Psychoacoustic investigations on the efficiency of a vehicle's encapsulation in the underbody area

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Introduction

New concepts of passive measures to improve the sound quality of Diesel powered cars have already been presented in former investigations. Particularly a full encapsulation of the exhaust system has been proposed in this context [Patsouras D. et al. 2003].

The present study is focused on the possibility to get ahead with the conflict in the development of Diesel engines by means of such measures. On the one hand there stands the optimization of power, exhaust fumes and consumption, on the other hand there is an increase of the very unpleasant sound of Diesel engines. Therefore, several passive measures in the vehicle's underbody area have been integrated in an upper middle class car. The resulting improvements in the outdoor idling noise have been measured in an anechoic chamber and were the basis for filter functions to simulate in the following the passive measures at the power enhanced version of the car. The efficiency of the passive measures have been studied in psychoacoustic experiments.

Stimuli

Figure 1 schematically shows the procedure of signal generation for the psychoacoustic experiments.

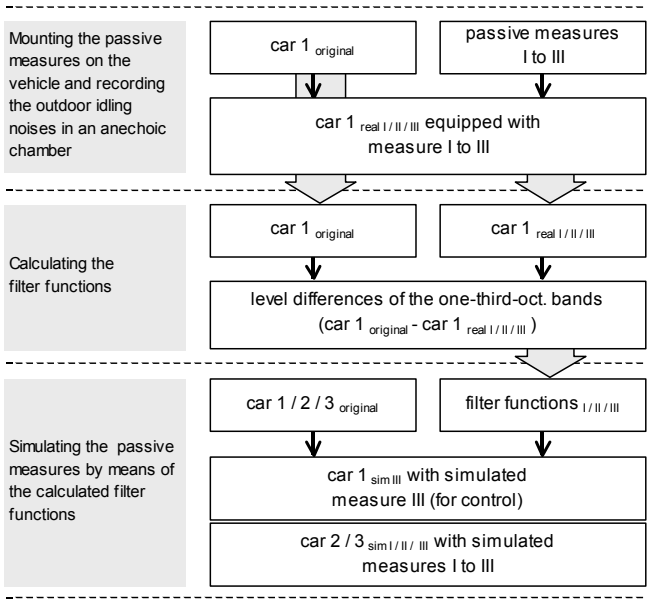

Figure 1: Block diagram of signal generation.

In a first step the passive measures I to III have been integrated in a car of the upper middle class (car 1) with a standard motorization. The outdoor idling noise in the original status as well as with the attached passive measure were recorded in an anechoic chamber with an artificial head system positioned at the right B-pillar.

In a second step filter functions for three realized acoustic packages were calculated in subtracting the one-third-octave bands of the measured outdoor idling noises with the respective measure of those measured without any measure.

Those filter functions finally served in the third step of the figured block diagram (fig. 1) for simulating the passive measures at the outdoor idling noises of car 1, 2, and 3. For car 2 and 3 all three acoustic packages were realized in this way digitally, for car 1 only measure 3 was simulated to prove the case for the modus operandi.

Whereas the vehicles 1 and 2 were equipped with a standard motorization, vehicle 3 was featured with a power enhanced version of the engine.

Experiments

In this manner 13 stimuli were realized to be evaluated in psychoacoustic experiments. Table 1 shows once more all stimuli discriminating between „real" sounds (R), which are real recordings of the vehicles' outdoor idling noises (either of the original status or equipped with the respective passive measures), and „simulated" sounds (S), that resulted from the simulation of the respective passive measure.

	original	passive measure		
		I	II	III
car 1 (standard engine)	**S1** (R)	**S2** (R)	**S3** (R)	**S4** (R) **S13** (S)
car 2 (standard engine)	**S5** (R)	**S7** (S)	**S8** (S)	**S9** (S)
car 3 (power enhanced engine)	**S6** (R)	**S10** (S)	**S11** (S)	**S12** (S)

Table 1: Stimulus S1 to stimulus S13 for the psychoacoustic experiments. R: real recordings of the vehicles' outdoor idling noises. S: Simulation of the passive measures.

For the experiments, the sounds were presented in a quiet surrounding via a STAX headphone calibrated to reproduce the original sound level. To study the efficiency of the realized passive measures in the experiment, the subjects had to judge the sound quality of the presented stimuli. For this,

the psychometric method of magnitude estimation with anchor sound was chosen with stimulus S1 (table 1) serving as anchor sound. Each sound pair was estimated four times by each of the 11 subjects.

