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CHARACTERIZATION OF THE NOISE REDUCTION OF ENGINE HOOD: EXPERIMENTAL METHOD

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Abstract

With the growing interest in noise pollution, the characterization and propagation of noise produced by the vehicles in road traffic has become a priority in vehicle noise radiation to the environment.

In this work, the characterization of acoustic transmission of the engine compartment is performed with an experimental method. The technique was improved with an electroacoustic system including an inverse filtering method.

The results on such characterization are achieved with the Sound Transmission Loss technique, (TL) which has been measured in several positions surround the vehicle hood. In the measurements, a loudspeaker (close to the engine of the vehicle) was used as a noise source. Besides the microphone in the engine compartment, other microphones are located outside of the vehicle. The impulses responses between the loudspeaker and the microphones were measured using the Maximum Length Sequence (MLS) method and also its frequency responses were calculated. The outcomes show that noise reduction provided by the engine hood depends on the frequency bands and the microphone locations, varying from 17 dB to 26 dB at the lateral positions including the angle dependence (a directivity polar function) and the frequency band.

Introduction

In the recent days, all the luxury automotive manufacturers have directed a great interest on acoustic characteristics of vehicles. The sound power level is certainly an important parameter for noise emission of finished products. It is used for compliance and benchmarking in the competitive market of automotive field.

The noise characterization and the vibration reduction could regard numerous materials and components in the automotive field, such as panels, doors, engine hoods, seats, etc. However, engine noise represents the most significant element of the overall noise perceived inside and outside of the car. The engine hood, additionally represents an aesthetic component on the engine cover, if it is well designed could be able to reduce noise emissions of the engine, producing a better acoustic comfort on the cabin and a better insulation outside of the engine compartment. For these reasons an effective study of practical characterization methods for new materials is needed, which ensures the noise prediction in all working circumstances. It is nowadays a very significant research issue.

In the literature there are some works about the noise transmission across of firewall of a passenger car [1,2], with the characterization of the noise inside the cabin just for the comfort of the people inside of the vehicle, but only a few studies investigate the effect of the chassis upon engine noise and the developed methods to quantify the vehicle noise radiation to the outdoor [3,4].

Standardized exterior and interior noise tests are frequently used to determine the sound quality in vehicles development. The combination of static test and pass-by measurements is essential to undertaking a successful refinement process [5].

The microphones are the most common devices used to measure sound pressure [6]. They have an internal membrane which responds to air pressure fluctuations, moving backwards and forwards as the pressure force acts over the membrane surface. A sound pressure microphone is omnidirectional and measures the sound field in all directions.

The importance of this work is to release an experimental technique named sound transmission loss [7] with inverse filtering, which is widely used in architectural acoustics, it is an effective and practical method compared with another method to estimate propagation of vehicle noise sources as the NVH method [8-10].

Acoustic characteristics of engine noise

The noise sources of a vehicle are the power unit (including the engine, air inlet and exhaust), the cooling fan, the transmission system (including the gearbox and rear axle), the rolling (including the aerodynamic and the tire/pavement components), the brakes and the load [11].

The frequency spectrum of the engine noise observed in measurements of passenger car running at different speeds, generally fall in a dominant frequency range of 100 Hz - 3 kHz, centering around 1.5 kHz band, see Fig. 1. This tendency is common in both gasoline and diesel engines vehicles. The engine noise measurements were made on a controlled route with several microphones inside of the engine compartment, confirming that the noise is constant at different positions.

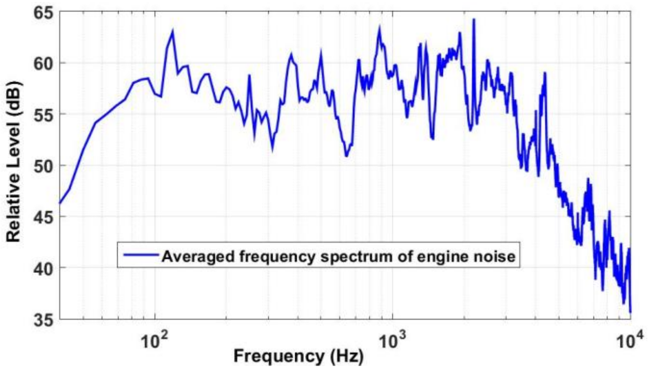

Figure 1. Averaged noise spectra of engine noise of a passenger car

Once the source was characterized, the engine compartment was assumed as a small enclosure in a reverberant field, that is the basic principle of the sound transmission loss [12], this assumption is due to the sound pressure level measured inside of the engine compartment is homogeneous.

