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Results of simulations tests of a global index proposed for the acoustic assessment of machines

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ABSTRACT

For the assessment of noise emitted by machines, a global index of machines has been elaborated. The global index is a function of the following partial indices: sound power index, index of distance between the workstation and the machine, radiation directivity index, impulse and impact noise index and noise spectrum index. Each partial index always adopts positive value. If the value of the global index does not exceed 1, the noise of the assessed machine will not exceed the admissible value of the A-weighted sound pressure level at the workstation. The experimental tests were carried out in order to determine values of the global index for a group of engine-generators with the use of inversion method allowing for the determination of sound power level. It required the modelling of each of the tested generators with one omnidirectional substitute source. The correctness of the determined values of indices was confirmed by the results of A-weighted sound pressure level measurements on hypothetically assumed workstations in simulated "in situ" conditions. Simulation tests of the partial indices as well as the global index were carried out. The results has proved among other things that the value of the global index increases both with the increase of sound power and the decrease of distance between workstation and a machine. The correctness of the results of the simulation tests was confirmed by the results of the experimental tests.

INTRODUCTION

Reduction of noise emission from machines is one of priority tasks and at the same time one of the most efficient method for reducing the risk resulting from exposure to noise. According to the requirements of the directive 2006/42/EC on machinery [1], a machine should be designed and manufactured in a way that will allow the hazards resulting from the emission of noise to be reduced to the lowest possible level. The European Standard ISO 11688-1 [2] harmonised with this directive refers among other things to the practice for the design of low- noise machinery. However, according to the practice, exploitation parameters, which influence the value of sound pressure at workstations, are not taken into account on design stage. Therefore it is proposed to develop a method for prediction of noise emission from machinery in exploitation conditions, using index method of acoustic assessment.

GLOBAL INDEX OF ACOUSTIC ASSESSMENT OF MACHINE

For the purpose of acoustic assessment a global index Q_{GWA} was developed [3]. The index is a function of 5 partial indices and can be described by the dependency presented below:

$$Q_{GWA} = Q_N \cdot Q_R \cdot Q_\Theta \cdot Q_{imp} \cdot Q_F \tag{1}$$

where:
- Q_N - sound power index,
- Q_R - index of distance between the workstation and the machine,
- Q_Θ - radiation directivity index,
- Q_{imp} - impulse and impact noise index,
- Q_F - noise spectrum index.

Whereas sound power index Q_N is defined by:

$$Q_N = 1 + \frac{L_{NA} - L_0}{50} \tag{2}$$

for $L_{NA} \geq L_0$ and by:

$$Q_N = \frac{1}{1 - \frac{L_{NA} - L_0}{50}} \tag{3}$$

for $L_{NA} < L_0$,

where:
- L_0 - admissible value of A-weighted sound power level of a machine (if there is no admissible value of sound power level, it is recommended to adopt L_0=90 dB), in dB,
- L_{NA} - A-weighted sound power level, in dB.

Index of distance between the workstation and the machine Q_R is described by the following formula:

$$Q_R = \frac{3.7}{3.2 + lg\left(\Omega r^2\right)} \tag{4}$$

where:
r – distance between the workstation and the machine, in m,
Ω – solid angle of radiation, in rad.

Radiation directivity index Q_Θ is defined as:

$$Q_\Theta = 1 + \frac{L_{pA} - L_{pAa}}{50} \quad (5)$$

for $L_{pA} \geq L_{pAa}$ and as:

$$Q_\Theta = \frac{1}{1 - \frac{L_{pA} - L_{pAa}}{50}} \quad (6)$$

when $L_{pA} < L_{pAa}$ where:

L_{pAa} - averaged A-weighted sound pressure level value around the machine in the distance equivalent to the distance between the workstation and the machine, in dB,

L_{pA} - A-weighted sound pressure level value at the work-station in test environment, in dB.

Next index i.e. impulse and impact noise index Q_{imp} should be determined according to Table 1.

Table 1. Impulse and impact noise index values

C-weighted peak sound pressure level L_{Cpeak}, in dB	Number of im-pulses during 8 hours of work	Impulse and impact noise index Q_{imp}
$135 < L_{Cpeak}$	n = 0	1.1
$125 < L_{Cpeak} \leq 135$	n ≤ 100	1.08
$115 \leq L_{Cpeak} \leq 125$	n ≤ 1000	1.06
$105 \leq L_{Cpeak} \leq 115$	n ≤ 10000	1.04
$100 \leq L_{Cpeak} \leq 110$	n ≤ 100000	1.02
$L_{Cpeak} \leq 100$	Without limita-tions	1.0

The last of partial indices, noise spectrum index Q_F, adopts the values according to Table 2.

