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DIAGNOSTICS OF SOUND QUALITY IN THE INTERIOR OF A HYBRID CAR USING PSYCHOACOUSTIC MEASUREMENTS

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Abstract: In recent years, sound design has become one of the most important research topics in sound quality technology. Sound quality research, which focuses on how people perceive and evaluate sound, has gained attention especially in the automotive, transportation, and electrical appliance industries worldwide. This article focuses on the description of the methods used to evaluate sound quality and the application of an objective evaluation method. The subject of the measurements was a vehicle with a hybrid drive, and psychoacoustic parameters were measured at different vehicle speeds. With the development of noise monitoring technologies, sound quality research has gained attention, especially in the fields of automotive, transportation, industry and electrical appliances worldwide. The concept of product sound was strongly influenced by the automotive industry's need to design the sounds generated by vehicles to give the impression of high quality in every respect. The sounds generated by the car indicate certain aspects of how it works and these positive sounds are enhanced to compete with other car brands.
Keywords: Sound quality, psychoacoustics, hybrid vehicle, psychoacoustic parameters

INTRODUCTION

With the development of noise monitoring technologies, sound quality research has gained attention, especially in the fields of automotive, transportation, industry and electrical appliances worldwide. Intensive theoretical and experimental work on human perception of sound quality in the automotive industry has been carried out by companies such as Honda, Delphi, Ford, GM etc. Many car companies have optimized their product designs based on this research data. Researchers also discuss the impact of sound quality on airplanes, trains, and Maglev trains. Studies are also focused on air conditioners, refrigerators, washing machines, mobile phones, etc. [1][2]

Marketing studies have shown that customers pay close attention to sound quality not only in situations where sound is the primary object of interest, but also when sound is just a side effect of the product's operation.[3]

Sound quality studies in the automotive industry also focus on sounds such as the sound of a car door closing. Even this sound can contribute to the overall impression of the car, which is very important, because closing the door is one of the operations that the customer can perform when viewing the car in the dealer's hall. Etienne Parizet, Erald Guyader and Valery Nosulenko focused on the sound of the door closing in the article Analysis of car door closing sound quality. They analyzed the perception of the sound emanating from a car door closing, focusing on the image of the quality of the car that the listener might have in mind with this sound.[4]

SOUND QUALITY AND PSYCHOACOUSTICS

Noise can be defined as a disturbing or unpleasant sound. This subjective definition does not exclude any sounds, as essentially any sound can be distracting depending on many factors related to the listener. Noise as such is also interesting in the context of sound quality and also in the context of psychoacoustics. [5]

Blauert and Jekosh [6] define the sound quality of a product as "adequacy of sound in the context of a specific technical goal and/or task". For all products that produce perceptible sound, the sound quality of the product is assessed each time it is used.

The concept of product sound was strongly influenced by the automotive industry's need to design the sounds generated by vehicles to give the impression of high quality in every respect. The sounds generated by the car indicate certain aspects of how it works and these positive sounds are enhanced to compete with other car brands. In addition to engine sounds, product sounds for cars include sounds generated when various parts of the vehicle are used, such as windows opening, seat movements, sunroof opening, and button presses. Sounds and audio–tactile interaction when getting into the car are very important: unlocking the lock, using the door handle and closing the door create both auditory and tactile perception, which creates an impression of the quality of the car's finishing. The sound of the engine that is audible in the interior of the car should be designed so that it is not intrusive, although it must be audible over other sounds in the cabin, as it provides information about the operation of the engine. [7][8]

The most popular approaches to determining the sound quality of a product can basically be divided into two areas: subjective and objective evaluation [9][10].

The first of them emphasizes that sound can be subjective and sensitive for a person; the latter expresses sound in terms of an objective numerical value, such as physical acoustics and psychological acoustics [11].

ASSESSMENT OF CAR SOUND QUALITY

Sound engineering in research, development, but also in the production of cars represents a connecting link between physics (design characteristics, such as excitation, transmission, etc.) and psychology, which presents acoustic comfort, but also a feeling of health and well–being. The driving comfort of a particular car is understood as the perception of the effect of comfort features through one or several channels of perception in each person: visual (sight), auditory (hearing), haptic (tactile), olfactory (smell).

