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Research Papers

Cumulative Industrial Noise Impact on the Environment

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The paper presents basic legal conditions, applicable to the calculation of cumulative noise levels in the environment with indication mainly on lack of detailed regulations both in formal and methodological approach for evaluating those levels. The paper is focused on methodological approach with the emphasis on analysis of existing case studies in the industry. The main subject of the analysis is the cumulation of industrial noise sources: newly designed and existing ones, together with a proposal of accumulate other types of the noise. Evaluation of cumulative noise levels for new (designed) objects is realised by computational methods, and for existing objects, by measurements or by combination of measurement and computational methods. It is assumed that the cumulative level is an energetic sum of the rating levels for all installations and it will not exceed the limit value in a given place. For the cumulation of different noise sources, the weighting for criterion values of these sources will be applied in aggregation.

Keywords: industrial noise; cumulative impact; noise indicators; cumulative noise levels.

1. Introduction

Subjective reception of the noise makes it difficult to determine measurable parameters, adequate to its annoyance, criterial values, and other quantities related to evaluation of its annoyance. In spite of multiple directives (Directive 2002/49/EC, 2002; Commission Directive (EU) 2015/996, 2015), standards (ISO 1996-2 (2007), ISO/DIS 1996-1 (2016), ISO 9613-2 (1996)) and other methodological regulations (Environment Protection Law, 2001), there are still many doubts and disputes related to definition of a "universal" single-number noise index (frequency and time weighted sound pressure level, additionally adjusted, used for noise impact assessment, includes various features of the sound, especially impulsiveness and tonality). The topic is discussed in many papers and publications (Committee on Hearing, Bioacoustics and Biomechanics [CHABA], 1996; Berry *et al.*, 1989; Fidell *et al.*, 2011; Hamernik *et al.*, 1996; Miedema, 2004; Schomer *et al.*, 2001; Pedersen, 2008; Vos *et al.*, 2001), which still leave a lot of unanswered questions. As a result, the main basis for evaluation of the noise annoyance is still the value of equivalent A-weighted sound pressure level, adjusted to the presence of single pulses and the contribution of tonal components. One can also find proposals for correction of the impact of level time variations and considerable contribution of low-frequency components (Wszołek, 2015; Kłaczyński, 2014). The tonal and impulse sounds, being some special types of noise, have a great impact on its annoyance, as well as on the human psychological condition and health, therefore their contribution to the evaluation of noise annoyance seems obvious.

The psycho-acoustical approach to the evaluation of noise annoyance has been particularly singled out in the most recent version of the standard (ISO/DIS 1996-1 (2016)). Any other considerations, regarding a particular type of noise, are focused on that type of noise, without taking into account the interaction (cumulative effects) with other types of noise.

In the legal acts presently binding in Poland (Environment Protection Law, 2001; Act on providing information on the environment and environmental protection, public participation in environmental protection and on environmental impact assessment, 2008; Regulation of the Ministry of Environment, 2014), one can find regulations that impose the necessity to take into account the cumulative environmental impacts, particular in the environmental impact assessments. However, in many cases the absence of detailed regulations results in superficial evaluations of such assessments, e.g. based on individual, subjective approach, and sometimes in total absence of such assessments. Such a situation, in particular, also regards the noise impact, where in addition one encounters varied parametrisations (and annoyance evaluations) for various noise types and the absence of simple procedures for "summing up" their impacts.

For the case of acoustic impact in practice one always encounters the summing up of various sounds, which in general may lead to both pleasant or unpleasant impressions, and usually the latter are regarded as noise nuisance. Irrespective of the subjective classification of such sounds there is a need to elaborate an objective parameter and respective procedure that will allow summation of individual components impacts, not only physical, but also psychoacoustical, at least within the scope of a single noise type. Still in the present paper the topic is focused on the cumulative impact of industrial noise, generated by various installations – both existing and the newly designed, and a proposed procedure for the cumulative impact coming also from other types of noise.

The basic legal acts in Poland specifying the legal procedure for receiving an environmental decision for the planned undertakings are the acts mentioned above. However, in practice only in articles 62, 63, and 66 of the Environment Protection Law (Environment Protection Law, 2001) there are records concerning the necessity to take into account the cumulative impact, without any detailed regulations and interpretations on such impacts, neither in the quantitative approach nor the time domain of the impact. In the Polish legislature there is also no definition of the cumulative impact itself.

According to Canadian Environmental Assessment Agency (CEAA) the cumulative impact is a: "Cumulative effect of environmental changes caused by the human activity in connection with other action in the past, as well as present and future" (Sadler, 1996).

In the present work the author will analyse the effects of cumulative industrial noise impacts (generated in industrial installations) and describe a proposal how to take into account the additional effect from other types of noise sources, like traffic or railway. In most cases related to noise the effects will be simply additive, but in some situation one can describe it as synergetic effects.

