

Definition and Measure of the Sound Quality of the Machine

Dariusz PLEBAN

*Central Institute for Labour Protection – National Research Institute
Czerniakowska 16, 00-701 Warszawa, Poland; e-mail: daple@ciop.pl*

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The analysis of available literature indicates that tests of products sound quality, which would not involve participation of groups of listeners supposed to evaluate the sounds emitted by these products, are neither carried out in Poland, nor in the world. That results in the fact that the products sound quality is determined on the basis of psychoacoustic information and comprises both objective and subjective factors of sound perception. With reference to those factors and to different life cycles of the machine, an original definition of the “sound quality of the machine” has been developed and presented in this article. The global index of the acoustic quality of the machine, accounting for the relations between the noise level at the workstation and the selected parameters characterising both the machine’s sound activity and the working environment, was adopted as the measure of the sound quality of the machine. The experiments that followed confirmed the appropriateness of the assessment made with the use of the global index of acoustic quality.

Keywords: sound quality, machine, noise.

1. Introduction

Since the beginning of the 1980s, intensification of works on quality has been observed. The results of these works are implemented mainly in the form of documents, such as standards and legal acts. Initially, quality was perceived either as a quality system or as quality of the product. With time, the quality system, defined as organisational structure, division of responsibilities, procedures, processes and resources enabling implementation of quality management, was replaced by the quality management system understood as system of managing and controlling an organisation with reference to quality (PODGÓRSKI *et al.*, 2001). The research on management resulted in the development of different management systems that cover the most common quality management and environment management systems, as well as occupational safety systems. Those systems are based on standardised requirements and guidelines, and are implemented more often in the companies in the form of integrated management system.

The meaning of the product’s quality has also changed with time. Quality can be associated with properties and technological characteristics of the product (e.g. operation, reliability, endurance, safety of use). Another approach is to express the degree in

which the product satisfies the user’s needs by means of quality.

The study on the quality systems was accompanied by intensive works in the area of product testing, assessment and certification, which also comprised machinery. In effect, in the middle of the 1980s, the EU member states introduced the so-called new approach to testing and certification, which made a basis for implementing procedures of assessing products’ conformity with basic health and safety requirements, defined by appropriate directives. With reference to machinery, the conformity assessment procedure covers requirement of assessing sound quality by determining only one or two noise emission values characteristic for the machine, yet without specifying their permissible levels (European Parliament, 2006) (with the exception of machines intended for use outdoors (European Parliament, 2000)). The lack of permissible noise values is not the only disadvantage of the conformity assessment of machinery, as it neither provides the operator with answers to the following questions: will the maximum permissible noise level at the workstation be exceeded in given working conditions? and: How to use the results of acoustic assessment for determining optimum localisation of the machine in the operation room?

The abovementioned change in the understanding of the product quality resulted, *inter alia*, from extend-

ing both the list of product types that undergo quality assessment and the scope of features and properties that affect the quality level. A proper example of that is intensification of works on the products sound quality (since 1990s). The quality is assessed on the basis of information gathered e.g. in psychoacoustic tests and subjective tests on sound impressions. However, no objective method has been developed for determination of the product sound quality.

2. Product sound quality

Systematic increase in the number of products on the market makes the producers undertake activities aiming to increase their competitiveness. Sound quality is one of the features that affects product competitiveness. Intensification of works in the area of product sound quality was observed at the turn of the 21st century. Richard H. Lyon, who created a new definition and classification of products in the light of sound quality, was one of the forerunners in this area (LYON, 2004). According to this definition, a product is: “a constructed system or device for the benefit and/or use of persons”. This definition covers three types of products:

- products in which sound is fundamental for quality: musical instruments, sound reproduction systems and audio monitoring rooms;
- products in which sound is an important factor that decides about their acceptance: devices for individual use, cars, as well as heating and air-conditioning systems;
- products that are outside of our control or that do not bring us benefits: products generating communal noise (transportation means, construction machinery), heating and air-conditioning systems used by our neighbours.

