inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 0.0

DEFINITION OF THE ENGINE SOUND QUALITY INSIDE VEHICLES

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Keywords:
ACOUSTIC QUALITY, ENGINE NOISE, MODULATION, WHISTLING

ABSTRACT
This paper presents a way to quantify the acoustics quality of engine perceived inside the vehicle from the definition of sensors to the choice of acoustics parameters. Normalized metrics like loudness or sharpness are used to give a global feeling of the acoustics quality. Three other acoustics parameters are introduced, they are linked to well-known phenomena: modulation and whistling due to the driving belt, shock balance for the piston slap. The engine is measured in three typical conditions where those characteristics can occur: low idle with cold and warm diesel engines, run-up condition from low idle to 2500 rpm. Results show that the level is not linked to those parameters value. From an acoustics quality point of view, some new critical speeds have been detected.

1 - INTRODUCTION
Automotive constructors have reduced the noise level in the past and now want to guarantee a pleasant noise inside their vehicles. To reach such an objective, many works have been presented about subjective evaluation of the noise quality.
The acoustic quality should also be determined from an objective study with objective results. This study is interested in quantifying the acoustic quality of the engine noise source inside the passenger compartment. To illustrate the study, measures from three cars whose engine is used in three conditions give interesting results.

2 - DEFINITION OF THE MEASURE

2.1 - Choice of sensors
The signature of the noise at the level of the passenger's ear is usually recorded. The noise from engine is composed of different sources (piston slap, driving belt, first revolution orders) with different transfer paths: airborne and structure borne noise. From a single signature, it is difficult to separate the different sources. The measure requires several sensors:

- an accelerometer on cylinder head quantifies the problems due to piston slap,
- an accelerometer in each direction on engine mount is well-adapted to quantify first orders for which structure borne noise is predominant,
- a microphone in the engine compartment qualifies airborne noise.

2.2 - Conditions of the measure and subjective judgements
Vehicles are stopped to eliminate sources from the aerodynamic shape or the pavement. Three engine conditions are considered. This choice is guided by the usual subjective judgement that are linked to the condition:

- low idle when engine is cold: piston slap is typically stronger (two out of three engine of vehicle are diesel),

- low idle at the normal temperature: piston slap and modulation effects are often characteristic,
- run-up conditions (the results are obtained here with an acceleration from low idle to 2500 rpm in 10 seconds): the noise fluctuates with the engine speed, it is all the more annoying since the phenomenon is temporary.

3 - DEFINITION OF PARAMETERS

3.1 - Global acoustics parameters

Some acoustics parameters quantify global aspects of the noise that contribute to the acoustics quality and are not specific to a single source. Among them, it is interesting to use:

- Loudness: compared to a dBA level, it introduces the masking effects [1],
- Sharpness: the global tonality of the engine taking into account masking effects,
- dBA level of the 2^{nd} order: dBA level is mainly composed of this component and it gives the tonality.

They quantify the global frequency content. The microphone at the level of the driver's ear is used to compute them. All temporal characteristics like modulation or impulses are difficult to quantify from its filtered signal in specific bands because different noise sources are added. It would be useless to try to detect other characteristics from this signature.

3.2 - Modulation and repetitive shocks

Modulation and repetitive shocks are kinds of roughness metrics but they are specifically developed for engine [2].
Those phenomena usually occur in a specific frequency or order band. They are visible from the temporal filtered signal (Figure 3). The choice of the filter is intuitive with the aspect of the spectrum: modulation and repetitive shocks are usually combined with a higher level in a specific order and frequency band.
One of the components that can give modulation is the driving belt. The typical bands are those around its frequency and the first harmonics. The microphone inside the engine compartment measures the best the phenomenon.
The repetitive shocks come from the burst. The "shock balance" parameter measures the dispersion of piston slap. In this case, the phenomenon occurs in frequency band around 1000 to 3000 Hz. The best sensor is the accelerometer on the cylinder head.

