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COMPOSITION OF CHARACTERISTIC VEHICLE INTERIOR SOUND - DEVELOPMENT PROCESS WITH RESPECT TO THE POWER TRAIN

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1. Abstract

Looking to worldwide automotive development strategies it must be recognized that development targets tend to unify. High vehicle performance and a superb quality are the leading future targets for all car manufacturers. Therefore noise behaviour is undoubtedly an important topic for passenger vehicle concepts. Nowadays it is a demand of product marketing to tune the in-vehicle noise according to the vehicle type and the driving conditions. This article gives an overview of today's demands on noise quality. Computational sound synthesis as well as practical design methods are described. Technical measures to fullfill these demands will be figured out and examples of different hardware measures will be discussed.

2. Demands on noise quality

In the past cars mainly were designed for low interior and exterior noise level. Therefore, all components emitting noise were significantly improved. Based on such low noise levels, car developers have to realize that the customer expects special vehicle interior noise characteristics. Future vehicles will be developed to a specific and individual sound. The sound design work will be focused on the interior sound. Exterior sound will primarily be developed for idle and starting up conditions. Legislative restrictions on exterior noise energy levels must also be fulfilled. The consumer expected intèrior-sound characteristic depends on the vehicle-type as well as on the driving conditions [1], [2]. Therefore, the target sound has to be comfortable primarily for luxury vehicles and constant driving conditions (Fig. 1), and more powerful for sportive vehicles, namely in acceleration. Especially in interactive driving conditions, e.g. during overtaking other cars, drivers expect a powerful and dynamic sound. Unregular noise components, typically may be misunderstood as technical defects. The regularity of the engine sound has to be matched with the driving conditions. Sound continuity during cruising gives the feeling of good product reliability. Judgements of sound quality during accelerating always show, that noise perception generally varies between two extrema. Vehicle noise either exposes a pleasant/ luxury or a powerful/sportive character, as shown in the psychometric map (Fig. 2). It is evident that vehicles in the first quadrant - featuring a balanced sound characteristic between luxury and sportiveness, pleasant and powerful, respectively - are only rarely represented [3]. The sound engineer has to take into account the different aspects of sound perception and should balance them to achieve an interior noise characteristic considering the vehicle's image. The sound should express the character of the product. So, if it is remarkable for a special vehicle, a characteristic sound will assist in marketing and sales.

3. Sound development process

The sound development process covers two parts elaborated simultaneously:
1) Basic Analysis and Sound Cleaning
2) Sound Design Work

starts by figuring out typical sound portions, as they are relevant for the characteristics like impulsiveness, modulations or engine orders (Fig. 3). Impulsiveness and outstanding engine orders mostly create an unpleasant effect. Modulations in the time history of the noise signal, known as roughness, usually also create an unpleasant sound. If the roughness intensity is not too high and not yet disturbing, however, roughness can create a dynamic sound perception.

Based upon the relevant signal portions next a target sound has to be defined [4], [5], [6], [7] (Fig. 3). Therefore, the vehicle interior noise is to be designed synthetically. Sound manipulation must be based upon technical experience and powertrain / vehicle hardware potential. Computer-based tools for sound manipulation and sound synthesis are used for tuning the synthetic sound composition. These systems allow for a simultaneous and engine map related gain the increasing or decreasing of up to 20 individual engine orders. However, the hardware potential is figured out by vehicle and engine development, originally aimed at a detailed level reduction on all individual powertrain and vehicle components. This detailed improvement potential is the data base for the synthetical manipulations. It is important that NVH Development Sound Synthesising is carried out simultaneously to figure out the full potential of technical design solutions for a realistic setting of target sounds. Only consequent simultaneous engineering will provide success. Examples shown for sound-related hardware modifications could be modified exhaust or intake system dampers, stiffnesses of the crank case structure as well as modifications of the crank system. The evaluation of the subjective sound impression of synthesised noise signals will be determined by audio demonstrations via headphones to representative evaluators. These persons give their subjective judgement on the noise quality. Thereby, a statistical definition of a realistic, hardware orientated target sound is provided [3], [7].