Lyon proposed the following definition of the product sound quality (LYON, 2003; 2004): “sound quality is a perceptual reaction to the sound of a product that reflects the listener’s reaction to how acceptable the sound of that product is: the more acceptable, the greater the sound quality”. Thus, the sound quality is our reaction to sound and can be typical of a given product, e.g. a hairdryer, assessed as the product of high sound quality, does not sound the same as the washing machine which is also assessed as the product of high sound quality.

It can be said that the sound quality of the product is not only its noise level, but also the way it is perceived according to its sound. Up to the mid 1990 s, the sound quality tests were mainly carried out on automotive products, i.e. on cars (VAN DER AUWERAER *et al.*, 1997).

The present studies around the world concern products, such as cars (CERRATO, 2009; CHO, 2010; GENUIT, 2011a; 2011b; GIUDICE *et al.*, 2008; JUNG,

2010; KANG, BYNN, 2010; PENG *et al.*, 2010; SHIN *et al.*, 2009), household devices (BOWEN, 2010; KANG *et al.*, 2010; PIRETILA, CERRATO, 2012) or computer equipment (HATANO, HASHIMOTO, 2010; LIN, PEI, 2006; MAGILL *et al.*, 2006; MINORIKAWA, HASEGAWA, 2011; NISHIGUCHI, MINORIKAWA, 2006; TAKADA *et al.*, 2010). The studies not only aim at assessing the sound quality of the products, but also determine the correlation between the way the product sound is perceived by the selected group of testers and the noise emission parameters. However, the above works and studies do not cover machinery which is most common in the processes of work.

The latest group of products tested for their sound quality are medical devices and emergency signals in hospitals (PIETILA, CERRATO, 2010), as well as portable handheld or manually operated machines (HORVAT *et al.*, 2012). The core of the tests is data obtained in psychoacoustic tests. When the aforementioned portable machines (drills, jigsaws and chainsaws) were tested, the test group was supposed to assess both the noise and other parameters of the machine, such as e.g. handle safety or proper operation of the machine.

A significant disadvantage of the assessment of sound quality of products is not only the limited range of products to which it applies, but also the subjective factors that hinder achieving repeatability and reproducibility of tests (BELDA *et al.*, 2004). Moreover, the results of the sound quality assessment of the same products differ with reference to ethnic or cultural groups, which were demonstrated in comparative analysis (BELDA *et al.*, 2004). Irrespective of whether they undergo sound assessment (in any mode) most goods have to be tested for compliance with basic requirements (specified by law). The assessment of machinery is carried out at the stage of design and production and covers noise assessment whose principles only require of specification and possible declaration of data characterising noise emission – emission the sound pressure level and possibly sound power level (European Parliament, 2006). The lack of permissible values for these parameters results in the possibility of entering any machine into the market, irrespective of the level of noise it emits (with the exception of the machines that are intended for use outdoors). Moreover, the values characterising the machinery noise emission, as declared by the manufacturers, do not give the users any information about the acoustic climate in the operation room after the machine has been installed.

3. Sound quality of the machine

The detailed analysis of available literature shows that the term of sound quality of the machine has not yet been defined. Neither the acoustic quality index has been determined that would enable sound assess-

ment of the machine and anticipate its noise emission in working conditions.

The sound quality of the product is acquiring more and more importance in the total assessment of the product's quality. Attractiveness, and – in effect – price and sales of such products, as vehicles, household goods or computer devices depend more and more on their sound quality. There are many factors that affect that quality. However, the works carried out in foreign scientific centres are only related to the correlation between the subjective perception of the product's sound to the selected group of testers and objective noise emission parameters. The results of all these parameters make a basis for sound quality of the product.

