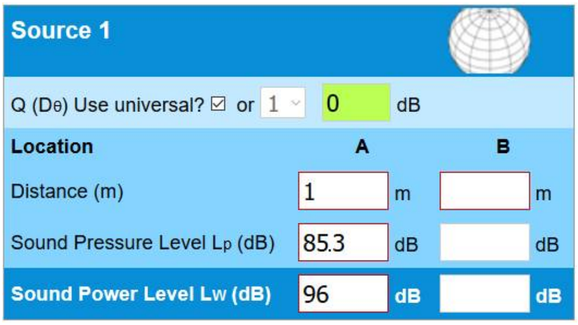

Figure 4. Sound pressure level and sound power level for source 1 at a distance of 1 m from the navigator in situation 1 (=whole) (fig. 7) [7]

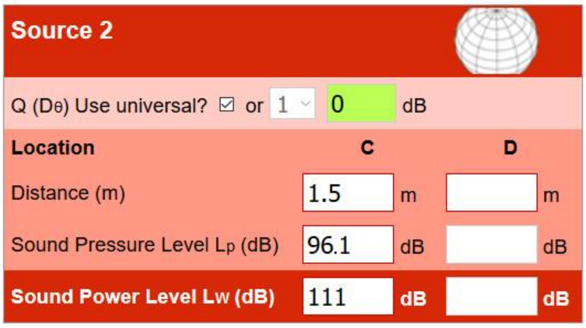

Figure 5. Sound pressure level and sound power level for source 2 at a distance of 1,5 m from the navigator in situation 1 (=whole) (fig. 7) [7]

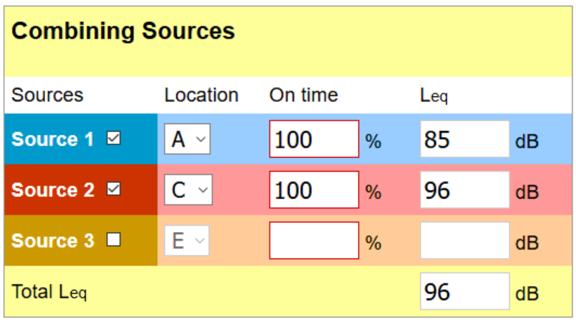

Figure 6. Cumulative noise for the 2 sources [7]

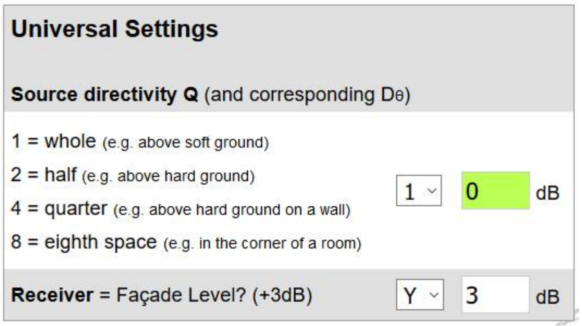

Figure 7 .Situation 1 = whole (e.g. above soft ground)

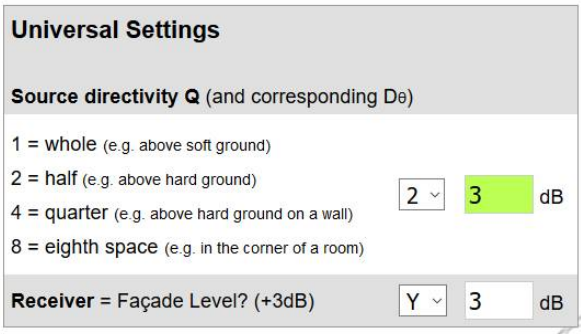

Figure 8. Situation 2 = half (e.g. above hard ground)

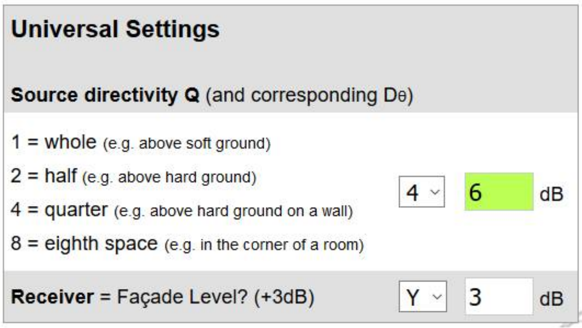

Figure 9. Situation 4 = quarter (e.g. above hard ground on a wall)

