[1.]Anna YEHOROVA, [2.]Ervin LUMNITZER, [3.]Laura DŽUŇOVÁ, [4.]Veronika GUMANOVÁ

METHODOLOGY FOR INCREASING THE QUALITY OF TECHNICAL EQUIPMENT

[1–4.]Technical University of Kosice, Faculty of Mechanical Engineering, Department of Process and Environmental Engineering, Kosice, SLOVAKIA

Abstract: The paper deals with the optimization of the acoustic properties of selected noise sources of household appliances, specifically washing machines. The introductory parts are focused on the analysis of parameters affecting the quality of the product, the so–called "general features of product quality" and a proposal of a new methodology for their evaluation. Attention is paid mainly to a new type of properties, the so–called customer–oriented acoustic properties of the product. Methodologies have been developed for laboratory measurements of psychoacoustic properties and noise visualization, which are then tested in an anechoic chamber by measurement with an acoustic camera and a psychoacoustic head. Methodologies after their evaluation are used in measurements in real conditions. A listening test is created, the results of which can be used to evaluate practical measurements and determine customer–required acoustic, customer–oriented properties.
Keywords: General features of product quality, sound, psychoacoustics, sound quality, listening test

INTRODUCTION

In nowadays, product development is advancing at a very rapid pace. Manufacturers strive to keep current products in a high technical level, for example, a long–term warranty becomes common. However, an increasing problem is not to produce the product, but to sell it. For this reason, manufacturers are focusing on those features that have not been interesting for them so far, but are currently able to increase customer interest in the product. Research into customer behavior shows that it is these features that come to the fore when the customer decides to buy a product.

This process began with the advent of the so–called industrial product design, especially in the automotive industry. Currently, these are areas such as recyclability, energy optimization, adaptive and intelligent properties, acoustics, lighting properties, energy field optimization and much more. One of the attractive areas in which the topic of the paper is focused is the customer–oriented properties of products, which are related to a number of areas, such as noise visualization, psychoacoustics, simulation of sound propagation, the influence of sound on perception and emotional state of a person. An example is the sound that is generated when the car door is closed. In terms of functionality, this is an insignificant phenomenon. However, it is one of the first things that attracts the customer immediately after getting into the car, which is the subject of his interest.

METHODOLOGY

The general objective is to propose a methodology for optimizing the acoustic parameters of products and verify a methodology on a specific product. It is a development in the field of acoustic design and its implementation in the production process of a everyday consumer good – an automatic washing machine. Ultimately, the proposed methodology:

— defines the required acoustic properties of the product,
— evaluates which parameters, quantities and sound properties need to be optimized,
— propose a criterion against which these properties can be assessed.

The methodology is verified on a practical example, used to evaluate the properties of current products on the market. Subsequently, based on this methology, a recommendation was proposed, in which is defined what is necessary to make for specific products, what changes need to be implemented in the development process. It is goal–oriented for practical use in the process of optimizing the acoustic design of machine products, which, however, does not limit the wide range of its use in other areas, practically everywhere where there is a human interaction with sound–generating equipment.

The methodology consists of the following basic stages:

— analysis of the current state in the field of acoustic product design,
— analysis of sound parameters, mostly psychoacoustic, which can be used in the processes of optimizing the acoustic design of products,
— synthesis of acquired knowledge,
— proposal of the method according to the acquired knowledge and on the basis of the study of current knowledge in the researched area,
— creation and evaluation of an listening test,
— recommendations for practice.

Before the process of developing the methodology, a thorough analysis of the current state of the matter in the world was performed. Several authors deal with

this issue in order to improve the acoustic properties of products in their research. T. Novakovic in his publication „Validating impeller geometry optimization for sound quality based on psychoacoustics metrics“, [5], deals with the assessment of vacuum cleaner noise. The author propose a new design of the centrifugal impeller and optimized the sound quality.