Results

Figure 2 shows the results (median and interquartile ranges) of the psychoacoustic investigations.

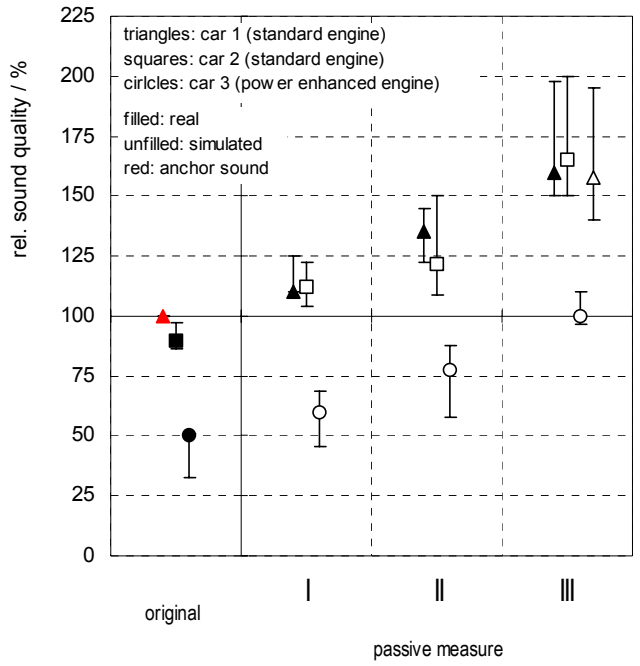

Figure 2: Relative sound quality of car 1 (triangles), car 2 (squares) and car 3 (circles). Filled symbols: real recordings of the vehicles' outdoor noises; unfilled symbols: simulation of the passive measures by digitally filtering. Red symbol: anchor sound.

Vehicles' outdoor idling noise in original status

If at first the sound quality of all three cars is compared for the vehicles' original status (figure 2 leftmost), similar results are received for the two cars with the standard engine car 1 (red triangle) and car 2 (filled square). However, the outdoor idling noise of the car with the power enhanced engine (filled circle) is estimated only half as good.

Integration of the passive measures I to III

When mounting the passive measures I to III on car 1 (filled triangles), an improvement in sound quality of 10 % (measure I), 35 % (measure II), respective 60 % (measure III) can be achieved.

Real versus simulated measure

In the case of car 1 /measure III (figure 2 rightmost) a comparison between really integrated measure (filled triangle) versus simulated measure (unfilled triangle) can be drawn: whereas the really mounted measure yields an improvement in sound quality of 60 %, the simulated measure is estimated by the subjects in average 57,5 % better. Hence, the simulation of the passive measures seem to be precisely enough.

Simulation in case of the standard engine

If the passive measures were realized for car 2 (unfilled squares) according to the investigations similar improvements as in the case of car 1 (filled triangles) could be achieved.

Simulation in case of the power enhanced engine

However, the main intention of the present investigations was to see into the following question: Is it possible to improve the sound quality of the vehicle with a power enhanced engine by means of the investigated passive measures in such a way that we get an approach towards the sound quality of the vehicle with the standard engine?

The results in figure 2 show in this context (unfilled circles) that by mounting measure I or II already a significant improvement in sound quality can be obtained though the sound quality even inclusive the measures I or II is still estimated below that of the vehicles with standard engine (leftmost filled square and triangle). However, if measure 3 was realized (rightmost unfilled circle) an improvement of the original outdoor idling noise of car 3 of 100 % can be achieved and hence a comparable sound quality to the vehicles with standard engine.

Resume

Several passive measures have been mounted in an upper middle class car. The herewith obtained and measured improvements were the basis for the design of digital filters for the respective acoustic package.

The often quite extensive mountings of passive measures could be avoided in this way by simulating the passive measures for other vehicles with same geometry of the engine compartment. Nevertheless, predictions for the efficiency of the respective passive measure could be done.

In the presented case it could be shown by means of a consequent realization of passive measures in the vehicles' underbody area that the sound quality of a Diesel car with a power enhanced motorization can be improved in such a way that it is getting equal to the same vehicle with standard motorization.

References

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