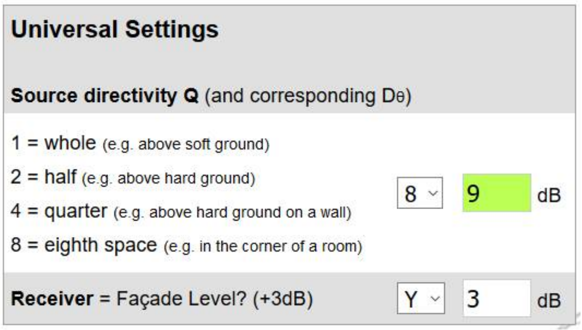

Figure 10. Situation 8 = eighth space (e.g. in the corner of a room)

Part II - The 2 sources work consecutively

Further, it will be studied the case in which the first engine (85.3dB) runs for 4 hours, then it will be stopped and the second engine (96.1dB) will be started, which will also run for 4 hours. In this way, an extra important parameter was introduced: the exposure time.

One of the most important web sites to check the regulation and enforcement of laws that protect people in terms of health at work is the Health and Safety Executive (HSE), in the UK.

The web site of this institution has a number of easy-to-use calculation models to see if the law on the protection of workers' health is complied with.

The HSE focuses regulation of health and safety in the following sectors of industry: Agriculture, Air transport, Armed forces, Catering and hospitality, Construction industries, Crown establishments, Chemical manufacture and storage industries, Professional diving, Shipyard, Education sector, Engineering sector, Entertainment and leisure industry, Fire service, Food and drink manufacturing, Footwear and leather industries, Haulage, Health services, Gas supply and installation, Laundries and dry-cleaning, Mining, Motor vehicle repair, Office work, Offshore oil and gas installations, Paper and board manufacturing industry, Pesticides, Police forces, Printing industries, Public services, The quarrying industry, Recycling and waste management industries, Textiles industries [8].

Case 5) Noise exposure ready reckoner (daily and weekly exposure)

Using Table 1 ”Workplace Noise Analysis” [9], the daily exposure of people working in a noisy environment can be calculated relatively easily. It can be used for situations where the noise level is constant during the day but also if it is variable.

In addition, the "noise exposure points" can be calculated for individual jobs and can be combined to obtain the total exposure points for a day, therefore the daily exposure.

5.1) Noise exposure ready reckoner (Daily exposure)

The left side of Table 1(a) shows how the noise level and duration of exposure are combined to provide noise exposure points. The right side of Table 1(b) is used to convert the total exposure points into daily personal exposure.

This result (93 to 94dB) is close to that obtained by the other methods.

Table 1. Noise exposure ready-reckoner (Daily exposure) [10]

HSE

Noise exposure ready-reckoner (Daily exposure)

Sound pressure level, L_{Aeq} (dB)	*Duration of exposure (hours)*								*Total exposure points*	*Noise exposure $L_{EP,d}$ (dB)*
	¼	*½*	*1*	*2*	*4*	*8*	*10*	*12*		
105	320	625	1250							
104	250	500	1000							
103	200	400	800							
102	160	320	630	1250						
101	125	250	500	1000						
100	100	200	400	800					3200	100
99	80	160	320	630	1250				2500	99
98	65	125	250	500	1000				2000	98
97	50	100	200	400	800				1600	97
96	40	80	160	320	630	1250			1250	96
95	32	65	125	250	500	1000			1000	95
94	25	50	100	200	400	800			800	94
93	20	40	80	160	320	630			630	93
92	16	32	65	125	250	500	625		500	92
91	12	25	50	100	200	400	500	600	400	91
90	10	20	40	80	160	320	400	470	320	90
89	8	16	32	65	130	250	310	380	250	89
88	6	12	25	50	100	200	250	300	200	88
87	5	10	20	40	80	160	200	240	160	87
86	4	8	16	32	65	130	160	190	130	86
85		6	12	25	50	100	125	150	100	85
84		5	10	20	40	80	100	120	80	84
83		4	8	16	32	65	80	95	65	83
82			6	12	25	50	65	75	50	82
81			5	10	20	40	50	60	40	81
80			4	8	16	32	40	48	32	80
79				6	13	25	32	38	25	79
78				5	10	20	25	30	20	78
77					8	16	20	24	16	77
76					6	13	16	20		
75					5	10	13	15		