If we take into account various life cycles of the machine, their relation to various models of quality management systems and compatibility tests of the machine, we can say that the works on the sound quality of the product have so far been limited to the activities resulting in giving the designer (or producer) the information about whether the sounds emitted by the product are well perceived by the users. As it has already been stated, these activities only refer to a small group of products which excludes machinery. Moreover, what is important for the machine is its noise in working conditions, i.e. the machine's sound quality in the working conditions. Therefore, the author proposes the following definition of the sound quality of the machine (PLEBAN, 2012): the sound quality of the machine in working condition is a combination of the features of the machine and operation room, affecting the level of noise that has an impact on people working in this room. The sound quality of the machine can be parameterised and can reach high values, when the level of sound pressure at the workstation does not exceed the permissible values, or it can reach low values, when the permissible noise level is exceeded.

The sound quality can be developed as a result of a set of planned and systematically implemented activities at the stage of machine designing, production, installation and use, in order to guarantee the relatively low emission of sound that would not pose the noise exposure risk at the operator stations in the working room. The sound quality of the machine is measured by the global index of acoustic quality.

In order to guarantee the high sound quality of the machine, the following rules should be applied:

- designing should be carried out according to the principles of ecodesign (CEMPEL *et al.*, 2006), with the provision of noise reduction methods (EN ISO 11688-1, 2009),
- at the stage of machine designing and production, the quality management system meeting the requirements of appropriate standard documentation should be implemented (EN ISO 9001, 2008),
- at the stage of machine installation and use, the requirements specified in the operation and mainte-

nance documentation or instruction for use, and the parameters of the room, as well as acoustic parameters and localisation of other sources of noise in this room should be accounted for.

4. Quality assurance at the stage of designing and production

The proposed definition introduces a new dimension of quality for the machinery and comprises all stages of the machine life cycle, except the stage of liquidation. However, that stage is accounted for indirectly at the stage of sound ecodesign. Yet, the sound quality of the machine can be guaranteed not only by using standard principles of the quality management system implementation at the stage of designing and production or during testing and acoustic assessment. Important means that contribute to the high sound quality of the machine are best acoustic practices applied in the process of designing of low-noise machinery. Those practices account for the principles of sustainable development in the process of designing, as well as for the objective of this development, i.e. appropriate quality of living (appropriate social level, life in civilised environment, in terms of both industry and nature) (ENGEL, 2012).

Adjusting the process of machine designing to the aim of sustainable development requires meeting the rules of environment-friendly machine designing, i.e. the rules of ecodesign (CEMPEL *et al.*, 2006). These requirements can be met by executing the 3R rule (reduce, reuse, recycle). Therefore, the best acoustic practices in the machine designing process have been set in the form of a procedure composed of four stages in which the designing tasks are specified with the provision of the noise reduction methods (PLEBAN, 2012) and the 3R rule with reference to the choice of materials, in order to minimise environmental impact due to their degradation or the possibilities of their reuse at the end of the machine's life cycle, which requires provision of environment-safe process of machine disassembly.

The acoustic ecodesign stages are (Fig. 1):

1. Tasks specification: at this stage, a list of requirements accounting for the abovementioned 3R rule is prepared as a control document for the whole design task. The list also includes the requirements for noise, accounting for valid laws, current know-how, competitive products, user requirements or machine acoustic assessment treated as commercial assets.
2. Design concept: this designing stage mainly focuses on achieving set goals. At this stage, the information about the final product is still limited; therefore, acoustic characteristics and reliability of the 3R rule provision are usually evaluated on the basis of comparing them to popular solutions.