4. Typical sound characteristics

The basis of the subjective judgements of the sound quality is classical acoustic signal analysis to describe those typical signal characteristics, which are relevant for acceptance and dynamic of the sound e.g.. The interior sound will not be accepted if there are tonal or impulsive noise shares. Additionally it is important to eliminate roughness and resonances, especially if they are caused by low frequency engine orders. Impulsive noises can be caused by the tooth flank impacts of the gear box (Fig. 4) (gear rattle noise) e.g. Piston noise, caused by impacts between piston and cylinder liner, is transmitted through the structures of the cylinder and of the engine block. Piston contour, piston top land diameter, piston clearance and piston pin offset are well known design parameters to influence piston noise. The combustion rate shaping of diesel engines also leads to impulsive noise. Modulations causing harshness can originate both in an asymmetric structure transmission behaviour and unsymmetric combustion forces. Also specific low frequency engine orders due to valve train excitation can generate harshness. Tonality noises are well known from the gear box tooth meshing orders (whining noise), timing chain and belt meshing as well as from the generator' fan. A dynamic sound perception is caused by dynamic order levels shaped versus engine speed (Fig. 5). A powerful sound arises during acceleration conditions and requires a careful matching of the dynamic portion. Extreme level gradients, however, create uncomfortable sound. If the sound level shape is undynamically flat, the subjective impression of the sound character will only be comfortable. Such signal characteristics can be generated by carefully balanced resonances of individual engine components [8] [2]. Additional dynamic may be created by smooth signal modulations caused by main orders and their 0.5th neighbour orders (Fig. 6) [3]. The resulting sound character depends on the frequency spacing of these orders on the one hand and on their level ratio on the other. To avoid unpleasant sound character it is important to balance these modulations with regard to modulation ratio.

5. Examples of hardware measures

Concerning sound quality, it is important, that the human hearing is most sensitive in the frequency range between 500 and 1500 Hz, and roughness phenomena mainly occur in the frequency intervall of 200 - 800 Hz. Therefore, structural sound modifications of the engine block should be focused on the bottom end and main bearings. Fig. 7 shows the effect of structural optimization at the crankcase. The modeling is based upon Finite Element (FE) Method [9], [10]. The balanced reduction of the surface velocity (Fig. 7) lead to a tuned sound energy in the roughness frequency range. The subjective impression changed from very unpleasant and powerful to acceptable pleasant and still powerful. For the sound design of intake systems a desirable intake sound must be combined with an optimized torque and power characteristic of the engine. Therefore, acoustical modeling and calculations of the volumetric efficiency have to be conducted in parallel. The result of the computerized modeling is an optimized interior geometry of the intake system. The size of different volumes and the length of various pipes are tuned and, if necessary, additional resonators and quarterwave pipes designed and adapted [11], [12] [2]. Figure 8 shows the results of a CAE supported sound optimization on the intake system [6]. The modification of the intake system results in a reduction of the system's transfer behaviour between 600 and 800 Hz and increase in the 250 Hz octave. The results of the test cell measurements of the orifice noise level show that the 500 Hz octave is reduced over the entire speed range, and the 250Hz octave is increased in the speed range above 4000 rpm. With this modification the unpleasant sound character could be reduced, and a powerful sound character, still fulfilling the legislations, was created due to the dynamic level characteristic of the 250 Hz octave. Further modifications can cover the airfilter attachement, the filter wall stiffness, or the intake orifice orientation. Other typical sound measures consider the exhaust system, a classical source of sound design, the powertrain mounts and vehicle base, the cranksystem, the driveshaft and the ancillary drive system. Exterior noise may be balanced by modifications of the intake and exhaust, but also of the oilpan.