Generally for the noise cases the cumulative effects of a planned undertaking (installation) will overlap with other, already existing effects and those coming from other preplanned undertakings. If so, a very basic question arises: when (on which stage of its planning or realisation) should a given undertaking be taken into account in the analysis of the cumulative impact. A premature inclusion of its impact into the analysis of the cumulative impact may result in issuing wrong decisions for other neighbouring installations, while in fact the considered undertaking will be still in the making (under construction).

2. Parametrisation of industrial noise in application to aggregation of effects of its environmental impact

The superior legal act determining the state's policy in the area of environment noise protection is the Environment Protection Law mentioned above – in particular Section V, entitled "Noise protection".

On the other hand, the legal act determining the EU member countries policy in the area of evaluation and supervision of noise level in the environment is the Directive 2002/49/EC and the EU Commission Directive 2015/996. The main objective of both Directives is the specification of common approach oriented on priority actions leading to avoidance, prevention, and limitation of harmful noise effects.

Environment Protection Law (Environment Protection Law, 2001), especially in the recent versions, is in general compatible with the records included in Directive 2002/49/EC.

According to the mentioned above legal acts in Poland, the basis for noise level evaluation in the environment are the L_{den} (day-evening-night level defined in Directive 2002/49/EC) and L_{night} (determined over all the night periods of a year, defined in Directive 2002/49/EC) levels, used in the long-term policy in the area of environment noise protection, in particular, elaboration of noise mapping. On the other hand, the indices being applied for setting and supervision of environment use with respect to 24 h period are the $L_{Aeq\,D}$ and $L_{Aeq\,N}$ levels in dB. $L_{Aeq\,T}$ is the A-weighted equivalent continuous sound pressure level, defined in ISO/DIS 1996-1 (ISO/DIS 1996-1:2016), for daytime interval ($T = D$) between 6:00 AM and 10:00 PM and for night-time interval ($T = N$) between 10:00 PM and 6:00 AM.

Environment Protection Law (Environment Protection Law, 2001) when specifying the acceptable-permissible noise values allows for the possibility of taking into account its time variation, frequency characteristics, and pulse nature. However, according to the reference methodology, see the regulation (Minister of Environment, 2014), in the calculations of the final value of the noise index, the value of which is being compared with the limit values, only the pulse nature of the sound is being taken into account (the K_1 adjustment in formulas (1) and (2), $j = 1$), determined by the rules specified in Appendix 8 of the methodology document (Minister of Environment, 2014). However, in general, according to the standard (ISO/DIS 1996-1:2016), the adjusted noise levels (indices), defined in formulas (1) and (2) make the basis for the noise evaluation.

L_{REij} is the adjusted sound exposition level for the evaluation of the i-th single acoustic event, it is given by the sound exposure level L_{Eij} plus the level adjustment K_j for the j-th type of sound, excluding high energy events and events with considerable amount of low frequency components (1), dB

$$L_{REij} = L_{Eij} + K_j, \tag{1}$$

$L_{Reqj,\,Tn}$ is the adjusted equivalent A-weighted continuous sound pressure level, in the time domain T_n which is given by the actual equivalent continuous sound pressure level, $L_{Aeqj,\,Tn}$ plus the level adjustment K_j, for the j-th sound source (2), dB,

$$L_{Reqj,\,Tn} = L_{Aeqj,\,Tn} + K_j. \tag{2}$$

The K_j adjustments, referring to the sound (source) characteristics should be applied only in the time period in which the characteristics are present at the reception point.

The pulse adjustment K_1 (for $j = 1$) may take values between 5 and 12 dB, depending on the sound type and the measured value, for measurements of the exposition level (1) and between 3 and 12 dB for measurements of the equivalent level with contribution of acoustic pulse components (2). Values of these corrections, referring to particular sound types, are listed in Table in Attachment No. 8 of the Ministry order (Minister of Environment, 2014).

For combined sources acting in a specific normative time period T the rating levels are defined, which can be calculated according to formula (3)

$$L_{ReqT} = 10\log\left[\frac{1}{T}\left(\sum_{i=1}^{n} T_i 10^{0.1L_{Req(i)}} + \sum_{j=1}^{m} k_j 10^{0.1L_{RE(j)}}\right)\right] \text{[dB]}, \tag{3}$$

in which: T is the normative time period equal to 8 or 16 hours, but expressed in seconds; n is the number of distinguished noise sources during the exposition time T_i (also expressed in seconds) and adjusted equivalent level $L_{Req(i)}$; m is the number of distinguished acoustic events categories (e.g., a number of car categories passing by during the time T); k_j is the number of acoustic events in a given category (e.g., the number of cars of the$j$-th car category passing by during the time T) with j-th adjusted exposition levels $L_{RE(j)}$.