Methodology

Inverse Filtering

As we see in Fig. 1, basically the range of frequency spectrum is between 0.1–5 kHz. The source that is used throughout the sound transmission tests was characterized in this range applying an inverse filter in order to obtain a flat frequency response in that frequency range. In an anechoic chamber the measurements were carried out using the Matlab software as data acquisition system, in order to calibrate it, Fig. 2, which provides the impulse response between the output and input, and this includes all instrumentation and transducers connected to it. Therefore, it is very important to keep all instrumentation at the same setup throughout all measures. Fig. 3 shows the transfer function (FFT of the impulse response) *H(f)* between the speaker and 6 microphones (including the speaker amplifier microphone and preamplifier). Since frequency response of the microphone MX 183 is fairly flat as reported in data sheet [13], essentially it represents the frequency response of the loud speaker.

Because the loud speaker has an irregular frequency response that does not correspond with a flat frequency response, an inverse filtering is applied to equalize frequency response. This technique involves convolving the excitation voltage speaker with inverse filter of the impulse response of the speakerphone [14,15].

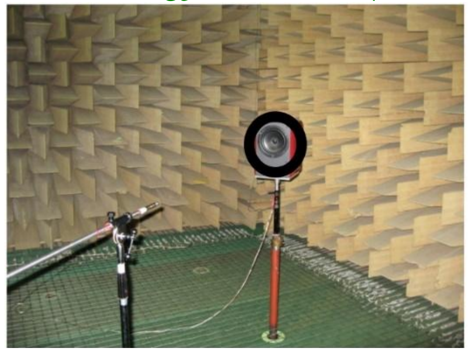

Figure 2. Experimental set up of the system calibration in the anechoic chamber

The electrical signal which should drive the loudspeaker is

$$x_s(t) = IFT^{-1}\left[Y_s(f)\frac{H^*(f)}{|H(f)|^2 + p^2}\right], \quad (1)$$

where IFT^{-1} stands for inverse Fourier transform When the loudspeaker is driven by $xs(t)$ the system responds with

$$h(t) * xs(t) = ys(t). \quad (2)$$

For cosine-magnitude spectra, with $B = f_2 - f_1$ the frequency band where the source must be equalized, $f_0 = (f_2 + f_1)/2$ the central frequency.

$$|Y_s(f)| = \begin{cases} \cos^g\left[\dfrac{\pi(f-f_0)}{B}\right] & f_1 \le f \le f_2 \\ 0 & f < f_1, f > f_2 \end{cases} \quad (3)$$

and

$$\Psi_{Y_s(f)} = \begin{cases} 0 & \text{for zero-phase pulses} \\ -\dfrac{1}{\pi}\displaystyle\int_{-\infty}^{\infty}\frac{|Y_s(\xi)|}{f-\xi}d\xi & \text{for minimum-phase pulses} \end{cases} \quad (4)$$