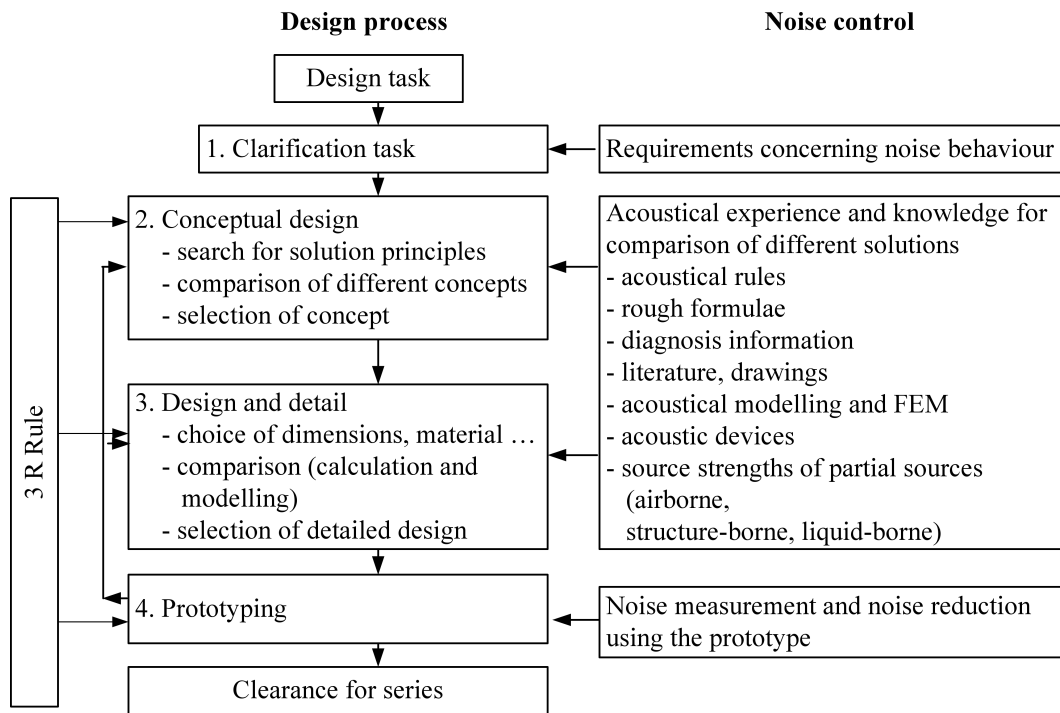


Fig. 1. Stages of acoustic ecodesigning.

3. Detailed design: in the process of designing works and selecting construction materials with the aim to minimise environmental impact due to their degradation, the quantitative analysis of acoustic characteristics can be made by proper selection of possible solutions meeting the 3R rule.
4. Prototype construction: carrying out acoustic tests of the machine prototype in order to analyse in a quantitative way the main sources of noise and sound propagation paths. The tests can indicate the necessity of modifying the design or can confirm meeting the requirements, including the sound and 3R rule based ones (and especially in terms of protection against uncontrolled noise emission to the environment).

5. Global index of the acoustic quality of the machine

The global index of the machine's acoustic quality, accounting for the relations between the noise level at the machine's workstation and the selected parameters of the acoustic activity of the machine and the acoustic parameters of the room, was adopted for measuring the machine's sound quality.

In order to determine that index, the noise emitted by the machinery was described by means of partial indices. It was assumed that the global index of acoustic quality of the machine, specified on the basis of values of partial indices, would enable approximate acoustic assessment of the machine and would help anticipate

the noise in the working rooms, and thus optimise the locations of machinery and workstations in these rooms in order to minimise noise impacts. According to this assumption, the global index of acoustic quality of the machine, Q_{GWA} , should be determined on the basis of the following dependence:

$$Q_{GWA} = \prod_{i=1}^n Q_i, \quad (1)$$

where Q_i – partial quality indices; n – number of partial quality indices.

It was assumed that the value of each of the partial indices Q_i is always a positive number. Moreover, the value of any index that is higher than 1 means that a given parameter has a negative impact on acoustic climate in work environment, which indicates the necessity of undertaking appropriate measures in order to reduce that value. However, if the value is lower or equal to 1, the parameter has a positive impact on acoustic conditions and acoustic climate at work.

If the value of the global index Q_{GWA} is lower or equal to 1, the machine can be considered as acoustically safe, i.e. the of sound pressure level at the workstation does not exceed the permissible value. However, if that value is higher than 1, the noise emitted by the machine exceeds the permissible value of the A-weighted sound pressure level at the workstation. Installation of such a machine in the industrial hall can lead to discomfort of other employees who are not involved in the direct operation of the machine.