6. Conclusion

Future vehicles will be developed to a specific and individual sound. The consumer expects specific interior-sound characteristics depending on the vehicle-type as well as on the driving conditions. Especially in interactive driving conditions, e.g. during overtaking other cars, drivers expect a powerful and dynamic sound. The sound development process covers two workscopes elaborated simultaneously, the typical Sound Cleaning and the Sound Design. Work starts by figuring out the origins of typical noise characteristics like impulsiveness, modulations or engine orders. Next, analytical and hardware modifications and synthetic manipulations are performed in parallel. Only a consequently simultaneous engineering will provide success. The character of sound can be influenced by some typical signal characteristics according to pleasantness and dynamic. Tonal sound shares or impulsive noise create uncomfortable sound. Modulation in the time history of the noise signal, known as roughness, should also not be dominant, but in a balanced manner it can also create dynamic of sound. Additionally, a dynamic vehicle sound is created by reasonable order amplitude variations accelerating the vehicle. Examples for technical measures to design smooth modulations are structure modifications of the bottom end of the engine. Amplitude variations can be generated by smooth resonances of singular engine components. Background is the technical potential, to be elaborated during the detail work of level reduction and also experienced in long term practice. The sound engineer has to take into account the product-specific sound targets, e.g. concerning pleasantness and dynamic and has to balance the technical measures to achieve an interior noise characteristic focused on the product image.

7. References

[1] Takao, H.; Hashimoto, T.: Die subjektive Bewertung der Innengeräusche im fahrenden Auto - Auswahl der Adjektivpaare zur Klangbewertung mit dem Semantischen Differential. Zeitschrift für Lärmbekämpfung 1994, 41, Heft 3

[2] Wilhelm, M.; Schneider, M.; Wagner, T.; Nehl, J.: Die Gestaltung charakteristischer Fahrzeug-Innengeräusche: Entwicklungsmethoden und technische Potentiale des Antriebsstrangs. Aachener Kolloquium, Fahrzeug- und Motorentechnik 1995.

[3] Schneider, M.; Wilhelm, M.; Alt, N.: Geräuschdesign - Ziele und Entwicklungsmethoden für Antriebsaggregäte. HDT Essen: Geräuschminderung bei Kraftfahrzeugen, 2./3. März 1995, 30-303-056-5 [4] Vo, Q.-H. & Sellesse, W.: Entwicklung eines subjektiv angenehmen Innengeräusches, ATZ 1995 (1993)10

[5] Bisping, R.: Psychoacoustic Shaping of Car Indoor Noise. Audio Engineering Society (Eds), 91th AES Convention, New York, 1991

[6] Brambilla, G.; Flindell, I.H.; Rice, C.G. (1992): Noise Quality In Cars: Field Evaluation Versus Laboratory Assessment; in: Proc. 2nd A.T.A., Bologna 1992, 1045-1053

[7] Schneider, M.; Wilhelm, M.; Alt, N.: Development of Vehicle Sound Quality - Targets and Methods. Noise and Vibration Conference, Traverse City, MI, May 1995, SAE 951283

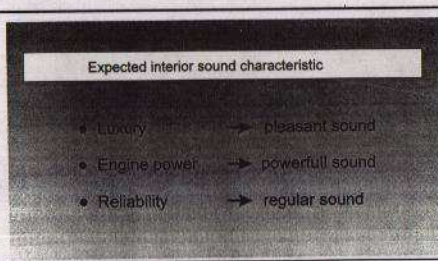
[8] Wilhelm, M.; Schwaderlapp, M.: Geräuschsimulation zur Verbesserung des akustischen Charakters von Verbrennungsmotoren, Sound Engineering: Kundenbezogene Akustikentwicklung in der Fahrzeugtechnik, Quang-Hue Vo (Hrsg.) - Renningen-Malmsheim: expert - Verlag, 1994