3.3 - Whistling

This phenomenon is due to the difference of level of a pure frequency and the critical band around it. The acoustics parameter is usually named "Tone to Noise". Several component can give this feeling like timing belt or alternator. The microphone inside the engine compartment also measures the phenomenon, but whistling and modulation can not coexist! First one is typically characterized by a pure frequency as the second one is composed of three frequencies.

4 - RESULTS

Results come from the experiment with three vehicles:

- vehicle 1: gasoline engine (red curves),
- vehicle 2: common rail diesel engine (green curve),
- vehicle 3: direct injection diesel engine (blue curve).

Parameters are computed for each engine cycle. In run-up condition, it is interesting to analyze the evolution of values with the engine speed.

4.1 - Global characteristics

From the analysis of Figure 1 and Figure 2, global characteristics are:

- low level for the vehicle 1 (gasoline engine) from 850 to 2000 rpm with a higher frequency content, afterwards, the level increases quickly, and low frequency are more dominant,
- with diesel engine, sharpness is lower. For vehicle 2, engine noise in passenger compartment is louder while vehicle 3 keeps a reasonable level apart from around speed 1000 rpm,

- at low idle, same tendencies are visible in Table 1.

The difference of sharpness level is essentially due to the part of the 2nd order compared to the global level. 10 dBA is measured with vehicle 1 at low idle, then this difference decreases, reaching 2 dBA at 2500 rpm.
To detect bad acoustics quality noises that are not loud but annoying, it is necessary to go ahead.

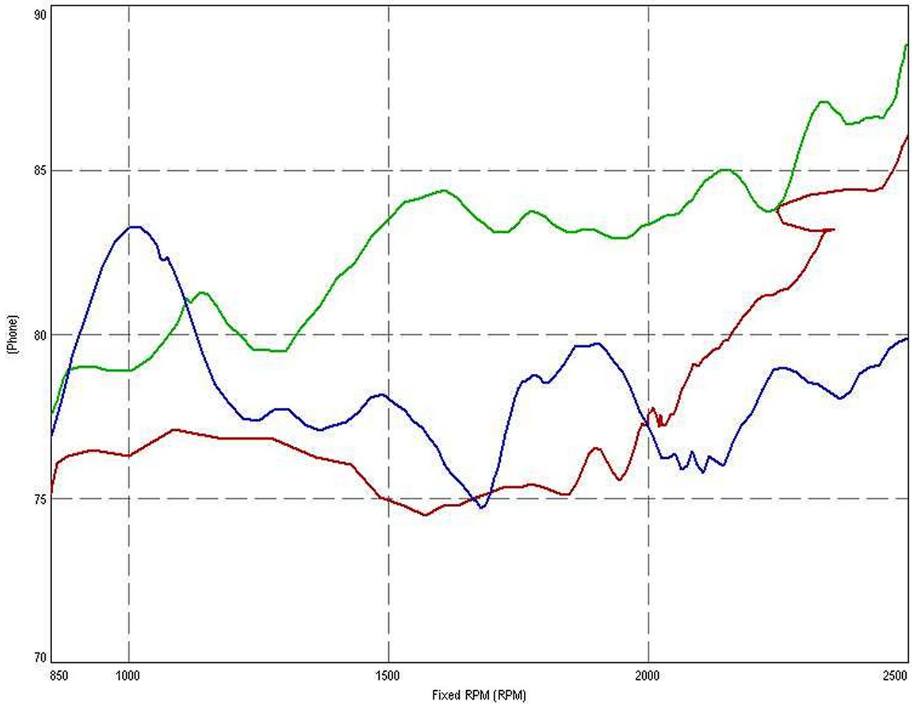

Figure 1: Evolution of loudness.

4.2 - Acoustics quality
The analysis of the new acoustics parameters presented before gives information about the noise quality. It is not necessary linked to levels.
At low idle, the most interesting parameter is the shock balance. For cold diesel engine (vehicle 2), piston slap is very strong.

Low idle	Loud. Phone	Sharp. ACU	S.B. 0.5 1-3 kHz		Modulation 0.5 17-25 O	Tone to noise (dBA)
Engine	warm	warm	warm	cold	warm	warm
Vehicle 1	75.0	0.58	.045	-	.167	2.1
Vehicle 2	77.2	0.45	.097	.190	.168	-6.9
Vehicle 3	76.8	0.41	.041	.075	.176	-4.7

Table 1: Averaged values at low idle of acoustics parameters.