Table 2. Noise spectrum index values

$\Delta_{C\_A} = L_{pC}{}^{*)} - L_{pA}$, in dB	Noise spectrum index Q_F
≤ 0	1.00
0.1 – 2.0	1.02
2.1 – 4.0	1.4
4.1 – 9.0	1.6
9.1 – 15.0	1.8
> 15.0	1.10

*) L_{pc} – C-weighted sound pressure level, in dB.

Each partial index always adopts a postitive value, dimen-sionless and the value of 1 is a neutral value. If the value of each index is higher than 1, it means that a given parameter has an adverse influence on acoustic climate in working envi-ronment, whereas the value lower than 1 means that a given parameter can improve acoustic conditions.

If the value of Q_{GWA} is lower than 1 the machine can be con-sidered acoustically safe, otherwise when the value of Q_{GWA} is higher than 1, the noise emitted by the machine will exceed the admissible value of the sound pressure level at the work-station.

INVERSION METHOD

Inversion may be one of the methods used in acoustic model-ling for the acoustic assessment of machines on the basis of the analysis of acoustic field parameters [4]. By modelling the process of the radiation of vibro-acoustic energy from source to receiver and knowing the real values of sound pres-sures at measurement points, one can inverse the model of the propagation path and thus determine the parameters of the sound source.

To calculate the parameters of substitute sources by using the inversion method [5] one must know the real distribution of acoustic pressure around the machine. This requires the de-termination, on the surface of a hemisphere, of both the dis-tribution of the amplitude of sound pressures, as well as the distribution of phase shift angles between acoustic signals.

As a results of sound modelling, we obtain the number n of the substitute sources, their sound power or sound pressure amplitude and the position of every source.

The above mentioned parameters of substitute sound sources can be used to determine the distribution of sound pressure levels around the machine. The distribution of sound pressure levels can be calculated using the following relationship [6]:

$$L_p(\theta,\varphi) = 10\log\left(\sum_{i=1}^{n} A_i R_i(\theta,\varphi)\frac{\exp(-ikr_i)}{r_i}\right) \text{ [dB]} \quad (8)$$

where:
A_i – moment of the i-th substitute source, in Pa · m,
$R_i(\Theta,\varphi) = \exp[ik(x_i \cos\varphi \sin\Theta + y_i \sin\varphi \sin\Theta + z_i \cos\Theta)]$ – directional radiation characteristics of the i-th source,
x_i, y_i, z_i – co-ordinates of the location of the i-th source, in m.

EXPERIMENTAL TESTS ON ENGINE-GENERATORS

Tested engine-generators

The tests programme included the measurement of acoustic field around two engine-generators (Figure 1) of different power:
- CMI C-G800 800 W – two-stroke engine,
- NT250Up 2.6 kW – four-stroke engine.

All engine-generators were powered by gasoline engines, cooled by air, producing electric current of standardised volt-age of 230 V and frequency of 50 Hz.

Figure 1. Gasoline engine-generators prepared for acoustic measurements

During the work of each engine-generator the eclectic current was received, supplying the heater with regulated heating power of 400 W, 700 W and 1500 W. The engine-generators were operating on the following settings presented in Table 3.

Table 3. Power received for individual work settings of heater

Type of engine-generator	Power received from the engine-generator, in W			
CMI C-G800 800 W	0	350	-	-
NT250UP 2.6 kW	0	350	700	1400

Sound power indices

Sound power levels of the engine-generators were determined with the use of inversion method. It was assumed that each engine-generator was modelled with the use of one. omnidirectional substitute source. The measurements (modelling) were carried out for the frequency range from 10 Hz to 12500 Hz. Figure 2 presents the spectrum of sound power levels of one of the tested engine-generators. The results allowed for the determination of sound power indices of generators. The results of indices calculations for all settings of generators are presented in Table 4.