Noise level	**Duration**	**Notes**	**Exposure points**
85.3	4	Meet the vertical line from 4h with the horizontal line from 85dB	50
96.1	4	Meet the vertical line from 4h with the horizontal line from 96dB	630
		Total noise exposure points	680

(a)

Exposure points	**Notes**	**Noise level**
700	At there is no value of 700 points, choose the one between 630 and 800 points.	$L_{EP,d}$ = 93 to 94dB

(b)

Table 2. Noise exposure ready-reckoner (Weekly exposure) [11]

Noise exposure ready-reckoner (Weekly exposure)

Daily noise exposure, $L_{EP,d}$ (dB)	Points						
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
95	1000	1000	1000	1000	1000	1000	1000
94	800	800	800	800	800	800	800
93	630	630	630	630	630	630	630
92	500	500	500	500	500	500	500
91	400	400	400	400	400	400	400
90	320	320	320	320	320	320	320
89	250	250	250	250	250	250	250
88	200	200	200	200	200	200	200
87	160	160	160	160	160	160	160
86	130	130	130	130	130	130	130
85	100	100	100	100	100	100	100
84	80	80	80	80	80	80	80
83	65	65	65	65	65	65	65
82	50	50	50	50	50	50	50
81	40	40	40	40	40	40	40
80	32	32	32	32	32	32	32
79	25	25	25	25	25	25	25
78	20	20	20	20	20	20	20

a

Total exposure points	Weekly noise exposure $L_{EP,w}$ (dB)
5000	95
4000	94
3200	93
2500	92
2000	91
1600	90
1300	89
1000	88
800	87
630	86
500	85
400	84
320	83
250	82
200	81
160	80
130	79
100	78

b

5.2) Noise exposure ready reckoner (Weekly exposure)

In the left part of Table 2(a), meet the vertical line corresponding to the day on which the measurement was made with the horizontal line corresponding to the value read, obtaining the number of exposure points for that day.

In the end, the sum of these points is made: 320+500+800+630+400+320=2970 points

The value of 2970 points is not found on the right side of Table 2(b); for this reason, the one between 2500 and 3200 points is chosen, obtaining the weekly exposure value of 92-93dB. In this way, the total exposure points were converted to weekly personal exposure.

Case 6) Daily Noise Exposure Calculator and Weekly Noise Exposure Calculator

Other types of HSE-compliant software are shown in Table 3 (for daily exposure) and Table 4 (for weekly exposure).

6.1) Daily Noise Exposure Calculator

Table 3 shows the sound level values measured with the sound level meter, as well as the exposure time for each task. In this way you will get Exposure points (job/task), Exposure points per hour and Daily noise exposure in dB and number of points.

The action value of the exposure (L_{EP}=80dB) is represented by 32 exposure points and the exposure limit value ($L_{EP=}$85dB) by 100 points.

6.2) Weekly Noise Exposure Calculator

Table 4 lists all daily exposure values. The software will give us the value of weekly noise exposure.

Table 3 Daily Noise Exposure Calculator

HSE Health & Safety Executive	**Noise Level (L_{Aeq} dB)**	**Exposure duration (hours)**	**Exposure points (job/task)**	**Exposure points per hour**
Job / task 1	85.3	4	54	13
Job / task 2	96.1	4	644	161
	Total duration	8		
		Daily noise exposure ($L_{EP,d}$)	**93 dB**	**698 points**

Table 4. Weekly Noise Exposure Calculator [10]

HSE Health & Safety Executive	**Daily exposure ($L_{EP,d}$ dB)**	
	Day 1	90.4
	Day 2	92.2
	Day 3	94.1
	Day 4	93.2
	Day 5	91.4
	Day 6	89.6
	Day 7	-
	$L_{EP,w}$	**93dB**

It can be seen that in both cases (Daily and Weekly Noise Exposure) the calculated value is 93dB, higher than the exposure limit value. For this reason, it is necessary to wear ear protectors. Wearing them is based on the value of the Single Number Rating (SNR) that is provided by the manufacturer (Table 5)

<u>Part III – Sonometry</u>

Case 7) Graphic analysis of a complex sound

Sonometry is the comparative study of sounds using a sound level meter. A sonogram is a graphical representation of a complex sound over a period of time (top right). It contains 3 parameters: sound level, frequency and time. In the upper left is the frequency spectrum at a certain time. In the lower right is represented the evolution over time of the sound level for a given frequency.