For the assessments of environmental impact for a planned undertaking, according to the legal act (Act on providing information on the environment and environmental protection, public participation in environmental protection and on environmental impact assessment, 2008) the basic indices will be $L_{Aeq\,D}$ and $L_{Aeq\,N}$. In practice, the rating levels (with adjustment K_1, taking into account the pulse characteristics) are calculated with respect to one or more acoustic sources. The rating levels calculated according to formula (3) should be also applied for determination of the cumulative levels.

3. Prediction of cumulative noise impacts by computational and measurement methods. Effects of the acoustic background

Prediction of the noise emission level can be based on computations or measurements. Often, both methods occur combined, then one can call it as a measurement computational method. The final effects of computations in both the first and second case should be the total emission level, determined on the borders of the protected area, coming from a given installation or a planned undertaking. In practice both types can be present in greater number. For newly designed objects (installations) usually the computation method is applied, based on the algorithms specified by the standards (ISO 9613-1 (1993) and ISO 9613-2 (1996)) while the input data (levels of acoustic power) if they are not provided by the manufactures/constructor can be determined from measurements (e.g on another but similar object). The measurement methods are also applied for verification of model calculations on various stages of the modelling process.

In both cases the calculation (and measurement) results should refer to specific points, most sensitive to the noise impact from a given installation, and at the same time being representative for a given protected area.

3.1. Computational methods

The computational methods may be applied both to the newly designed objects and existing objects in cases when the noise emission levels from an individual installation cannot be determined from measurement.

Computational models of sound propagation from all installations contributing to a given reception point should be constructed on similar (preferably the same) assumptions, regarding the sound propagation conditions, in particular, the ambient conditions, sound dampening by the green, etc.

In general, one can distinguish several possible situations, whenever calculations of the cumulative noise impact will be required:

1. Two or more undertakings, realised at the same time, i.e., parallel formal procedures are under way resulting in issuing environmental decisions and final planning permissions, allowing the contractor to start with the project realisation. Then the limited (cumulative) noise emission level,

$L_{AeqX(lim)i}$, for every (i-th) above mentioned undertakings should not exceed the value of (4):

$$L_{AeqX(lim)i} = L_{AeqX(lim)} - 10\log(n) \text{ [dB]}, \quad (4)$$

where n is the number of parallel environmental procedures with some reception points in common, $L_{AeqX(lim)}$ is the limited noise level during the daytime ($X = D$) or night-time ($X = N$), without taking into account the cumulative effects, dB.

For instance, for the case of two parallel undertakings the limited noise level ($L_{A(lim)}$) will be reduced by 3 dB and, respectively, for three undertakings the value of the noise limit level should be reduced by 4.7 dB.

If the acoustic background includes contributions from various sources but not from other (physically existing) installations, its characteristics should be specified, with detailed description of the contributing sources and values, without taking the cumulative effects into account in the calculation of the resulting level. The cumulative background effects can be in some cases applied for another (predominant) source, e.g., traffic noise, after application of a weight coefficient being the difference of limit values between the traffic and industrial noise. When the difference between the limited values is ΔL (Minister of Environment, 2007) then

$$L_{AeqX(lim)i} = 10\log\Big[\Big(10^{0.1L_{AeqX(lim)}} - 10^{0.1(L_{AeqX}-\Delta L)}\Big)\Big] \text{ [dB]}, \quad (5)$$

e.g. for $\Delta L = 11$ dB and the traffic noise level in the night-time period $L_{AeqN} = 53$ dB one gets:

$$L_{AeqX(lim)i} = 10\log\Big[\Big(10^{0.1(45)} - 10^{0.1(53-11)}\Big)\Big] = 42.8 \text{ dB}. \quad (6)$$

It directly indicates that the acceptable value for the night-time period for the new installation, after taking into account the cumulative effects with the existing traffic noise, should be reduced to 42.8 dB.

In general, such a case should be treated as more complicated because of various normative time periods, for which the noise indices are determined (8 h and 1 h for the industrial noise and, respectively, 16 h and 8 h for the traffic noise, respectively, for the daytime and night-time periods) and also because of non-issuing decisions on the acceptable noise levels for the traffic noise.