The interior of the car, and specifically the control buttons, is dealt with by J. Gaspar in his publication «Psychoacoustics of in–car switch buttons: From feelings to engineering parameters» [6]. The author uses research and questionnaires to design buttons that produce a pleasant sound and thus allows the development of preferred car models.

A. Treiber in the publication "Psychoacoustic evaluation of rotary switches" [7] deals with the evaluation of psychoacoustic parameters of rotary switches.

Various types of sounds from refrigerators in Korea are solved by J. Jeon in the publication "Sound radiation and sound quality characteristics of refrigerator noise in real living environments" [8]. From the results of correlation and multiple regression analyzes of psychoacoustic parameters and subjective evaluations, the author proposed a sound quality index.

The analysis shows that this is an issue that is at a rapidly growing importance in the world. Manufacturers are aware of the need to optimize the acoustic parameters of their products. However, there is still no comprehensive methodology that has brought these tendencies to a standard level.

ANALYSIS OF PARAMETERS AFFECTING PRODUCT QUALITY

Product quality is the main goal of every manufacturer. The basis of all efforts to achieve high product quality are the requirements of customers and all interested parties.

According to the standard STN EN ISO 9000: 2016, "quality is defined as the degree to which a set of inherent characteristics of an object fulfils requirements ". Quality can be defined as the ability to ensure that customer needs are satisfied. Product requirements can be specified by customers or organizations that respond to customer requirements or regulations. Compliance with all requirements must be managed and controlled in such a way that all interested parties are satisfied.

It is clear that all these product quality requirements apply throughout the product life cycle. Significant in the light of efficiency and effectiveness of the implemented quality characteristics (quality features) appears to be the initial stage, i.e. design, development and construction of the product. The quality, safety and reliability of the product requires from all engineers involved in the project a set of activities, starting from the definition of the product characteristics to the implementation phase of the project, which take place simultaneously to achieve a quality and marketable product.

These activities include planning, analysis of results and tests, qualification of components and materials, and control of production processes. Recently, specific product features have come to the forefront. These features do not affect the safety and reliability of the product, have no limits, but are strongly customer–oriented, improve customer–required "quality" features, which increase the attractiveness of the product and eventually its marketability.

The relationship between quality, reliability, safety and specific parameters is described using the so–called general product quality features, Figure 1.

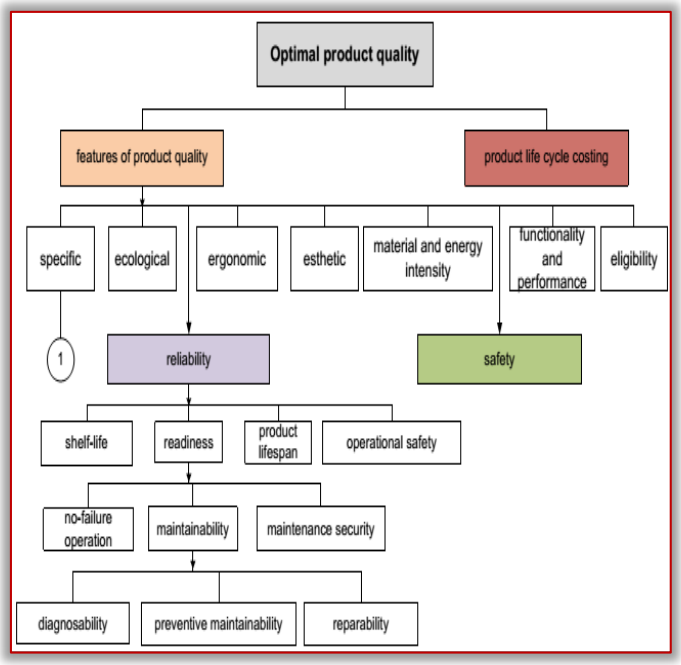

Figure 1. General product quality features

Understanding the needs and expectations of interested parties affects an organization's ability to provide products and services on a permanent basis. It is especially important to identify relevant interested parties in relation to a particular product, evaluate their impact on optimal product quality and identify which features have a critical impact. For these purposes, we have created our own methodology for evaluating general product quality features, specifically washing machines, where we have assigned an interested party to each quality feature and evaluated the customer's impact on quality, see Table 1.