Table 5. Choice of SNR for ear protectors

A-weighted noise level (dB)	**Select a protector with an SNR of device**
85-90	20 or less
90-95	20-30
95-100	25-35
100-105	30 or more

Figure 11 is the sonogram of the noise measured in the engine room (top right). Cursors are placed at 63Hz and the 1st minute (25.66dB(A)). At the 1st minute, the spectrum diagram (top left) shows a maximum of 93.17dB(A) at 2500Hz. The sound level L_{eq} has a maximum of 33.36 dB(A) at the 6 minute 57 s in the time history graphic (lower right) for 63Hz.

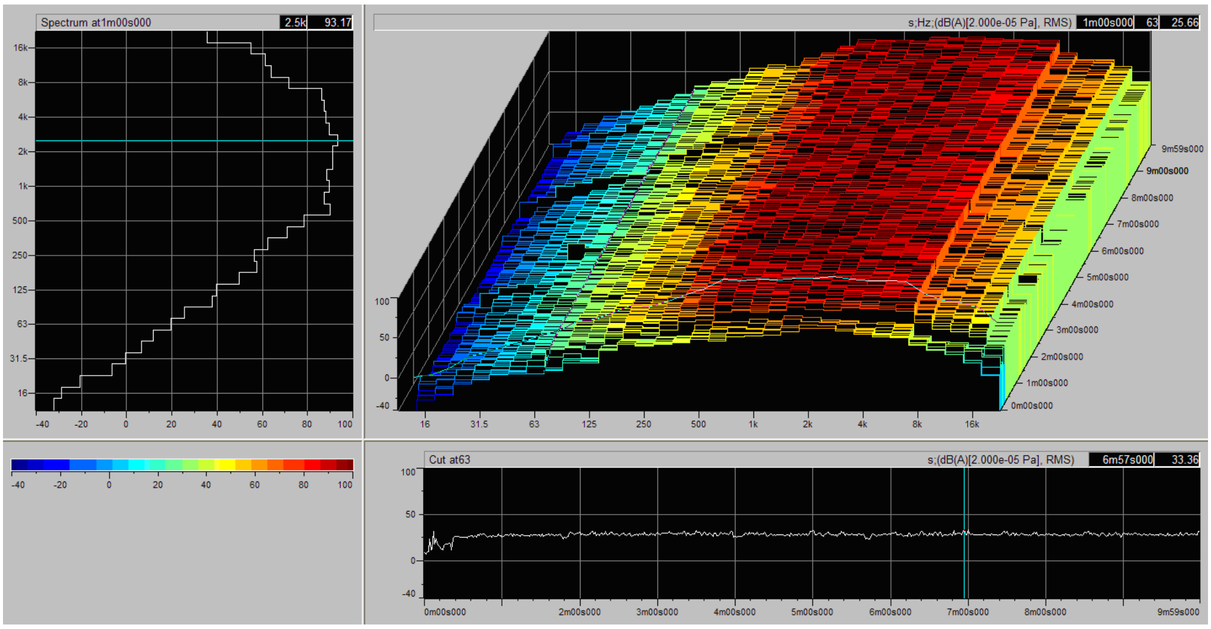

Figure 11. Sound analysis (frequency distribution, sonogram and time history)

Part IV – Dosimetry

Case 8) Noise dose calculation

Noise Dose is the total sound exposure normalized to an 8-hour working day (Eq. 13). The 8 hour level is known as the $L_{EP,d}$ (daily personal noise exposure) or $L_{EX,8h}$. Their time dependencies are shown in fig. 12 and 13. The Noise Dose (in physical units) for the whole measurement duration of sound exposure is known as E ($Pa^2 \cdot h$). For a given period of time, an increase of 10 dB(A) in sound pressure level corresponds to a tenfold increase in the noise dose (1 $Pa^2 \cdot h$=100% Noise Dose=85L_{Aeq}(8 h)= 85dBA for 8h - "Criterion" level) [12],[13].