In general, the partial indices Q_i can be divided as: dependent on a given machine, dependent on the

acoustic properties of the room and combined, i.e. dependent both on the machine and the room. Therefore, the index for acoustic assessment of the machine, i.e. the global index of acoustic assessment of the machine, can be determined from the dependence (PLEBAN, 2010):

$$Q_{GWA} = Q_N \cdot Q_R \cdot Q_\Theta \cdot Q_{\text{imp}} \cdot Q_F, \quad (2)$$

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.

6. Partial indices

The basic parameter for objective characterisation of noise emitted by the machine is the sound power level. The parameter is determined by partial index of sound power. Natural increase in the value of the sound power level should result in the increase in the value of the sound power index. Therefore, Q_N was defined on the basis of dependences (3) and (4):

$$Q_N = 1 + \frac{L_{NA} - L_0}{50} \quad \text{for } L_{NA} < L_0, \quad (3)$$

$$Q_N = \frac{1}{1 - \frac{L_{NA} - L_0}{50}} \quad \text{for } L_{NA} > L_0, \quad (4)$$

where L_0 – standard 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.

According to the principles of acoustic waves propagation, the sound pressure level decreases with the increase of the distance from the source of sound. The greater the distance of the machine from the workstation, the less an employee is exposed to the noise generated by the machine. The situation can be described by the index of distance between the workstation to the machine distance index, Q_R :

$$Q_R = \frac{3.7}{3.2 + \lg(\Omega r^2)}, \quad (5)$$

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

If the workstation to machine distance r is greater than 5 m, the $Q_R = 1$ value should be adopted.

Another partial index, radiation directivity index Q_Θ , is a function of the difference between averaged A -weighted sound pressure level around the machine (in the distance equal to the distance between the workstation and the machine distance) and the value of A -weighted sound pressure level at the work-

station. Dependences (6) and (7) describe the index Q_Θ :

$$Q_\Theta = 1 + \frac{L_{pA} - L_{pAa}}{50} \quad \text{for } L_{pA} \geq L_{pAa}, \quad (6)$$

$$Q_\Theta = \frac{1}{1 - \frac{L_{pA} - L_{pAa}}{50}} \quad \text{for } L_{pA} < L_{pAa}, \quad (7)$$

where L_{pAa} – averaged A -weighted sound pressure level around the machine at a distance equivalent to the distance between the workstation and the machine, in dB, L_{pA} – A -weighted sound pressure level at the workstation, in dB.

Many industrial machines generate impulse noise. In this connection the next index, i.e. the impulse and impact noise index Q_{imp} , should be defined according to Table 1.

Table 1. Impulse and impact noise index Q_{imp} .

C -weighted peak sound pressure level $L_{C\text{peak}}$, in dB	Number of impulses during 8 hours of work	Impulse and impact noise index Q_{imp}
$135 < L_{C\text{peak}}$	without limitations	1.1
$125 < L_{C\text{peak}} \leq 135$	$n \leq 100$	1.08
$115 \leq L_{C\text{peak}} \leq 125$	$n \leq 1000$	1.06
$105 \leq L_{C\text{peak}} \leq 115$	$n \leq 10000$	1.04
$95 \leq L_{C\text{peak}} \leq 105$	$n \leq 100000$	1.02
$L_{C\text{peak}} < 95$	without limitations	1.0

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

Table 2. Noise spectrum index Q_F .

$\Delta_{C-A} = L_{pC}^*) - L_{pA}$, in dB	Noise spectrum index Q_F
≤ 0	1.00
0.1–2.0	1.05
2.1–4.0	1.10
4.1–9.0	1.15
9.1–15.0	1.20
> 15.0	1.25

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

7. Experiments on engine generators

Verification of the global index of acoustic quality involved conducting many experiments. One of the groups of the noise sources was a set of four engine – generators of different power.

The values of the global indices of acoustic quality, Q_{GWA} , of the tested generators have been presented in Table 3 (PLEBAN, 2010). The values of global indices

Table 3. Values of global acoustic quality indices of engine generators.