[9] Schmillen, K. & Schwaderlapp, M. & Spessert, B.: Verbesserung des akustischen Verhaltens von Motorblöcken. MTZ 53 (1992) 4

[10] Wilhelm, M; Schwaderlapp, M.: Potentiale zur Verbesserung des Subjektiven Geräuschverhaltens von Verbrennungsmotoren, VDI Fortschritt Berichte, 15. Internationales Wiener Motorensymposium, April 1994

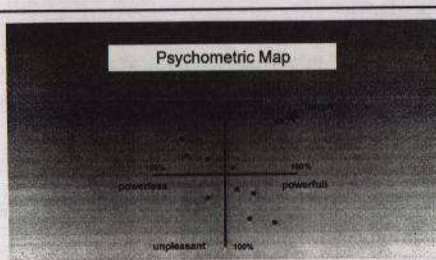
[11] Yoshitaka Nishio, Tokio Kohama and Osamu Kuroda: New Approach to Low-Noise Air Intake System Development. SAE 911042

[12] Suzukis, T. & Kayaba, F: The Analysis and Mechanism of Engine Intake Rumbling Noise, SAE 901755



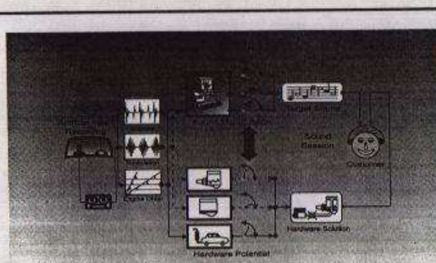
Vehicle interior sound
as relevant to marketing demands

Fig. 1



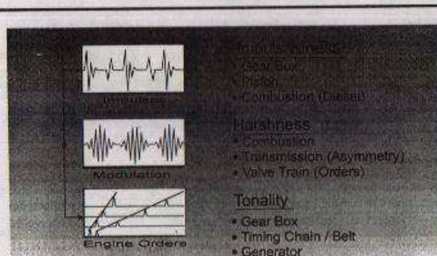
Psychometric Judgement
Interior Sound of 9 Vehicles

Fig. 2



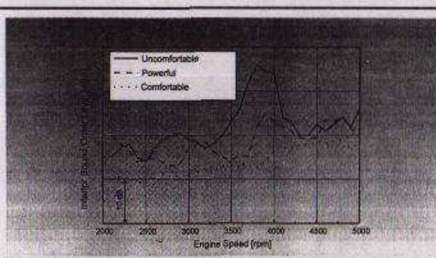
Interactive Sound - Engineering

Fig. 3



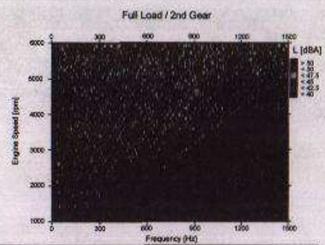
Sound Characteristics / Causes

Fig. 4



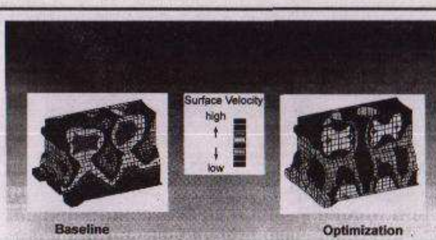
Sound Characteristics
Dynamic Engine Order Level Characteristic

Fig. 5



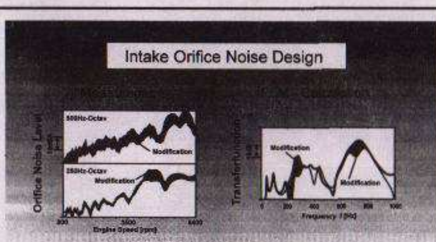
Sound Characteristics
Modulation

Fig. 6



Dynamic Structure Calculation
Roughness Optimization

Fig. 7



Intake System Noise Calculation
Dynamic Level Characteristic Optimization

Fig. 8