2. If in the area under consideration there is already one or more installations generating noise, then their effects should be cumulated separately in each of the reception points and the resulting level should be a sum (total energy) from all the planned undertakings and the noise levels from the existing installations. Then one can use formula (7):

$$L_{ReqT} = 10\log\left[\frac{1}{T}\left(\sum_{i=1}^{n} T_i 10^{0.1L_{ReqTi}} + \sum_{j=1}^{m} T_j 10^{0.1L_{ReqTj}}\right)\right], \quad (7)$$

where T is the normative time period equal to 1 or 8 hours; n is the number of planned undertakings, for which the resulting noise emission levels have been calculated for a given reception point, equal to L_{ReqTi} if the exposition time from the i-th source is equal to T_i; m is the number of distinguished presently existing industrial noise sources (installations) from which the measured resulting emission levels in a given reception point are equal to L_{ReqTj} when the exposition time is equal to T_j.

3. When the present situation is at the border of noise limit value, then realisation of a planned new undertaking is possible only after reducing the noise level to such a value that the resulting total noise combined (cumulative level) with the new installation will not exceed the limit value in a given reception point. Such a situation can occur when the owners plan to develop an existing installation, which results in addition of another noise source. The noise from that source (of additional acoustic power) should be compensated by adequate reduction of the acoustic power emitted from other (existing) sources, so that the total noise emission level will not exceed the limit value. In both cases the calculations may use the relations presented in formulas (5) to (7).

3.2. Measurement methods

Measurement methods in evaluation of cumulative noise levels are based on the reference method (Minister of Environment, 2014) and are applied for concentration of several independent installations (separate entities) in the area, sometimes interpenetrating. From time to time it is a result of separation or creation of new entities from a single plant. Such situations occur, among others, in AMP foundry in Dąbrowa Górnicza and Kraków, but also in PKN Orlen in Płock, and the task often is placed opposite, i.e., total noise level coming from all of installations and other noise sources are measured, at least at certain periods of time, and the problem is to determine the contribution of different entities (noise sources) to the measured noise level. There is a general need to build an acoustic model and compute the impact of separate installations on the emission level at a given observation point. In reality, this means the use of computer methods, in a situation when the conditions are not fulfilled for the application of the method of measurement within the meaning of the abovementioned reference methodologies. That approach allows to specify the level of noise emission and individual impact of the dominant noise sources also when the measurement method cannot be applied due to the interference from other non-industrial noise sources, e.g., traffic. Regardless of the emission evaluation method, the final condition should be the same as in the previous approaches, i.e., emission (cumulative) noise level from all entities, both existing and planned, should not exceed the limit value neither in the day, nor in the night. For the other (non-industrial) noise sources, their possible accumulation should be carried out with weighting as in the computational methods, provided there is a possibility of separate noise emission measurement for each of the analysed entities. In the case of using measurement techniques to determine the cumulative noise levels, in particular, involvement of each installation on the measured level, it is important to determine the uncertainty of such an approach. More practical details on the determination of the measurement uncertainty can be found in papers (Stępień, 2016; Batko, Przysucha, 2014).

4. Conclusions

In the present work the basic legal determinants have been discussed which should be applied in the calculations of cumulative noise levels in the environment, with indication of the absence of detailed regulations regarding both formal and methodological aspects of determination of such noise levels. The main focus of the paper regards the methodological aspects, with the accent to the practical approach and analysis of cases encountered in practical situations, and the main subject of the discussion is the cumulation of industrial noise sources, both existing and planned, with a proposed procedure to include also other types of noise.

As a result of the analysis and discussion the following conclusions can be formulated:

1. At present in both Polish and foreign legislature there are no detailed regulations and interpretations regarding the discussion of cumulative effects in the quantitative aspect as well as the normative time period of the noise impact. There is also no definition of the cumulative noise impact itself.
2. By the cumulative noise level one can understand the sum (in energy scale) of the rating levels, L_{ReqT} from all noise sources in a given category (e.g., industrial noise) both the existing and planned in a given area of the cumulative impact. For the case of noise generated by sources belonging to various categories, the summation should be performed after application of the appropriate weight coefficients, e.g., being the difference of limit noise values for the analysed categories. However, calculation of cumulative noise effects for noise sources of different categories requires additional legal regulations regarding both the normative time periods and issuing decisions specifying the noise limit levels.
3. The cumulative level should not exceed the noise limit level in a given reception point, determined by the order (Minister of the Environment, 2007). The reception points should be points representative for a given acoustically protected area, with minimised level of interference coming from other sources, so that test measurements can be performed, which verify the model calculations.
4. When the existing noise level is at the limit of acceptable values, the level of the noise emission from possible new (additional) noise sources should be compensated by adequate reduction of the noise from the existing sources, so that the cumulative (with the additional noise sources) level does not exceed the limit value.
5. Cumulation of various noise categories, e.g., traffic and industrial noise requires additional regulations (corrections) that take into account various acceptable values and normative time periods both in daytime and night-time. It is possible to cumulate (sum in energy scale) the noise from various sources after application of proper correcting weight coefficients, being the differences between the noise limit levels in the analysed categories.

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