Generator type	Operation mode – load, W	Global index of the acoustic quality of the machine, Q_{GWA}	A-weighted sound pressure level measured at the workstation [dB]
CMI C-G800, 800 W	0	0.85	74.4
	350	0.89	77.5
CMI C-G2000, 2.0 kW	0	1.02	85.4
	350	1.03	85.6
	700	1.03	85.6
	1,500	1.05	86.4
NT250Up, 2.6 kW	0	0.96	83.8
	350	0.96	84.2
	700	1.02	85.4
	1,500	0.98	84.4
CMI C-G3500, 3.5 kW	0	0.93	80.2
	350	0.94	80.8
	700	0.97	83.3
	1,500	1	85

of acoustic quality of the tested generators vary from 0.85 to 1.05. When the index value is higher than 1, the A-weighted sound pressure level at the workstation exceeds the permissible value, i.e. 85 dB. The A-weighted sound pressure level values, measured at the workstations, confirmed accurateness of the test conducted with the use of the global acoustic quality index. When the Q_{GWA} values were lower than 1, the measured the A-weighted sound pressure levels were below 85 dB. However, when the values of that index were higher than 1, the measured the A-weighted sound pressure levels were above 85 dB.

8. Summary

The proposed term of sound quality of the machine and the characteristic global index of acoustic quality, as well as the possibility of using that index for anticipating noise and optimum location of the machines and workstations in work rooms (due to the limited occupational exposure to noise) (PLEBAN, 2012), can be very useful with reference to individual machines that are manufactured on demand. These terms support cooperation of the producer and user in execution of tasks connected with machine design, production, installation and use and help avoid exceeding the permissible noise levels at the workstation in working environment. They can also be used with success for the volume produced machinery. In such a case, they are specially useful to the user both in the process of choosing machinery whose sound pressure level in operation room would not exceed permissible value, and

in the process of specifying its installation place in the room.

The developed indices serve for preparation of objective assessments of the work environment and improvement of the quality of life. The obtained results, including the defined terms of sound quality of the machine and the related global index of acoustic quality, provide new possibilities for shaping the work environment and support priority tasks concerning reduction of noise emitted by the machines and limiting the noise exposure risk.

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References

1. BELDA N., FLINDELL I., REIG A. (2004), *Automotive interior sound quality: The UK part of a large international comparative study*, Proceedings of Inter Noise 2004, Prague.
2. BOWEN D.L. (2010), *Sound quality studies of front-loading washing machines*, Sound&Vibration, December 2010, 8–13.

