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METHODS FOR AN ACCEPTABLE TRAFFIC NOISE LEVEL DESIGN

SUMMARY

Road noise disturbance on rough roads by means of loudness sensor caused by wideband signal components with a significant impact of tonal effects on smooth roads and in specific actions in driving lead to the annoyance of drivers. A systemic approach has been applied for the sound quality estimation of physical properties of various noise sources and structural vibroacoustic car properties and its components as an integrated parameter in car design for the purpose of the development and vehicle noise reduction. Simulation of the most important characteristics of listening impressions was performed by modern systems of signal analysis together with the presentation of loudness, sharpness, and roughness as essential quantities. Optimization of the noise control measuring regarding vehicle sound was obtained by means of a simulation system with the capability of the real time original sound filtering. Structural analysis was performed as an acoustic modal analysis on the rear part and the car interior with the quantitative analysis of sport and luxury car sounds. The possibility of active noise control was studied and examples are given for an application of psychoacoustic tools for car sound quality design. Sound quality was obtained by an observation of certain aspects, which are empirically or theoretically connected with the design. An experimental sound synthesis with psychometrical measuring was applied. The sound quality of car interior is presented taking into consideration the criteria of objectivity, reliability and validity.

KEY WORDS

sound quality evaluation, traffic noise, active noise control, noise patterns, annoyance index, optimisation of noise control

1. INTRODUCTION

Sound is a phenomenon of concentration and dilution of particles in a flexible medium synchronous with their displacement from the balance position. The study of a certain sound phenomenon leads to the understanding of temporal characteristic of the sound pressure. By means of the Fourier's integral, we analyze the non-periodical processes.

$$f(x)=\frac{1}{\pi}\int d\lambda \int f(\xi)\cos\lambda(x-\xi)d\xi \qquad (1)$$

where f(x) is Fourier's integral formula and the Fourier's integral.

If sound consists of a basic tone and a smaller or larger number of harmonic tones, it is called the complex (harmonic) sound.

The noise spectrum is of a continued structure as it contains an infinite sequence of spectral components with an accidental amplitude change in time.

Air particles behaviour under the influence of sound waves is determined by the physical values such as sound pressure and speed.

In the physical sense the sound consists of intensity, frequency and amplitude spectrum. In the area of hearing perception these characteristics correspond to the intensity (loudness), pitch and colour as psychoacoustic values of the hearing sensation.

The differential threshold of hearing perception is proportional to the differential threshold of the stimulus intensity, which is the general psychophysical Weber-Fechner law.

$$\Delta S=k\left(\frac{\Delta I}{I}\right) \qquad (2)$$

The pitch level is measured in mels. Mel is the ratio of change of the pitch level sensation and the change of frequency value. It has been agreed that 1000 mels present the pitch level of 40 phons/dB at 1000 Hz.

The dependency of mel and the frequency are obtained by experimental measuring in which the listeners (subjects), starting from 1000 mels judged the frequency of the two times higher pitch (2000 mels) and the frequency of the two times lower pitch (500 mels). Up to 500 Hz the dependency is linear, but over 500 Hz for equal change of mel, the frequency grows faster.

A complex sound contains components which occupy the whole hearing area, and stimulates the vibration of all parts of the basilar membrane. Its strength is not received as a whole but as 24 frequency bands. The tone group within each band makes up a unit of one Bark, which means that in the hearing range there are 24 Barks. One Bark corresponds to 1.3 mm length of the basilar membrane. The ratio between the Bark and mel is 1:1000.

The Bark scale has a linear relation according to the physiological parts of the human auditory system, that is the basilar membrane length in the interior of the human ear.

Time variations of sounds may lead to two different sensations: sound intensity fluctuation at low frequency variations and roughness at higher frequency variation.

Although there is a strict border between intensity and roughness fluctuation, for modulation frequencies higher than 20 Hz, the fluctuation of intensity and roughness disappears. The intensity fluctuations are given as a function of frequency modulation, at which the intensity fluctuation depends on the modulation depth.

As result of the excitation of two tones of close frequencies f_1 and f_2 and minimum intensity variations on the basilar membrane, the corresponding place of the basilar membrane will vibrate with a variable intensity in the rhythm of the frequency difference $(f_1 - f_2)$ and the effect of signal source perception will be obtained.

With the increased difference in frequencies of two tones the source signal is perceived as roughness.

2. CAR ROAD NOISE

A classical problem with car noise optimization is the road noise issue. Generally speaking, the road noise phenomena lead to the annoyance of drivers.

Annoyance on rough roads may be described by noise sensation caused by the wideband signal components.

Only on smooth roads and for specific actions like curving, the tonal effects are more significant. In this case, the loudness sensation is described as a "booming" effect, especially prominent on the rear seats, because of the vehicle rear mount impact.