Customer rating is rated on a scale from 1–10 where 10 is the highest rating and 1 is the lowest. We obtained the final evaluation by multiplying the scale of a feature of product quality and the customer rating.

All evaluations are the results of customer surveys in department stores as well as similar studies.

Subsequently, with the help of the matrix of the significance of product quality features (washing machines), we evaluated all properties and assigned them to 3 areas of significance, see Table 2.

Table 1. Evaluation of general product quality features

Features of product quality	Interested parties	Scale	Customer rating	Final evaluation
Specific – customer oriented	Customer	1	10	10
Ecological	Society EU	2	5	10
Recyclability	Ministry of Environment	3	3	9
Ergonomic	EÚ Ministry of Labour, Social Affairs and Family	3	6	18
Esthetic	Customer	1	9	9
Energy intensity	EÚ Manufacturer	2	9	18
Functionality and performance	Customer	1	10	10
Safety	EÚ Ministry of Internal Affairs	3	5	15

The legend: Scale – the importance of the relevant quality feature, evaluated according to a scale from 1–3, where: 3 – defined by legislation (law, government regulation, decree), 2 – recommendations, 1 – not defined by legislation, no recommendations.

Table 2. Matrix of the significance of product quality features

	Scale		
Customer rating	1	2	3
1	1	2	3
2	2	4	6
3	3	6	9
4	4	8	12
5	5	10	15
6	6	12	18
7	7	14	21
8	8	16	24
9	9	18	27
10	10	20	30

The legend: 1–6 – green color – insignificant features of product quality, 7–15 – yellow color – significant features of product quality, 15–30 – red color – very important features of product quality.

Customer evaluation may or may not be legally or normatively substantiated, for example, the energy properties of a product that a customer requires are also enshrined in legislation, but esthetic and specific properties are not specified anywhere.

Recently, the customer has been increasingly preferring specific quality features, which has caused these features to shift to a significant area, even though they have a low scale. That is why it is necessary to deal with the solution of this group of properties.

The definition of sound quality follows from this analysis. In any case we do not want to interfere with quality management systems that have their own area of application. We have focused mainly on a closer definition of the term acoustic quality of the product, or related terms, such as sound quality, product quality in terms of acoustic properties. Here, too, we identify several areas on which this research should be focused:

The area of effects of sound on a person, it is a classic approach, practically the most used so far. In practice, it is often the case about simple reduction of product noise, in rare cases – about the adjustment of the basic properties of sound – tonality or impulsivity.

The area of effects of sound on a person, defined in the scope of his psychological perceptions. It is a modification of psychoacoustic descriptors that affect the overall impression of the product. The point is that the sound of the product does not disturb the person, so that it is not perceived as much as possible. Examples are the modification of the sounds of individual sources in the car – the sound of the engine, aerodynamic sound, the sound generated by tires when rolling, the sound of closing the door, the sound of mechanical controls, the sound of the electric window mechanism, etc.

The area of the effects of sound on the person – the customer who decides to buy the product. Here, the area of sound influences often moves into the subconscious area. The customer does not focus on acoustic properties, but they must not irritate him, on the contrary, they must have a positive effect on his subconscious. Sometimes these are acoustic manifestations of the product, which will be almost never used in practice. Examples include various tapping of the product, switching on the product without load, testing the product in a mode in which it will never be operated, e.g. starting the car in the indoor environment of the show room.

PROPOSAL OF PRODUCT QUALITY IMPROVEMENT METHODOLOGY

The essence and goal of this paper is this proposal. Two types of measurements were performed – laboratory measurements and practical measurements.

