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ANALYSIS OF THE SOUND OF CARS WITH FOSSIL AND ELECTRIC DRIVEN BY PSYCHOACOUSTIC METHODS

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Abstract: One of the practical applications of psychoacoustics is the evaluation of sound quality. Sound quality assessment has been the domain of the music and audio industry for years. Driving comfort in cars is becoming an increasingly important demand of customers. In addition to many other properties, emphasis is also placed on oscillatory and vibrational acoustic properties – the so–called HVP (Noise, Vibration, Transmission) characteristics of the vehicle. The article is focused on the assessment of psychoacoustic parameters in the interior of selected types of vehicles. Measurements were made on vehicles with gasoline, diesel and electric engines. Five psychoacoustic parameters were measured and a psychoacoustic head was used for the measurement. The measurements were carried out at different speeds and the measured values were processed and evaluated.
Keywords: sound; noise; psychoacoustics; car; powertrain

1. INTRODUCTION

Psychoacoustics, as a relatively new field of acoustics, deals with the subjective perception of sound, its effect on a person and the analysis of its possible effects. More precisely, it is a science that studies the psychological reactions associated with sound (including noise, speech and music). Psychoacoustics is an interdisciplinary field of many fields, including psychology, acoustics, electronic engineering, physics, biology, physiology, and computer science [1,2].

One of the practical applications of psychoacoustics is the evaluation of sound quality. Sound quality assessment has been the domain of the music and audio industry for years. Since the mid–1980s, however, it has become the subject of interest in other sectors of consumer goods, especially the automotive industry. 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. The sound quality concept suggests that the noise control is not only to reduce the sound pressure level, but more importantly, the products can be adjusted according to the subjective feeling of the customer. Driving comfort in cars is becoming an increasingly important demand of customers. In addition to many other properties, emphasis is also placed on oscillatory and vibrational acoustic properties – the so–called HVP (Noise, Vibration, Transmission) characteristics of the vehicle [3].

Recently, the requirements for the properties of HVP have been increasing intensively. It is necessary to prevent the penetration of various sounds generated by various components of the car, as well as sounds from the surroundings into the interior of the vehicle. The most popular approaches to determining the sound quality of a product can basically be divided into two areas: subjective and objective evaluation [4,5]. 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 [6].

2. APPLIED METHODS OF MEASURING NOISE IN THE INTERIOR OF CARS

With the help of psychoacoustic quantities of perception and auditory thresholds of perception, which are determined using psychometric methods, various feelings can be displayed.

Sound quality assessment is carried out in two ways, which can be classified into two categories:

- subjective psychoacoustic assessment methods,
- objective psychoacoustic assessment methods. [7]

Objective assessment

Psychoacoustic parameters are used to describe different sounds caused by different subjective feelings about objective physical quantities. In the objective test, there are four international general main parameters: loudness, sharpness, roughness and fluctuation of strength [8,9].

Among the important and highly effective technical means of measurement psychoacoustic parameters include the so–called "artificial head" (or psychoacoustic head). It is an identical form with a human head. The psychoacoustic head (Figure 1) 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 where the

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evaluator of the quality of the sound event, who listens to the audio recordings obtained from psychoacoustic headphones, the impression that it is part of the space of acoustic events. [10,11]

Figure 1. Various options for making the psychoacoustic head

Subjective assessment

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 [12]. Two methods are commonly used . The method of semantic differential (SD) and the method of paired comparison. [13,14] The semantic differential method was created by Osgood in 1957 [15] and offers a quick way to measure people's attitudes and the emotional connotation of concepts. A number of indices of semantic differential are studied, including safe–dangerous, like–dislike, quiet–tumultuous, friendly–hostile, and happy–sad [16–18]. This method has been applied to various problems in marketing, personality measurement, clinical psychology, intercultural communication and auditory perception. The Paired Comparison (PC) method developed by David [14] offers a simple way to present people's attitude using a sequence of sound pairs A and B, where for each pair people have to decide which sound they prefer. [19]

3. MEASUREMENT OF SELECTED PSYCHOACOUSTIC PARAMETERS IN THE VEHICLE INTERIOR

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 in conditions of different car speeds when using gasoline, diesel and electric vehicles. The subject of the research were three passenger cars of the same brand, same model with different engines (gasoline, diesel, electric). Specifically, it is the Volkswagen Golf Edition Highline 1.5 TSI ACT 6G – 110 kW/150 hp, the Volkswagen Golf 2.0 TDI – 100 kW/150 hp and the Volkswagen eGolf – 100 kW/136 hp. Sound signals obtained at speeds of 50 km/h, 90 km/h, 110 km/h and 130 km/h were used.