In run-up condition, results about modulation are not presented because no vehicles are concerned in those examples.
Whistling phenomena are detected on vehicle 1 at 1400 rpm and at a larger scale on vehicle 3 at 1800 rpm (Figure 4). At least, vehicle 2 is concerned by piston slap. Around 1150 rpm, shock balance is higher (Figure 5). Figure 3 points out the fact that levels are not linked to the acoustics quality for "shock balance". The part of signal where piston slap is modulated at order 0.5 is visible Figure 3.

5 - CONCLUSION
By this way, the real noise quality characteristics perceived inside the vehicle are quantified and other critical speeds have been detected. Global metrics are not convenient to detect from the measure subjective judgments like whistling, piston slap and modulation. The measure limited to the microphone inside car is ineffective when several sources influence the noise.

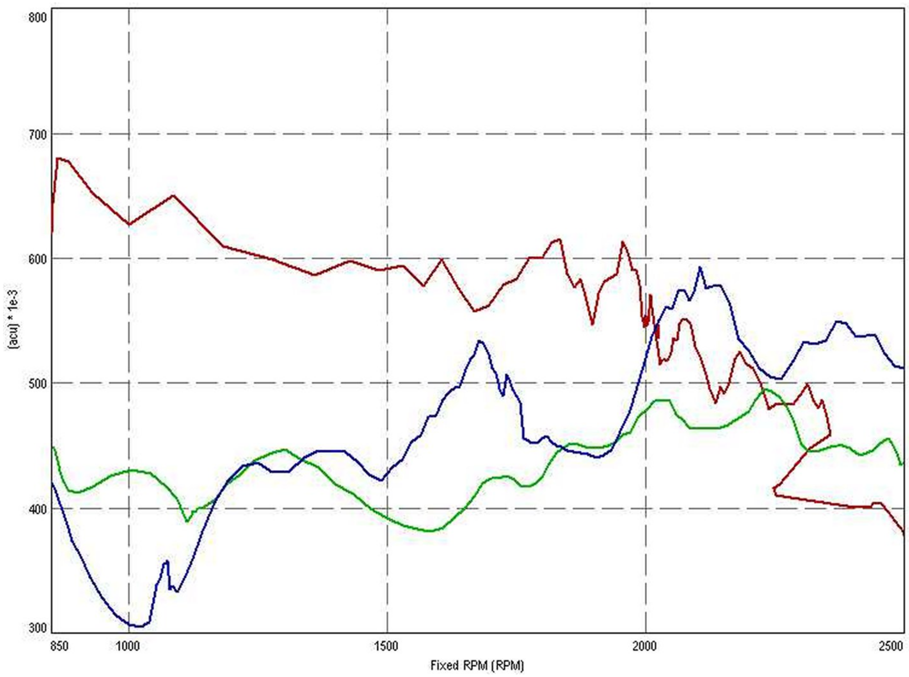

Figure 2: Evolution of sharpness.

REFERENCES

1. **E. Zwicker, R. Feldkeller**, *Das Ohr als Nachrichtenempfänger*, S. Hirzel Verlag Stuttgart

2. **L. Lamotte, B. Béguet**, Quantification of Sound Quality for Engine in Stationary and Run-Up Conditions, In *Proceedings of the 1999 Noise and Vibration Conference, Traverse City*, pp. 1277-1280, 1999