The laboratory measurements that were performed can be divided into 2 groups:

— measurements of psychoacoustic properties, and

— measurements for the purpose of analysis and visualization of sound by an acoustic camera.

In the initial stages, we focused on the following sounds of the washing machine:

— washing,
— centrifugation,
— opening and closing the doors,
— opening and closing the detergent dispenser,
— tapping on the side wall of the washing machine.

Washing and spinning are sounds that occur during normal washing machine operation. They cannot be heard before installing the washing machine in the home. They are important for the consumer who bought the washing machine. The opening and closing of the door and the detergent dispenser are sounds that can be heard during any manipulation of the respective elements. Tapping on the side wall of the washing machine is a typical customer–oriented feature – it is tracked by customer behavior when choosing a washing machine.

— Measurement with the Acoustic Camera

The primary goal of any localization technique is to accurately analyze and visualize the source of noise, most often directly on a photograph or video of the tested object. The sound source is usually represented as a color map, corresponding to the distribution of the sound pressure or also the place with the highest measured amplitude.

The basic configuration of the device consists of a microphone array (antenna), data recorder, special laptop and appropriate software. The number of microphones is about 30 to 120 and they are variously arranged in space. In the center of this microphone array is lokated a high–definition video camera that optically records a scene, thanks to which the result of the acoustic calculation, i.e. the acoustic map, can be projected into the recording. The acoustic camera includes a converter that "integrates" the signals from the individual microphones and converts them into a suitable format for further processing. Figure 2 illustrates a view of laboratory measurements with an acoustic camera.

Based on the study of the issue, the following methodology was proposed – the sequence of measurements:

(1) source selection,
(2) of assessment method,
(3) visualization of sound with acoustic camera,
(4) analysis of measured data, processing and evaluation,
(5) acoustic images, acoustic films, time course, spectrum, spectrogram,
(6) location of sources, determination of dominant frequencies, their localization, analysis of technical possibilities of sound modification.

Figure 2. A view of the measurement with an acoustic camera in an anechoic chamber

This methodology was tested in an anechoic chamber. In the initial stages of the methodology, decisions are made on the basic measurement methods. Subsequently, the detail measurement with acoustic camera with appropriate decision–making procedures is elaborated in the methodology. Figure 3 shows an acoustic image of door closing at dominant frequencies of 2300–2500 Hz.

Figure 3. Visualization of sound from door closing, dominant frequencies 2300 – 2500 Hz

— Measurements with psychoacoustic head

The following experiments are focused on measuring the psychoacoustic properties of the assessed sound

sources. The following sequence of activities was used for measurements with psychoacoustic head:

(1) selection of source and assessment method,
(2) determination of customer–oriented quality features – properties that do not affect the technical parameters of the product but affect customer decisions. They are dedicated from the analysis of customer behavior in decision–making, surveys, monitoring behavior in shopping centers, etc.
(3) selection of psychoacoustic parameters – roughness, volume, sharpness, fluctuation, tonality,
(4) measurements of psychoacoustic properties,
(5) time record, identification of required acoustic events,
(6) analysis, data processing, measurement evaluation, analysis of technical possibilities of sound modification.

Measurement of psychoacoustic parameters by means of a psychoacoustic head was also performed in an anechoic chamber. Behind the washing machine was a reflective surface that mimics conditions as close as possible to real household conditions. In Figure 4 is shown a view of the measuring point and the location of the sound source and the measuring device.

Figure 4. View of the measuring point in the anechoic chamber

We focused our measurements on 3 customer–oriented quality features – opening and closing the doors, opening and closing the detergent dispenser and knocking on the side wall of the washing machine.

Figure 5 shows a time record of all assessed acoustic events, on the basis of which detailed evaluations of individual acoustic events were performed.