The frequency of such loudness can be allocated to the 60-120 Hz by filtering. Significant importance of the rear axle mount has been identified as cause of noise propagation.

Measuring the noise level in the range of 20-300 Hz, according to Figure 2.1, indicates the car interior noise spectrum with partial rear axle weight under the standard driving conditions (x, y and z directions separately as well as combined).

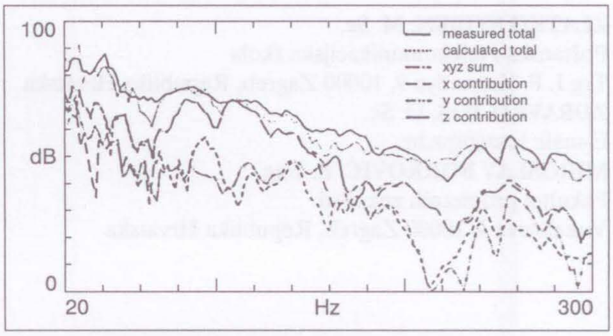

Figure 2.1 - Car interior noise; analysis of the rear axle mount contribution

We can see great contribution to the car interior noise due to the z direction within the range of 80-120 Hz. Within that frequency range the car mount vibrations are the largest.

The solution to the problem lies in design modifications which include the movement of the axle resonance.

An alternative solution suggests hardening of side links, which would result in reduced transmission of induced suspension vibrations in the vehicle cabin.

3. ANNOYING NOISE OF THE EXHAUST SYSTEM

The exhaust system sound also contributes to the annoying noise of cars, and the effect of the third harmonics is particularly prominent here.

An analysis of sport and luxury cars exhaust system shows for the speed range of 3000 revolutions per minute an impact of the third harmonics of the noise loudness.

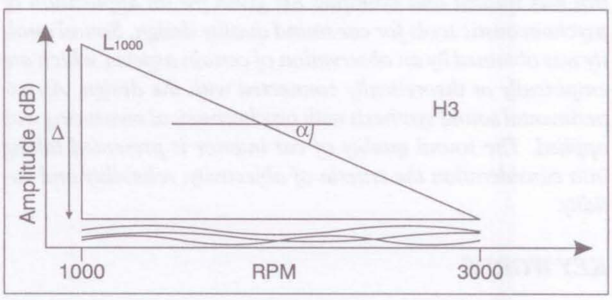

Figure 3.1. - Qualitative analysis of sport and luxury cars exhaust noise for the speed range below 3000 rpm

The third harmonic behaviour, as contrast to other harmonics and subharmonics may be described as a triangle scheme in the speed range of 1000-3000 rpm, at which the harmonics noise is dominant.

According to Figure 3.1. we can see that the slope of the third harmonic (α), the ratio of the third harmonic to other harmonics at 1000 rpm (Δ) and the absolute value of the amplitude of the third harmonic at 1000 rpm

(L_{1000}) have a dominant impact on the exhaust system noise. These three parameters are quantitatively different for the sport and luxury cars sound.

4. CAR INTERIOR SOUND QUALITY ANALYSIS

The sound quality within the car cannot be observed directly, but it can be obtained by observation of individual processes empirically or theoretically related to the design.

Measuring should take into consideration the criteria of objectivity, reliability and validity, that is, they should give the same result when applied several times to the same set of sounds.

The sound quality within a car refers to the perception of sound pleasantness and engine powerfulness.

Both factors are observed at standard driving situations: opened throttle, part load, and constant speed. Psychophysical methodology requires the subject to judge the intensity of sensations caused by an object relative to the standard object, which serves as a fixed standard during a whole series of judgments.

Figure 4.1. presents the results in the coordinate system for a set of sounds of five different vehicle categories; small, middle, luxury, sport and truck, by means of comparison described as pleasant/unpleasant, powerful/weak.

The figure demonstrates that the sound pleasantness decreases with the increase of power. The first and the second quadrant (pleasant-strong, pleasant-weak) refer to luxury cars and middle type cars, while luxury cars hold the highest position in the sound pleasantness.

The sensation of engine power in the sound we hear with the engine running depends on the engine volume, the number of revolutions per a minute (engine speed) and the number of cylinders. This effect is particularly present in the low frequency area, so it is possible to increase the power perception in that area by means of experimental increase of those factors.

The increase of powerfulness will lead to the reduction of pleasantness.

The sounds which present high power demonstrate an increase of loudness in the first and fourth quadrant, while the loudness is reduced in the second and third quadrant.

The comparison of the sound generated in a driving car with the basic sound at the increased loudness results in an unaffected pleasantness under 3 and 6dB conditions, whereas powerfulness is increased already at 3dB. In 6 to 12dB conditions powerfulness continues to increase while pleasantness is reduced. Therefore, within the range of 3-6dB balancing of pleasantness is possible whereas any further increase of loudness over 6dB will result in reduced pleasantness.