Figure 2. Cars used in the measurements

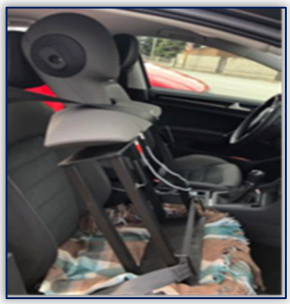

Figure 3. Placement of the psychoacoustic head in the tested vehicles

Figure 4. Measuring sections on the R4 expressway and the road in the Kechnec Industrial Park

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 tested vehicles is shown in Figure 3.

Sound signals obtained at speeds of 50 km/h, 90 km/h, 110 km/h and 130 km/h were used. In the picture you can see where the measurements took place. (Figure 4)

4. MEASUREMENT RESULTS

The obtained measurement results, including the average values of the psychoacoustic parameters at the specified speeds for the right and left ears, are presented in Table 1, Table 2 and Table 3.

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Table. 1 Values of psychoacoustic parameters for the left and right ear in a gasoline vehicle

	VW Golf – Gasoline									
	Sharpness (S) [acum]		Roughness (R) [asper]		Tonality (T) [tu]		Loudness (N) [son]		Fluctuation of strength (F) [vacil]	
Speed	Mic L	Mic R	Mic L	Mic R	Mic L	Mic R	Mic L	Mic R	Mic L	Mic R
50 km/h	0,698	0,795	0,0309	0,0366	0,423	0,376	11,5	13,1	0,0127	0,0155
90 km/h	0,902	1,05	0,0406	0,047	0,173	0,149	17,1	19,1	0,0154	0,0154
110 km/h	1,04	1,28	0,041	0,0455	0,65	0,626	21	24,8	0,014	0,0157
130 km/h	1,3	0,55	0,049	0,0508	0,292	0,6	27,6	32,9	0,0169	0,0173

Table. 2 Values of psychoacoustic parameters for the left and right ear in a diesel vehicle

	VW Golf – diesel									
	Sharpness (S) [acum]		Roughness (R) [asper]		Tonality (T) [tu]		Loudness (N) [son]		Fluctuation of strength (F) [vacil]	
Speed	Mic L	Mic R	Mic L	Mic R	Mic L	Mic R	Mic L	Mic R	Mic L	Mic R
50 km/h	0,888	0,713	0,0355	0,0365	0,707	0,644	12,1	13,2	0,0262	0,0281
90 km/h	0,882	0,96	0,0442	0,0465	0,183	0,0966	18,2	19,4	0,021	0,0231
110 km/h	1,04	1,13	0,0462	0,0472	0,914	0,161	21,6	23,8	0,0259	0,024
130 km/h	1,1	1,2	0,0468	0,0502	0,0548	0,289	24,5	26,4	0,0287	0,0303

Table. 3 Values of psychoacoustic parameters for the left and right ear in an electric car

	VW Golf – electric									
	Sharpness (S) [acum]		Roughness (R) [asper]		Tonality (T) [tu]		Loudness (N) [son]		Fluctuation of strength (F) [vacil]	
Speed	Mic L	Mic R	Mic L	Mic R	Mic L	Mic R	Mic L	Mic R	Mic L	Mic R
50 km/h	0,715	0,78	0,0312	0,033	0,252	0,467	10,1	12,1	0,0223	0,0272
90 km/h	0,953	1,03	0,0399	0,0435	0,125	0,0931	15,2	17,1	0,0253	0,0262
110 km/h	1,07	1,16	0,0396	0,0444	0,115	0,103	18	20,4	0,0195	0,0209
130 km/h	1,2	1,29	0,045	0,0482	0,122	0,131	22,8	25,6	0,0173	0,0189

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, where the values were higher, was closer to the surrounding environment than the left ear, which was directed into the interior of the vehicle.