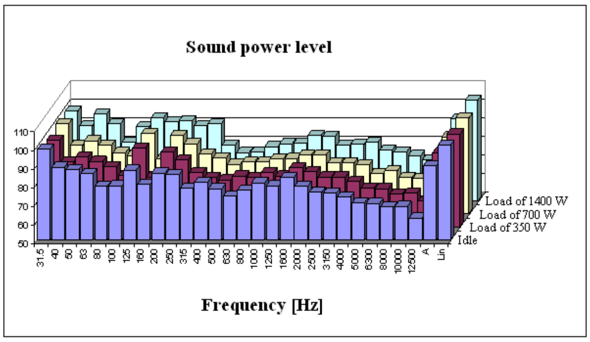

Figure 2. Sound power levels of NT250Up 2.6 kW engine-generator, in dB

Table 4. Sound power indices of engine-generators

Type of engine-generator	Power received from the engine-generator, in W	A-weighted sound power level, in dB	Sound power index Q_N
CMI C-G800 800 W	0	86.2	0.93
	350	89.0	0.98
NT250Up 2.6 kW	0	93.9	1.08
	350	94.9	1.10
	700	94.7	1.09
	1400	0.98	84.4

Indices of distance between the workstation and the machine

For all the tested engine-generators it was assumed that the workstation is located 1 m from the machine. Therefore the index of distance between the workstation and the machine calculated according to the formula (4) was equal to Q_R = 0.925.

Radiation directivity indices and noise spectrum indices

Radiation directivity index was determined according to formula (6). Indices values for individual settings of the tested engine-generators are presented in Table 5.

Also the values of noise spectrum index for the tested engine-generators are presented in Table 5. The values were determined based on the measurements at 1 m distance from the working engine-generator.

Table 5. Radiation directivity indices and noise spectrum of engine-generators

Type of engine-generator	Power received from the engine-generator, in W	Radiation directivity index Q_Θ	Noise spectrum index Q_F
CMI C-G800 800 W	0	0.93	1.06
	350	0.93	1.06
NT250Up 2.6 kW	0	0.96	1.02
	350	0.95	1.02
	700	0.98	1.02
	1400	0.93	1.04

Global indices of tested generators

Global indices of acoustic quality Q_{GWA} for each engine-generator are presented in Table 7. When the obtained Q_{GWA} index is higher than 1.0, it means that the noise emitted by the engine-generator will exceed the admissible value of A-weighted sound pressure level (85 dB(A)) at a workstation. The results of noise measurements at hypothetical workstations (located 1 m from the generators in simulated "in situ" conditions) presented in Table 7 confirm the correctness of the obtained Q_{GWA} indices values.

Table 6. The results of calculations global indices of the tested generators

Type of engine-generator	Power received from the engine-generator, in W	Global index Q_{GWA}	A-weighted sound pressure level at workstation, in dB
CMI C-G800 800 W	0	0.85	74.4
	350	0.89	77.5
NT250Up 2.6 kW	0	0.96	83.8
	350	0.96	84.2
	700	1.02	85.4
	1400	0.98	84.4

SIMULATION TESTS OF INDICES

Within the simulation tests of global index first the partial indices were tested – sound power index Q_N, index of distance between the workstation and the machine Q_R as well as radiation directivity index Q_Θ.

The results of simulation of sound power index Q_N of the machine are presented in Figure 3. According to the formulas (2) and (3) the decrease of sound power index of the machine entails the decrease of sound power index value Q_N The model value of Q_N decreases from 1.4 to 0.71 in case when sound power level of the machine decreases respectively from 110 dB to 70 dB.

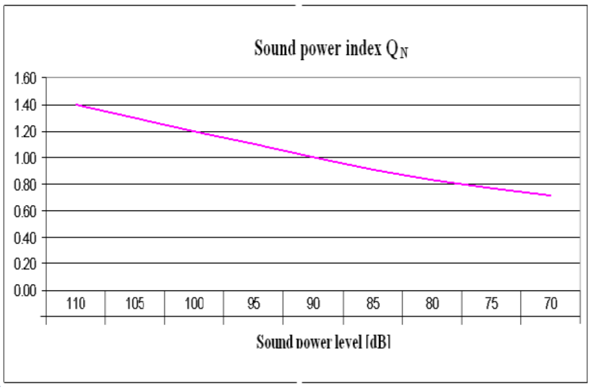

Figure 3. Influence of the sound power level on the value of the sound power index Q_N