3. CEMPEL C., KASPRZAK J., KŁOS Z. (2006), *Eco-engineering – complex design and environmental management* [in Polish], http://neur.am.put.poznan.pl/cempel/Wroclaw_CC_ZK_JK.pdf
4. CERRATO G. (2009), *Automotive sound quality – powertrain, road and wind noise*, Sound&Vibration, April 2009, 16–24.
5. CHO W.H., IH J.G., TOI T. (2010), *Quality check of automotive window motors using the sound quality metrics*, Proceedings of Inter Noise 2010, Lisbon.
6. Directive 2000/14/EC of the European Parliament and of the Council of 8 May 2000 on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors. OJ L 162, 3.7.2000.
7. Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast) (Text with EEA relevance). OJ L 157, 9.6.2006.
8. EN ISO 9001:2008, *Quality management systems – Requirements*.
9. EN ISO 11688-1:2009, *Acoustics – Recommended practice for the design of low-noise machinery and equipment – Part 1: Planning*.
10. ENGEL Z. (2012), *Vibroacoustics hazard and sustainable development*, Seminar, Central Institute for Labour Protection – National Research Institute, Warsaw, Poland.
11. GENUIT K. (2011a), *Particular importance of psychoacoustics for sound design of quiet vehicles*, Proceedings of Inter Noise 2011, Osaka.
12. GENUIT K. (2011b), *Sound quality metrics for vehicle interior noise*, Proceedings of Inter Noise 2011, Osaka.
13. GIUDICE S., GIUDICE R., JENNINGS P., CAIN R. (2009), *Capturing driver profiles and behaviour during on-road assessments of vehicle sound quality*, Proceedings of Inter Noise 2009, Ottawa.
14. HASHIMOTO T., HATANO S., TSUCHIDA T., KITAHARA S., TAKAO H. (2011), *Improvement of sound quality of car interior noise by introducing porous intake duct*, Proceedings of Inter Noise 2011, Osaka.
15. HATANO S., HASHIMOTO T. (2010), *Sound quality tuning of a printer noise*, Proceedings of Inter Noise 2010, Lisbon.
16. HORVAT M., DOMITROVIĆ H., JAMBROŠIĆ K. (2012), *Sound quality evaluation of hand-held power tools*, Acta Acustica United with Acustica, **98**, 487–504.
17. JAILANI M., NOR M., FOULADI M.H., NAHVI H., AR-IFFIN A.K. (2008), *Index for vehicle acoustical comfort inside a passenger car*, Applied Acoustics, **69**, 4, 343–353.
18. JUNG O. (2010), *On the acoustical quality of conversational speech inside vehicles*, Proceedings of Inter Noise 2010, Lisbon.
19. KANG K.T., BYUN U.S. (2010), *Sound quality development for passenger vehicle*, Proceedings of Inter Noise 2010, Lisbon.
20. KANG M.J., KIM J.D., HAN J.S., KIM H.S., LEE M.R. (2010), *Noise qualification index for refrigerator aligned with consumers*, Proceedings of Inter Noise 2010.
21. LIN S.H., PEI H.S. (2006), *Sound quality by design – a successful product development story*, Proceedings of Inter Noise 2006, Honolulu.
22. LYON R.H. (2003), *Product sound quality – from perception to design*, Sound and Vibration, March 2003, 18–22.
23. LYON R.H. (2004), *Product sound quality – from design to perception*, Proceedings of Inter Noise 2004, Prague.
24. MAGILL M., GENELL A., KLEINER M., VÄSTFJÄLL D., BELTMAN W.M. (2006), *Sound quality aspects of small computer fans*, Proceedings of Inter Noise 2006, Honolulu.
25. MINORIKAWA G., HASEGAWA S. (2011), *Study on improvement of sound quality in mechanical design*, Proceedings of Inter Noise 2011, Osaka.
26. NISHIGUCHI M., MINORIKAWA G., ITO T. (2006), *Improvement of sound quality of small fan for information devices*, Proceedings of Inter Noise 2006, Honolulu.
27. PENG W., JIN C., ZHOU H. (2010), *An experimental study on the influence of tire noise on the sound quality of car interior noise*, Proceedings of Inter Noise 2010, Lisbon.
28. PIETILA G., CERRATO G. (2012), *Sound quality guidelines for non-automotive products*, Sound & Vibration, April 2012, 8–16.
29. PLEBAN D. (2010), *Method of acoustic assessment of machinery based on global acoustic quality index*, Archives of Acoustics, **35**, 223–235.
30. PLEBAN D. (2012), *Sound quality of machines* [in Polish], Central Institute for Labour Protection – National Research Institute, Warsaw, Poland.
31. PODGÓRSKI D., MIARECZKO B., PLEBAN D. (2001), *Conformity assessment of machinery, collective protective equipment and personal protective equipment* [in Polish], Centralny Instytut Ochrony Pracy, Warsaw.
32. SHIN S.H., IH J.G., HASHIMOTO T., HATANO S. (2009), *Sound quality evaluation of the booming sensation for passenger cars*, Applied Acoustics, **70**, 309–320.
33. TAKADA M., ONODA S.I., HOSHI A., IWAMIYA S.I. (2010), *Effect of temporal structure of operating sounds on the sound quality of noise emitted from a copy machine*, Proceedings of Inter Noise 2010, Lisbon.
34. VAN DER AUWERAER H., WYCKAERT K., HENDRICKX W. (1997), *From sound quality to the engineering of solutions for NVH problems: case studies*, Acoustica – Acta Acustica, **83**, 5, 796–804.