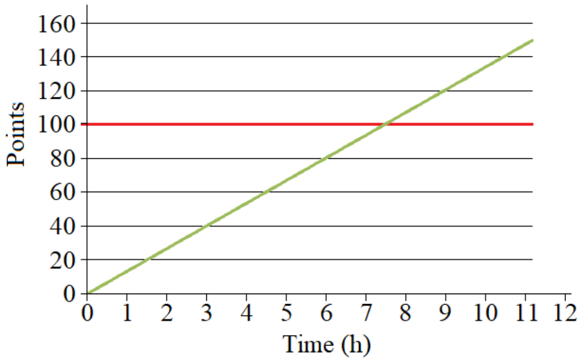

Figure 12. Relationship between %Dose and Time with an Leq of 85dBA (85dB; Points) [14]

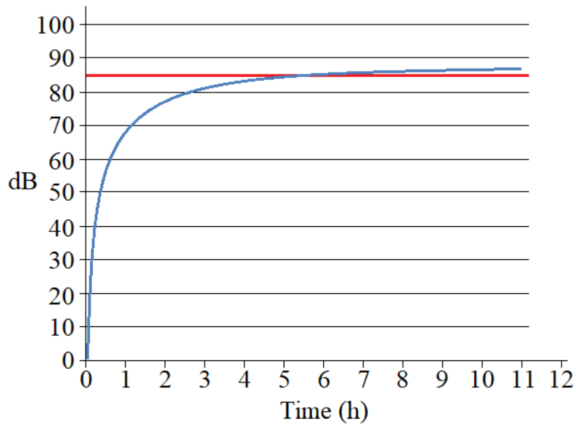

Figure 13. Relationship between Leq and Lep'd (Lex) (Lep'd; Leq) [14]

For discrete time intervals at a constant sound level, %Dose, can be written as:

$$D = \frac{100}{T_0} \cdot t_1 \cdot \frac{L_i - L_C}{q} \qquad (13)$$

where: D=Percentage exposure (%); T_0= Criterion sound duration (usually 8h); t_i=Time spent in the i^{th} interval (h); L_i=Weighted sound pressure level in the i^{th} time interval; L_C=Criterion sound level (usually dB(A)); q=Exchange rate parameter(dB): a) =10 for an exchange rate of 3dB; b) =5/lg2 for an exchange rate of 5dB [14].

A noise dosimeter is a small, light device that clips to a person's belt with a small microphone that fastens to the person's collar, close to an ear (Fig. 14). The dosimeter stores the noise level information and carries out an averaging process.

Cirrus CR110A dosimeters, attached to the shoulder near the ear, were used to study the sound level in the engine room. After the measurements, the collected data were downloaded and processed with the dBLink 3 software. Figure 15 presents 7 minutes of the measurements made in the engine room. The evolution in time of the noise level (in the presented period) also shows two peaks occurred in the engine operation (116.1 and 117.5dB). As can be seen, the engine has an uneven operating noise, which indicates the need for urgent repairs.

Figure 14. DoseBadge Industrial Noise Dosimeter

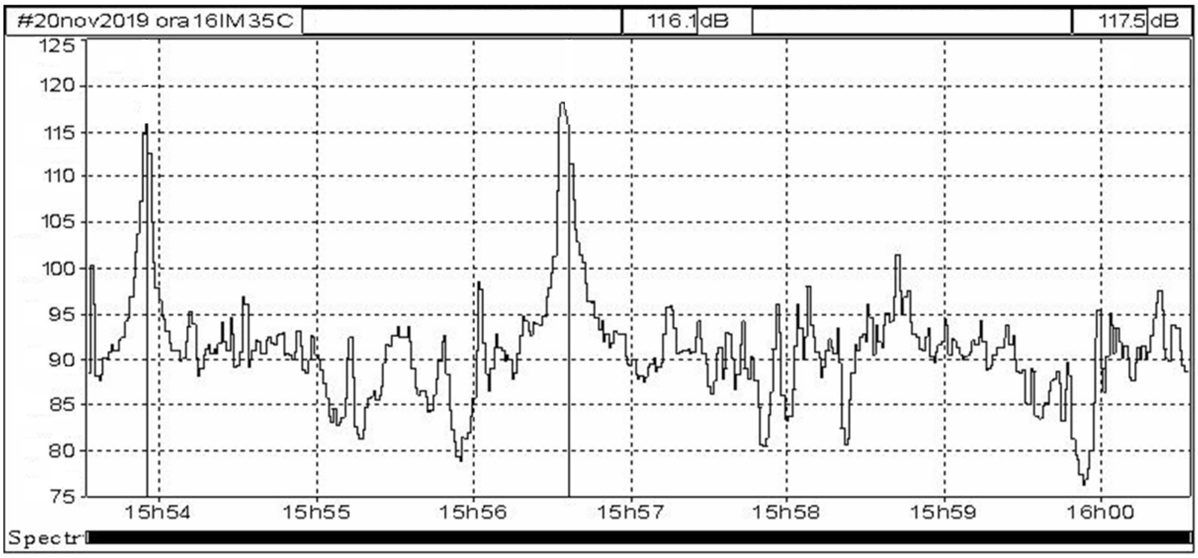

Figure 15. Evolution over time of the noise level in the engine room (during the presented period)