Figure 4 presents the results of simulation tests of the index of distance between the workstation and the machine Q_R in the function of the distance. The increase in the distance between the workstation and the machine results in the decrease on Q_R index value. Additionally for the distances larger than 2 m the index adopts constant value Q_R = 0.8. The distance of 0.71 m indicated on Figure 4 corresponds to the index value Q_R = 1, which corresponds to the sound pressure level value at workstations of 85 dB, provided that the value of products of the remaining indices, i.e. $Q_N \times Q_R \times Q_\Theta = 1$. Assuming, as an example, that the value of the above-mentioned product is constant (i.e. $Q_N \times Q_R \times Q_\Theta = 1$), the value of the index of distance between the workstation and the machine Q_R = 1.2 (which corresponds to the distance of ca. 0.38 m), it will signify that A-weighted sound pressure level will be of 95 dB – the admissible value will be exceeded by 10 dB, whereas the decrease of distance up to 0.2 m will results in the excess of A-weighted sound pressure level admissible value by 20 dB (Q_R = 1.4).

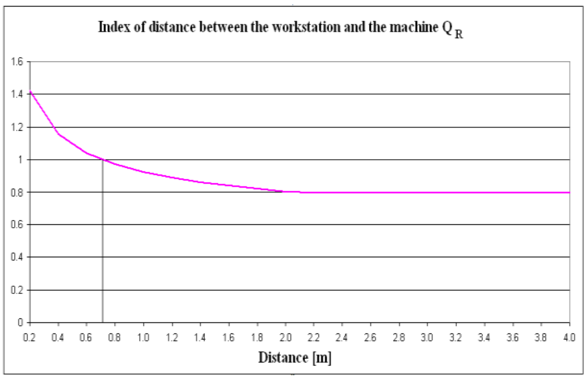

Figure 4. Influence of the distance on the value of the index of distance between the workstation and the machine Q_R

Another partial index, i.e. radiation directivity index Q_Θ provides the information about "favourable" or "unfavourable" location of the workstation in relation to the radiation directivity properties which is defined by the difference between sound pressure level measured at the workstation and averaged sound pressure level around the machine at the same distance as the workstation. Dependency of Q_Θ index value in the function of the above-mentioned difference is presented in Figure 5.

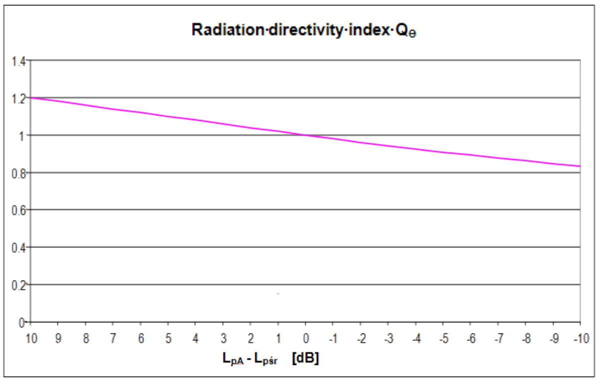

Figure 5. Influence of the diffence between the sound pressure level at the workstation and averaged sound pressure level around the engine-generator on the value of the radiation directivity index Q_Θ

The dependencies of the above-presented Q_N and Q_R partial indices are mirrored directly by the value of global index Q_{GWA}. The influence of the distance between workstation and the machine on the global index Q_{GWA} for the selected combinations of partial indices Q_N and Q_Θ is presented in Figure 6.

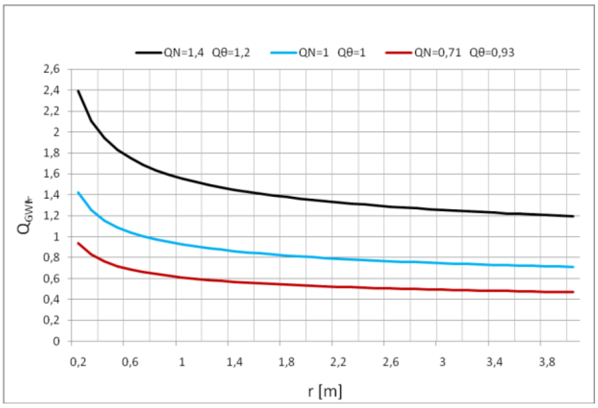

Figure 6. Influence of the distance between workstation and the engine-generator r on the value of the global index Q_{GWA}

The influence of A-weighted sound power level on the value of global index Q_{GWA} for different combinations of partial indices Q_R and Q_Θ value is presented in Figure 7.