The individual perception of a person is very subjective, and therefore it can only be described incompletely using purely physical and objectively measured quantities. It depends both on the characteristics of the car that is being observed, on the specific experienced situation, but also on the socialization of the evaluating person and the surrounding environment in which the evaluation process takes place. Each car is characterized by its typical acoustic properties, which are e.g. the sounds of a stationary car (interior and exterior sound), engine sounds during different driving modes (slow, fast, interrupted, smooth driving, etc.) also play an important role in the so–called functional sounds (sound of rear–view mirror adjustment, window lowering sound, seat adjustment sound, sunroof opening sound and more). The comfort of driving a car is also affected by spontaneously occurring sounds (e.g. whistling, rattling, screeching, etc.), which together create a qualitative impression of the well–being of driving a car (driving comfort), which is perceived by the car crew. [12][13]

Subjective evaluation methods

The goal of psychoacoustics research is man and his perception of sound. Unlike general acoustics, where data is obtained using microphones or other devices that are calibrated, psychoacoustics uses the person as the only instrument ("measuring instrument"). However, a person cannot be calibrated in the same way as e.g. microphone. In the case of the application of psychoacoustic listening tests, the emphasis is placed on the answers of people (evaluators) and it is worked as if calibrated microphones were not available. In data analysis, statistical analysis plays an important role, and for testing purposes it is always required that a statistically significant (relevant) sample of evaluators be available. [14]

The subjective perception test is a basic procedure for obtaining the sound quality character of sound events and for developing parametric models that describe sound quality quantities. Two methods are commonly used. The Semantic Differential Method, developed by Osgood in 1957, offers a quick way to measure people's attitudes and emotional connotations of concepts. A range of indices of semantic differential were studied, including safe–dangerous, satisfied–dissatisfied, quiet–noisy, friendly–hostile, close–distant, and happy–sad. This method has been applied to various problems in marketing, personality measurement, clinical psychology, intercultural communication, and auditory perception of sound signals. The Paired Comparison method offers a simple way to present people's attitudes using a sequence of pairs of sounds A and B. For each pair, people have to decide which sound they prefer. [15] [16]

Objective evaluation methods

In recent times, for the purposes of psychoacoustic measurements, technical means are also being increasingly promoted. They are highly sophisticated systems, developed to measure selected psychoacoustic parameters with highly specialized software support. Perceiving sound through two ears is called binaural hearing. It is the ability to hear sounds from the left ear and the right ear in parallel and the ability to locate the direction of the incoming sound. This type of hearing strongly depends on the geometric parameters of the human body (ears, head and trunk). [17][18]

Important and highly effective technical means for measuring psychoacoustic parameters include the so–called "artificial head" (or psychoacoustic head). (Figure. 1) It is an identical figure with a human head. The psychoacoustic head has two microphones that are installed in the ears. It is characterized by the same acoustic and auditory properties as the human head. The goal is to achieve a state so that the evaluator of the quality of the sound event, who listens to the audio recordings obtained from the psychoacoustic head, has the impression that he is part of the space of the acoustic event. [19]

Various feelings or perceptions can be displayed as using psychoacoustic parameters of perception, as well as using auditory thresholds of perception, which can be determined using psychoacoustic methods. Psychoacoustic parameters such as roughness, loudness, tonality, sharpness and fluctuation of strength are referred to as "classical" psychoacoustic parameters. Other parameters related to hearing are also known, such as height, color, subjective duration and others. [20]

Figure 1. Psychoacoustic head

PSYCHOACOUSTIC EXPERIMENT – MEASUREMENT OF SELECTED PSYCHOACOUSTIC PARAMETERS IN THE INTERIOR OF A HYBRID VEHICLE

The aim of the measurements carried out using a binaural measuring device, the so–called psychoacoustic head, was to determine the values of selected psychoacoustic parameters under conditions of different car speeds. The subject of the research was the vehicle Suzuki Vitara Hybrid. (Figure 2.)