CONCLUSIONS

In this paper was analysed the noise generated by 2 engines (with a sound level of 85.3dB and 96.1dB respectively) of a river vessel navigating on the Danube, by 8 methods divided into 4 categories:

- Part I - The 2 sources (engines) work simultaneously
- Part II - The 2 sources (engines) work consecutively
- Part III - Sonometry
- Part IV - Dosimetry

In *Part I* noise was studied in 4 cases:

Case 1) *Estimation of the combined noise level of two acoustic sources*: In this case, the classical calculations were made, according to the equations indicated by the current legislation. The result is 96.4469dB. In the following 3 cases were used different software, which can be found on the websites of the most important companies with the object of activity in environmental protection and the impact of pollution on biodiversity, implicitly on people at the working place.

Case 2) *Logarithmic addition of sound levels*: This software belongs to the WKC group [5]. The cumulation result is 96.33dB (almost identical to that in case 1). It should be noted that, neither in this case nor in case 1, were the distances taken into account.

Case 3) *Combined noise source and distance calculator*: This software can calculate the sound level in both cases: when the distance is not taken into account and when it is taken into account. When the distance was not taken into account, the result of the logarithmic sum of the 2 sound levels is identical to that of case 1 (96.45dB compared to 96.4469dB); when the distance is taken into account, the result differs by 10.7% (86.13dB).

Case 4) *Multiple noise sources calculator - Point source model*: In this case, the directivity of the noise source is also taken into account. The resulting cumulative noise (96dB) is unusual because it resembles cases 1, 2 and 3 when the distance was not taken into account.

In *Part II* the noise was studied in 2 cases:

In this part, the 2 engines run consecutively for 4 hours each; the calculation was made using the Health and Safety Executive (HSE) website in the UK, additionally calculating the "noise exposure points" for individual works that can be combined to give the total exposure points for a day, therefore to find out the daily exposure.

Case 5) *Noise exposure ready-reckoner (daily and weekly exposure)*: In cases 5.1 and 5.2 is calculated the noise exposure ready-reckoner (daily and weekly exposure), using the tables provided by the HSE. The method is not extremely accurate because it is a graphical method, but for usual practice they can be successfully used. In the case 5.1 the daily noise exposure is between 93 to 94dB, close to the other cases. In the case of 5.2 noise weekly exposure is between (92 to 93dB), close to the other cases.

Case 6) *Daily Noise Exposure Calculator and Weekly Noise Exposure Calculator*: In cases 6.1 and 6.2, the Daily and Weekly Noise Exposure Calculator are calculated using the tables provided by the HSE. It is one of the most common methods; it is fast, accurate and easy to use. In addition, it also provides the number of exposure points / task. In the case 6.1 the daily noise exposure is 93dB, close to the other cases. In the case 6.2 weekly noise exposure is 93dB, close to the other cases.

In *Part III* the noise was measured with the sound level meter

Case 7) *Graphic analysis of a complex sound*: In this case, the sonogram has many more characteristics: sound level, frequency and time. In addition, the frequency spectrum at a certain time is displayed, as well as the evolution over time of the sound level for a given frequency. In general, sonography is used for extremely precise analyses, e.g.: at the 1st minute, the spectrum diagram (top left) shows a maximum of 93.17dB(A) at 2500Hz.

In *Part IV* the noise was measured with the dosimeter

Case 8) *Noise dose calculation*: This device is most useful in a workplace where the noise usually varies in duration and intensity and where the person changes locations, because it is connected to the person, giving continuous information right next to the point of interest: the ear. It was found that in the studied period (7 minutes) the average is in the range of 90-95dB. As you can see, the sound is not uniform, so the engines do not work evenly, therefore, in addition to the fact that this device shows the sound level right near the ear of the worker, it can also provide information about the equipment operation.

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