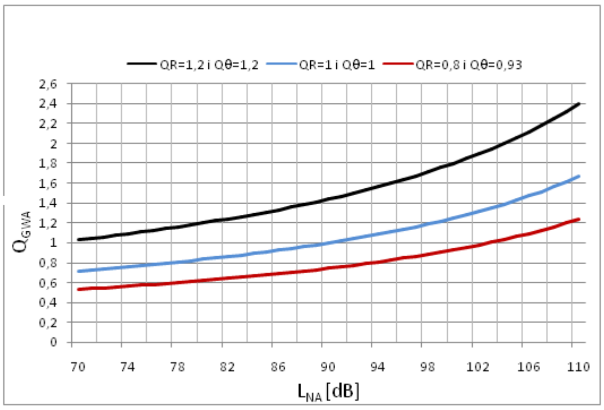

Figure 7. Influence of the A-weighted sound power level L_{NA} on the value of the global index Q_{GWA}

Moreover Raynoise programme was used to carry out the analysis of distribution of global index in a room. A workshop room, where the engine-generators were tested, was modelled with the use of Raynoise programme (Figure 8).

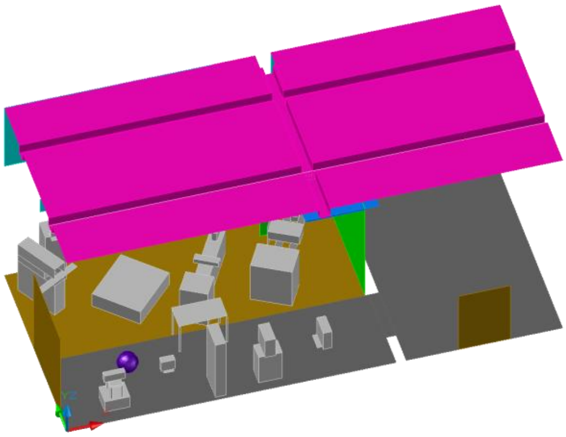

Figure 8. Model of the workshop room (purple sphere indicates the tested engine-generator)

The simulation of the distribution of sound pressure levels of the tested engine-generators on the industrial hall surface (at the height of 1.5 m above the floor surface) was carried out. The Figure 9 shows the distribution of A-weighted sound pressure level of the tested engine-generator CMI C-G800 800 W (the generator under no load (idling)).

Figure 9. Distribution of the values of the A-weighted sound pressure level, in dB, in the workshop room

The analysis of distribution of the global index values was carried out for the tested engine-generators in the function of workstation location in the workshop room. Figure 10 shows the distribution of the global index values of the above mentioned engine-generator. Depending on the workstation location the influence of engine-generator noise changes values of the global index. In many cases the global index adopts critical values in the vicinity of the tested machine.

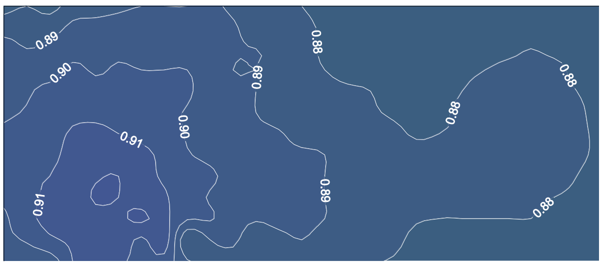

Figure 10. Distribution of the values of the global index in the workshop room

CONCLUSIONS

The correctness of the determined values of global indices of the tested engine-generators was confirmed by the results of A-weighted sound pressure level measurements at hypothetical workstations of the engine-generators. The simulation tests results are consistent with experimental tests results, with the general principles of sound waves propagation and with noise control methods.

Verification tests of the global index will be continued and a software for prediction method of noise emission of the machinery and support of the correct distribution of machinery in industrial rooms based on the global index will be developed. It will allow for among other things:

- determination of global index distribution in chosen sections of limited cubicoid areas which is a typical shape of an industrial hall with the use of statistical prediction method of sound pressure level in the room,
- graphic visualisations enabling an independent assessment of partial indices influencing the value of global index taking into account several machines simultaneously,
- optimization of machines and workstations location aimed at minimization of harmful effects of noise with the use of genetic algorithm applying the notion of global index value for the calculation of adaptation.

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