In the following section, graphs of the dependence between speed and psychoacoustic parameter values can be seen.

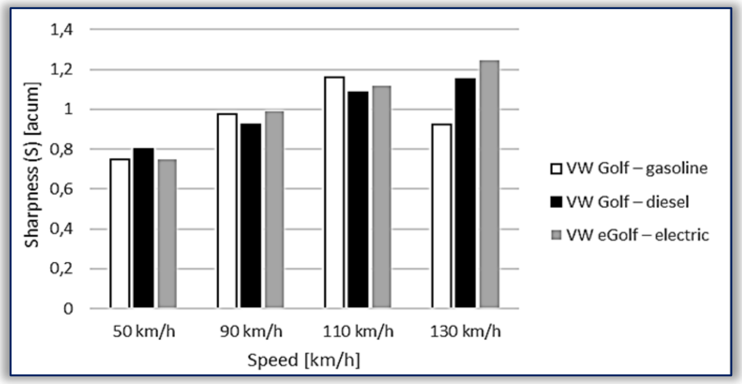

Figure 5. Dependence of sharpness on vehicle speed

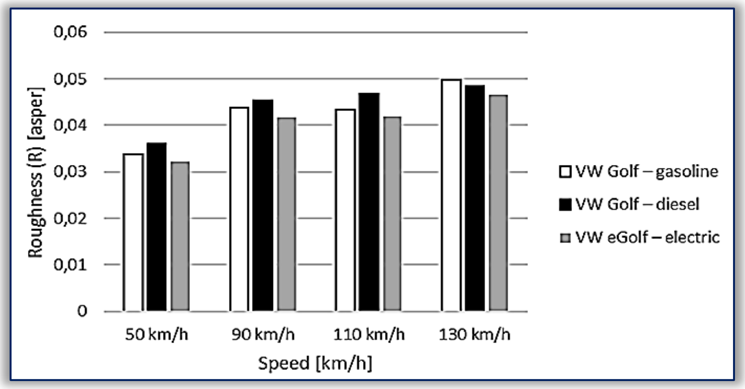

Figure 6. Dependence of roughness on vehicle speed

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Based on the results obtained from the performed sound measurements, it can be concluded that the psychoacoustic parameter "sharpness" with increasing speed tends to grow almost linearly for all types of motorization. The highest sharpness value was measured with an electric motor. The sharpness values of the diesel engine constantly move between the sharpness values for gasoline and electric motors (Figure 5).

Based on the obtained results from the measurement of the psychoacoustic parameter "roughness", it can be concluded that this parameter has a growing tendency for all types of motorization with increasing speed. This fact applies up to a speed of 110 km/h. The highest roughness value can be observed for the diesel engine, lower for the gasoline en–gine. And the lowest for an electric motor. (Figure 6).

Measurements of the psychoacoustic parameter "tonality" have shown that the tonal–ity of a car with a diesel engine reaches the highest values at lower speeds. Subsequently, it tends to gradually decrease at higher speeds from 130 km/h. rise again. In the case of the gasoline engine, the lowest tonality value was found at a speed of 90 km/h. The highest value of the monitored parameter was found at a speed of 110 km/h. with increasing speed, the tonality tended to decrease. In a car with an electric drive, the psychoacoustic parameter tonality increases at lower speeds, decreases with increasing speed, and is almost constant at higher speeds (Figure 7).