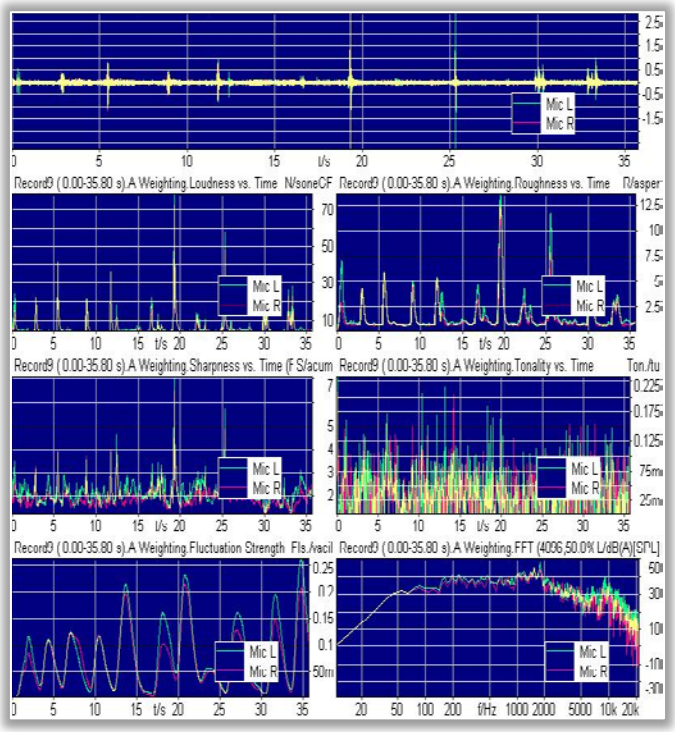

Figure 6. Graphic representation of acoustic and psychoacoustic quantities

CONCLUSIONS

At present, manufacturers strive for their products to reach a high technical level on the one hand and to meet customer requirements on the other hand, which are often different from the ideas of designers and constructors, who attach importance to other requirements, properties, capabilities and other technical parameters. For this reason, manufacturers are now beginning to focus on those features that have not been interesting so far, specifically customer–oriented quality features.

From the performed measurements and their evaluation as well as from the performed psychoacoustic experiment of selected customer–oriented properties of a specific product – washing machine it follows that these properties, although they have no effect on product functionality or technical parameters, are very important to the customer. They often affect the customer's subconscious, influence him and modify his decision–making. The performed experiment serves to determine the recommendations for a washing machine manufacturer who wants to improve these customer–oriented properties and thus increase the marketability of its product.

Acknowledgments

This paper was created within the project KEGA 032 TUKE–4/2018.

References

[1] LUMNITZER, E. et al.: Metodológia komplexného hodnotenia zdravotných rizík v priemysle I . Zręcin: MUSKA sp. z o.o. – 2015 – p. 240

[2] LUMNITZER, E. et al.: Základy psychoakustiky, 2012, Košice pp. 51–73.
[3] LUMNITZER, E. et al.: Hodnotenie vplyvov fyzikálnych faktorov na zdravie človeka. TU, 2014, p. 159
[4] LUMNITZER, E. et al.: Psychoacoustic aspects of the noise perception in engineering. Environmental Protection, Safety, Education and Managment 4 (2014), pp 33–36
[5] NOVAKOVIC, T. et al.: Validating impeller geometry optimization for sound quality based on psychoacoustics metrics. Applied acoustics, volume: 157, article number: UNSP 107013, 2020
[6] GASPAR, J. et al.: Psychoacoustics of in–car switch buttons: From feelings to engineering parameters. Applied Acoustics 110 (2016), pp. 280–296.
[7] TREIBER, A. et al.: Psychoacoustic evaluation of rotary switches. Proceedings of IWSSIP 2008: 15th international conference on systems, signals and image processing, pp. 17–19, 2008
[8] JEON, J. et al.: Sound radiation and sound quality characteristicsof refrigerator noise in real living environments. Applied Acoustics Volume 68, 2007, pp. 1118–1134

ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering
ISSN: 2067-3809