Figure 2. Suzuki Vitara Hybrid

The psychoacoustic head was placed in the interior of the vehicle in the position of the passenger on the front seat. The location of the psychoacoustic head in the test vehicle is shown in Figure 3.

Figure 3. Placement of the psychoacoustic head in the vehicle

Measurements were performed at speeds of 30 km/h, 50 km/h, 90 km/h and 130 km/h. The section of the road where the measurements were taken is shown in Figure 4.

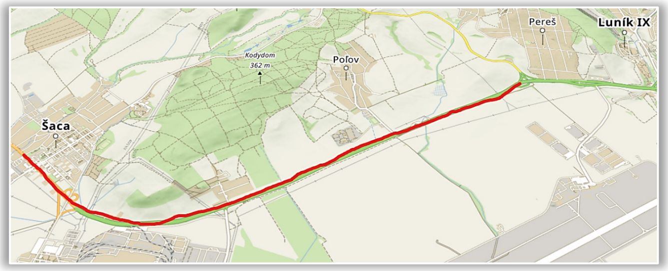


Figure 4. The section of the road where the measurements were performed

RESULTS OF MEASUREMENTS

The obtained results of measurements of psychoacoustic parameters at specified speeds for the right and left ear together with their average values for vehicle Suzuki Vitara are shown in Table 1.

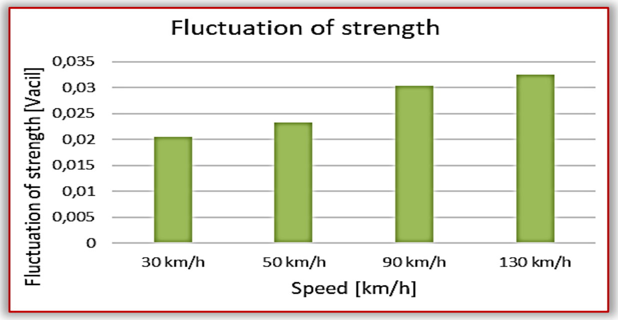
The results show a difference in values between the left and right ears, with the values in the right ear being higher than those in the left ear. These differences can be attributed to the location of the psychoacoustic head in the vehicle, which was placed on the passenger seat, and thus her right ear, in which the values were higher, was closer to the surrounding environment than the left ear, which faced the interior of the vehicle.

Table 1. Results of measurements of psychoacoustic parameters

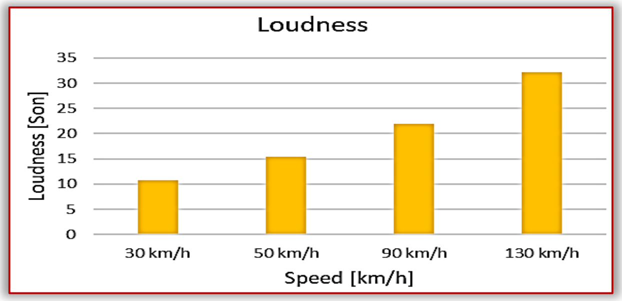
Speed	Microphone	Fluctuation of strength		Loudness	
			Average L-R		Average L-R
30 km/h	Left mic.	0,0199	0,02055	10,4	10,8
30 km/h	Right mic.	0,0212		11,2	
50 km/h	Left mic.	0,0232	0,02335	15	15,45
50 km/h	Right mic.	0,0235		15,9	
90 km/h	Left mic.	0,0298	0,03035	21,2	22
90 km/h	Right mic.	0,0309		22,8	
130 km/h	Left mic.	0,032	0,03255	31,3	32,15
130 km/h	Right mic.	0,0331		33	