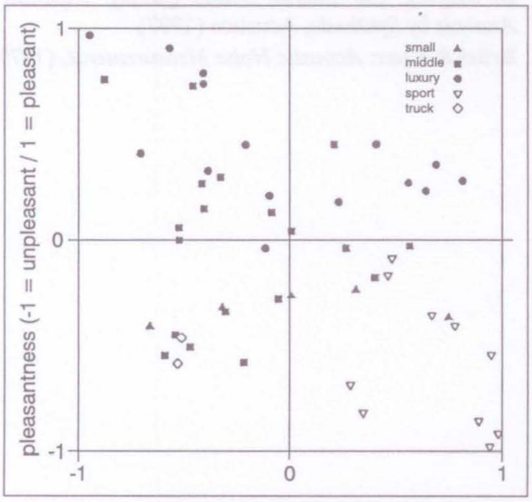

Figure 4.1. - Scattering of a set of car sounds within the four quadrants of pleasantness and powerfulness perception

5. SOUND OPTIMIZATION

Sound optimization follows sound evaluation. A fast method to find an optimal sound is the digital signal processing method until the sound optimization criterion is reached.

Most programs also offer signal manipulation and signal generation method. Some modifications may be performed in real time, whereas others must be calculated separately, depending on the hardware power and desired modification degree.

In the sound modification process, a connection with the physical sound source should be kept in mind and we should be able to modify the product to produce the desired sound. In addition, the interaction aspect between the sound source and the user cannot be adequately considered with these systems. Evolution is based on fixed recordings estimated by a listener or an instrument without interaction with the product.

6. CONCLUSION

The noise quality in the car is very important for the development and improvement of its characteristics. The system approach for the estimation of physical properties of sound quality for various noise sources and structural vibroacoustic properties of a car and its components are essential in order to use the sound quality not only as an idea of sound evaluation but as an integrated parameter in car design.

Levels of weight values, particularly if they are used as an indicator, are insufficient for the estimation of audible variations in sound quality. In practice, not only qualitative but also quantitative correlation is necessary between subjective evaluation and physical measuring. Only from the results of the psychoacoustic analysis, we are able to obtain an evaluation in accordance with the subjectively achieved reduction of sound control measuring.

The results indicate that for the impulsive sounds of car interior, psychoacoustic quantities of loudness, sharpness, pitch and roughness should be taken into consideration.

The most essential characteristics of essential hearing impressions may be stimulated by current signal analysis systems of non-periodical functions.

For the sound quality design, the received or accomplished sound impression plays an important role. The noise control measuring may be optimized regarding the sound of a vehicle or a specific product by means of a simulation system with the capability of the real time filtering of the original sound.

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SAŽETAK

METODE ZA DIZAJN PRIHVATLJIVE RAZINE BUKE U PROMETU

Ometanje cestovnom bukom na hrapavim cestama pomoću osjeta glasnoće prouzrokovane širokopojasnim signalnim komponentama uz značajniji utjecaj tonalnih efekata na glatkim cestama i kod specifičnih akcija u vožnji. Sistematski pristup za procjenu kvalitete zvuka fizikalnih karakteristika različitih izvora buke i strukturalnih vibro-akustičkih osobina auta i njegovih komponenata kao integrirani parametar u dizajnu auta u svrhu razvoja i smanjenja buke vozila. Simulacija bitnih obilježja neophodnih slušnih impresija modernim sustavima analize signala uz prikaz glasnoće, oštrine i hrapavosti kao bitnih kvantiteta. Optimizacija mjerenja kontrole buke s obzirom na zvuk vozila korištenjem sustava simulacije sa sposobnošću filtriranja pravog vremena originalnog zvuka. Izvedba strukturalne analize kao akustične modalne analize i to na stražnjem i na unutarnjem dijelu auta uz kvalitativnu analizu zvuka sportskih i luksuznih kola. Omogućavanje kontrole aktivne buke eliminacijom neželjenih akustičnih efekata Primjeri primjene psiho-akustičkih alata za dizajn kvalitete zvuka u automobilu. Izvođenje kvalitete zvuka putem promatranja pojedinih aspekata koji su empirijski ili teoretski povezani sa konstrukcijom uz primjenjivanje strategije eksperimentalne sinteze zvuka psihometrijskom izmjerom. Reprezentiranje kvalitete zvuka unutar automobila uzimajući u obzir kriterij objektivnosti, pouzdanosti i valjanosti.

KLJUČNE RIJEČI

vrednovanje kvalitete zvuka, prometna buka, aktivna kontrola buke, uzorci buke, indeks ometanja, optimizacija kontrole buke

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