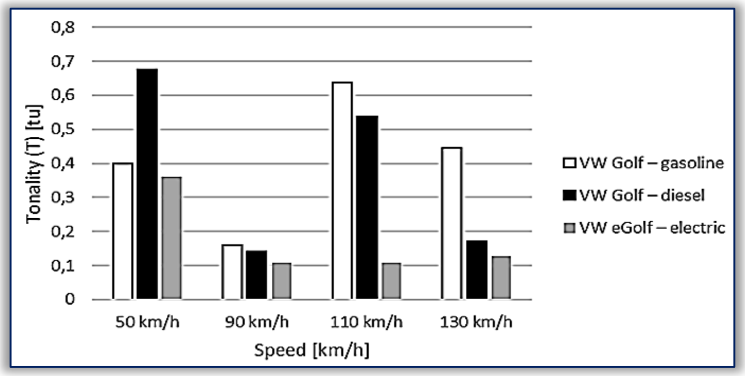

Figure 7. Dependence of tonality on vehicle speed

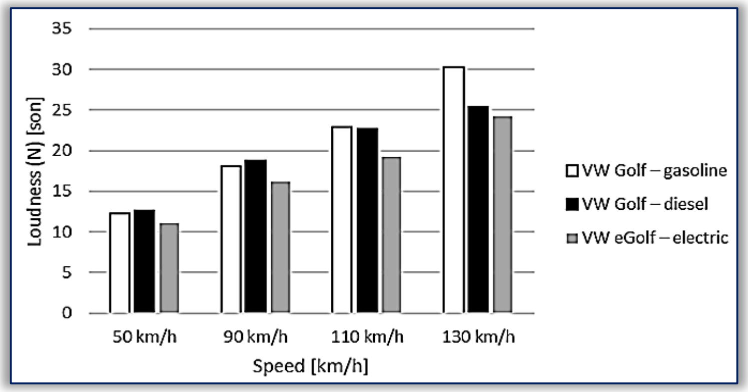

Figure 8. Dependence of loudness on vehicle speed

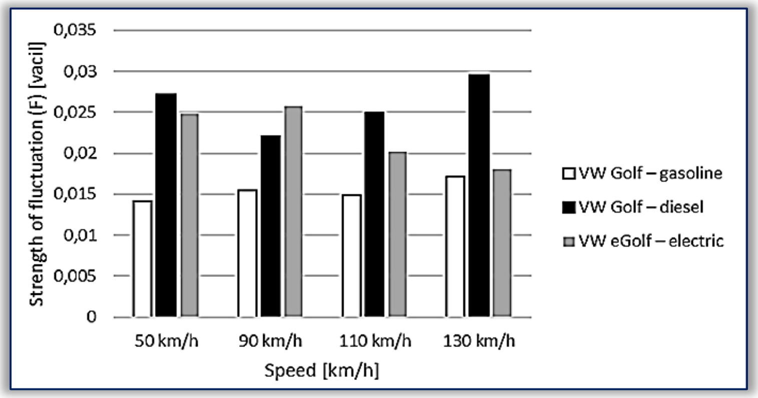

Figure 9. Dependence of strength of fluctuation on vehicle speed

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Based on the sound measurements of cars with different engines, it can be concluded that the psychoacoustic parameter "volume" increases linearly with increasing speed in the case of all three drives. (Figure 8)

The results of measurements of the psychoacoustic parameter "strength of fluctuation" proved that the observed parameter in the case of gasoline engines is stable and almost constant. In the case of a diesel engine, the parameter at a speed of 90 km/h. decreases and subsequently increases linearly with increasing speed. In the case of electric motorization, the monitored parameter rises again with increasing speed. After reaching a speed of approximately 90 km/h (Figure 9).

5. CONCLUSION

On the basis of the presented results, it can be concluded that the values of the psychoacoustic parameters are influenced by the speed of the vehicle as well as the motorization of the vehicle. For most parameters, the values of psychoacoustic parameters increase with increasing speed. However, from the motorization point of view, it affects individual parameters differently and at different speeds. From the point of view of motorization, a direct proportionality between motorization and the values of psychoacoustic parameters is not visible.

Differences in values between the left and right ear can also be seen. These differences can be attributed to the position of the head in the vehicle when one ear was closer to the environment, air flow, tire sound, etc. In addition to speed and motorization, the position of the head in the vehicle also affects the values of psychoacoustic parameters.

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