Speed	Microphone	Roughness		Sharpness		Tonality	
			Average L-R		Average L-R		Average L-R
30 km/h	Left mic.	0,0302	0,03045	0,597	0,6015	0,245	0,3165
30 km/h	Right mic.	0,0307		0,606		0,388	
50 km/h	Left mic.	0,0358	0,0379	0,789	0,791	0,222	0,1865
50 km/h	Right mic.	0,04		0,793		0,151	
90 km/h	Left mic.	0,0492	0,0495	0,968	1,009	0,15	0,12185
90 km/h	Right mic.	0,0498		1,05		0,0937	
130 km/h	Left mic.	0,0541	0,0562	1,3	1,375	0,239	0,187
130 km/h	Right mic.	0,0583		1,45		0,135	

In Figure 5, we can see the graphs of the total values of individual psychoacoustic parameters.



(a)



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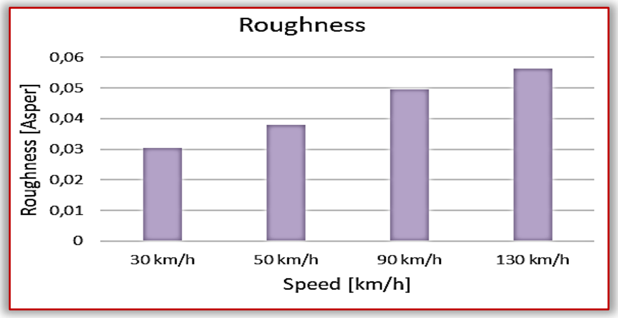

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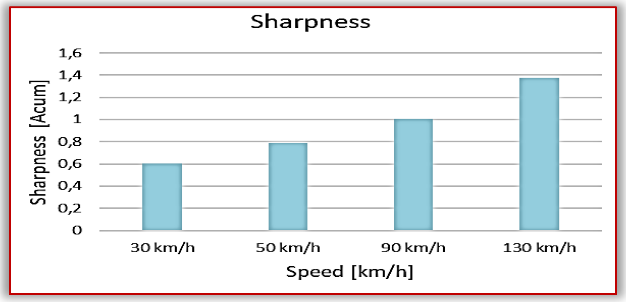

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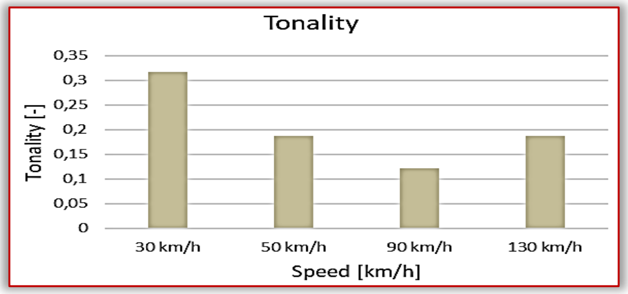

(e)

Figure 5. Graphs of the total values of individual psychoacoustic parameters

Based on the measured results, we can see that the values of most monitored parameters grew with increasing speed. The exception in this case was the Tonality parameter. Here we can see that this parameter even decreased up to a certain speed and started to rise suddenly only at a speed of 130 km/h.

CONCLUSIONS

The overall perception of the quality of the car is significantly influenced by its characteristics regarding noise in the interior. Therefore, it is important to find a balance between "pleasant" and "dynamic" sound that meets the customer's requirements with regard to the brand and class of the vehicle. The driver, passenger or customer perceives the car interactively and also through several senses in parallel. Customers, drivers and passengers form their perception of the quality of a particular car as a result of sensory impressions that are inextricably linked. Car sound assessment is currently taking on another new dimension, that of interactively influencing the sound. The effort is to arrive at the conceptual formation of vehicle acoustics (active sound design). Psychoacoustics can be considered a very suitable tool for assessing and optimizing the acoustic properties of various products. When applying objective methods during the experimental measurement of psychoacoustic parameters, it was found that the psychoacoustic parameter values are influenced by the speed of the vehicle in the vehicles that were the subject of the research. For most parameters, psychoacoustic parameter values increase with increasing speed. These values are also influenced by the location of the psychoacoustic head in the vehicle, when different values can be seen between the left and right ear.

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