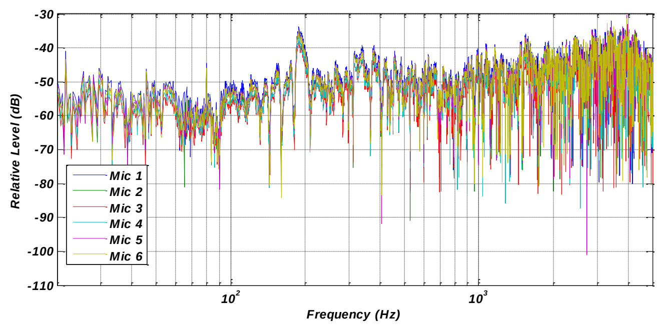

Figure 3. Transfer function of the data acquisition system

The equalization process outlined above depends on four parameters: f_1 and f_2, the low and high frequency limits of the frequency band, p, the regularization parameter, and g, the cosine shaping parameter. Fig. 4 shows the impulses responses of a loudspeaker – microphone system with and without inverse filtering. The shortening of the impulse response produced by inverse filtering is evident in Fig. 4 (below). The inverse filtered pulse has a zero-phase cosine-magnitude spectrum with parameters according to the natural frequency response function of the sound source. In this case, the selected parameters were (f_1, f_2, p, g) = (50 Hz, 5000 Hz, 1% of the spectral maximum, 1).

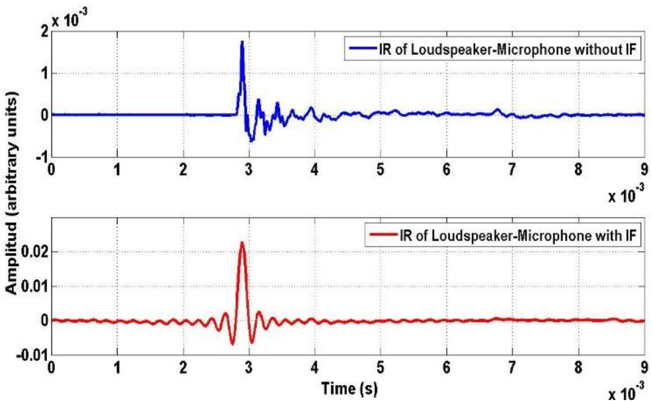

Figure 4. Impulse response of a loudspeaker–microphone system without (above) and with (below) inverse filtering

Sound Transmission Loss Measurement

The Sound Transmission Loss (TL) of an engine hood vehicle was measured using the setup shown in Fig 5. The loudspeaker is located inside the engine hood. In addition to the engine microphone, other microphones are located outside the vehicle, along a semi circumference of radius 1.2 m. Since the microphones are separated by 5º, we need 37 outer microphone positions to cover 0°-180 º.

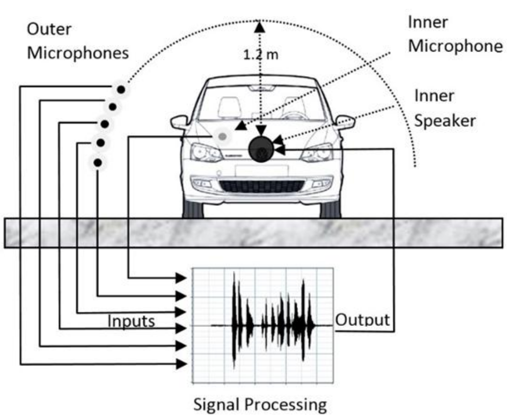

Figure 5. Setup for TL measurement

A simultaneous measurement of the transfer functions between the loudspeaker and the inside and outside microphones allows us to calculate the TL as a function of the frequency and the angle. The impulse responses were measured by using the Maximum Length Sequences (MLS) method and were performed with a data acquisition system, consisting of a DAQ NI USB-6211, maximum sampling frequency of 250 kHz, managed by MATLAB program. Fig. 6 shows the positions of the loudspeaker inside the engine hood, and the inner and outer microphones during the measurements carried out on a vehicle.

Figure 6. Positions of the loudspeaker and microphone inside the engine hood (right), and position of the microphones outside in the first 5 positions (left)

The measurements were carried out above a medium soil. The TL through the engine hood is defined as

$$TL(f,\theta) = 20log\left[\frac{|H_{alt-m1}(f,\theta)|}{|H_{alt-mo}(f,\theta)|}\right] \quad (5)$$

where H_{alt-m1} is the measured transfer function between the loudspeaker and the engine microphone, and H_{alt-mo} is the transfer function between the loudspeaker and the outer microphone at angle θ [16].