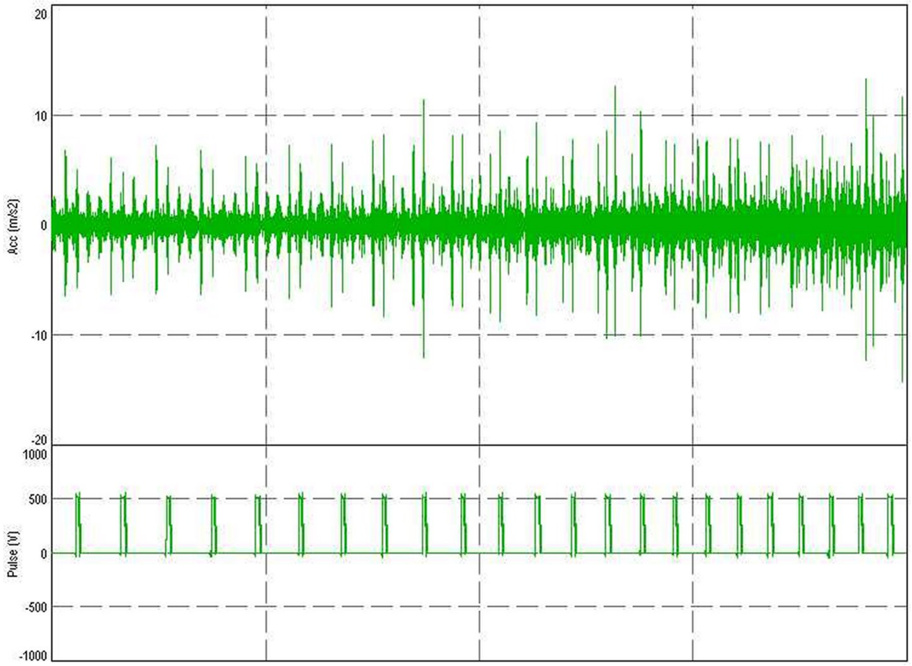

Figure 3: Filtered 1150-2500 Hz signal between 1130-1780 rpm.

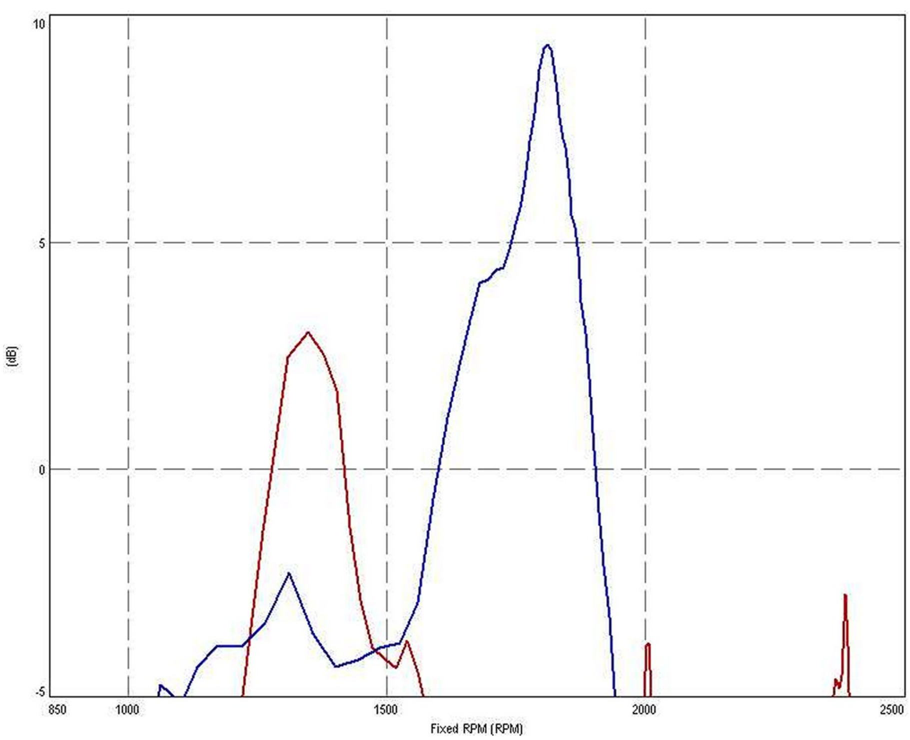

Figure 4: Evolution of whistling.

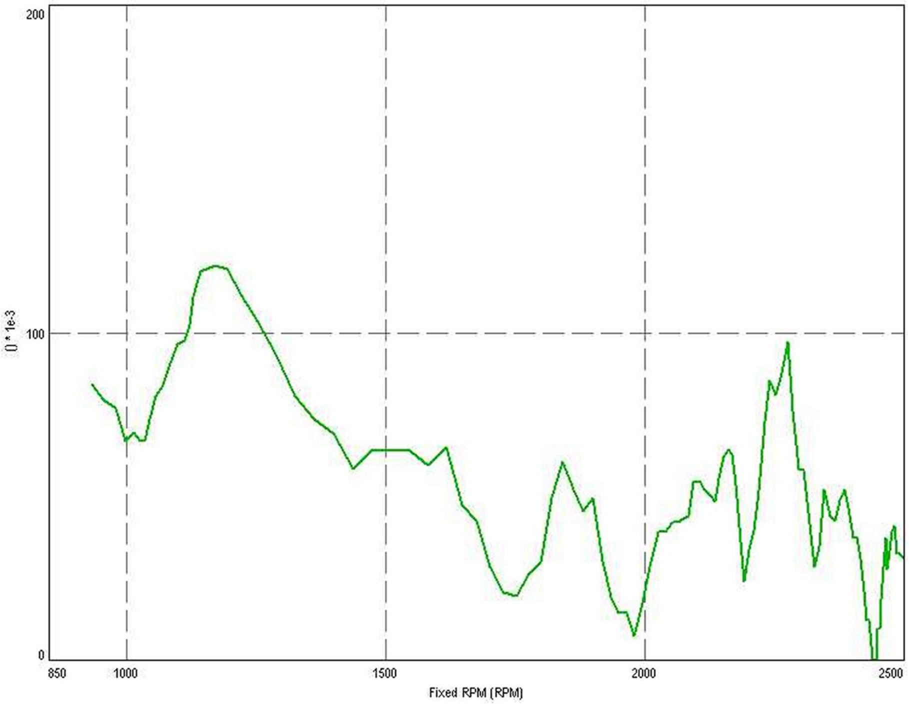

Figure 5: Evolution of shock balance 0.5.

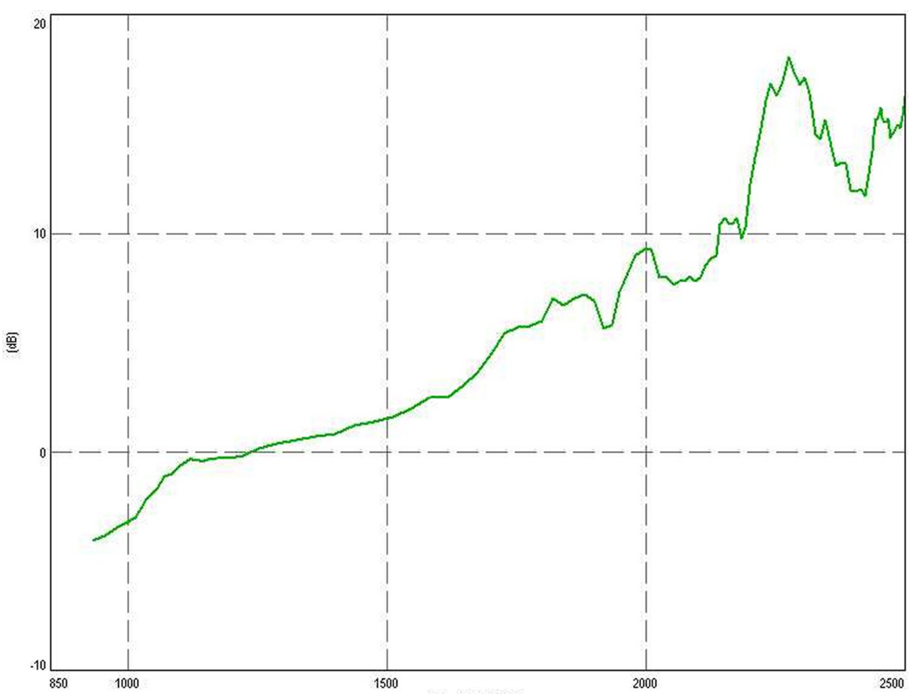

Figure 6: Evolution of level 1150 − 2500 Hz for accelerometer on cylinder head.