Experimental Results

Figure 7 shows the 3D directivity representation of the engine hood of a vehicle for the frequency range of 100-5000 Hz. As projected, TL grows when the frequency increases.

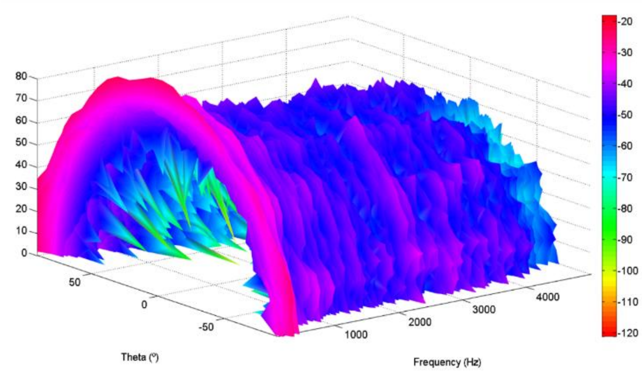

Figure 7. 3D directivity diagram of the engine hood for a passenger car

Figures 8 and 9 show the results of the angular dependence measurements of the TL through the engine hood at the central frequencies of the 1/3 octave bands. Notice as TL becomes more directional when the frequency increases. At low frequencies, a trend to radiate to the side of the vehicle that has less internal components behind the engine, it is appreciated to the right, in concordance with Mahajan and Rajopadhye [17].

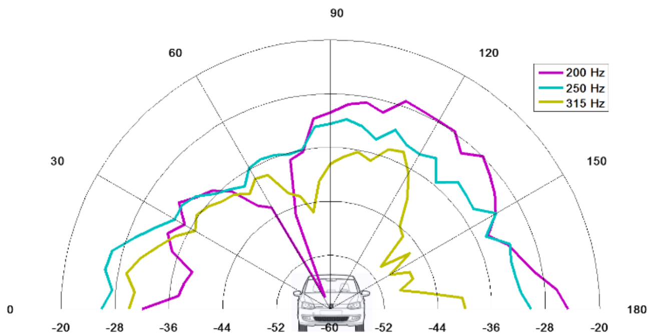

Figure 8. Directivity diagrams of the engine hood for several 1/3 octave band frequencies between 200 and 315 Hz.

The level difference of the internal microphone (microphone situated in the engine hood) with respect to external microphones (microphones outside of the engine hood in a semicircle), is going to be the transmission loss of the hood depending on which angle the microphones are located, i.e. for the microphone at 90°

$$TL_{hood\ 90°} = 20\log|H_{in}(f)| - 20log|H_{out\ 90°}(f)| \quad (6)$$

Where $H_{in}(f)$ is the transfer function between loudspeaker and inner microphone, $H_{out\ 90°}(f)$ is the transfer function between loud speaker and outer microphone at 90°.

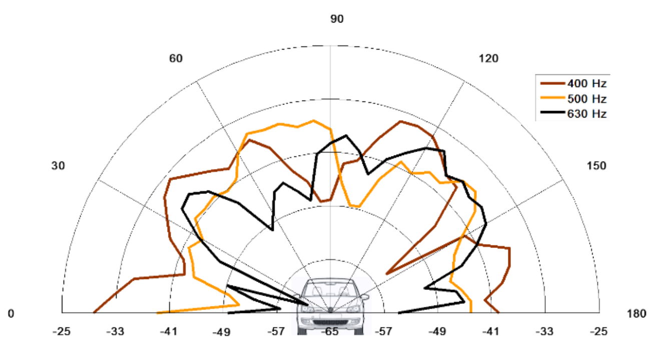

Figure 9. Directivity diagrams of the engine hood for several 1/3 octave band frequencies between 400 and 630 Hz

Figure 10 shows the transfer function between loudspeaker and inner microphone $H_{in}(f)$ and the transfer function between loudspeaker and 4 outer microphones at distinct angles $H_{out\ 90°}(f)$, $H_{out\ 120°}(f)$, $H_{out\ 150°}(f)$ and $H_{out\ 180°}(f)$. The attenuation effect due to the hood is evident at different angles.

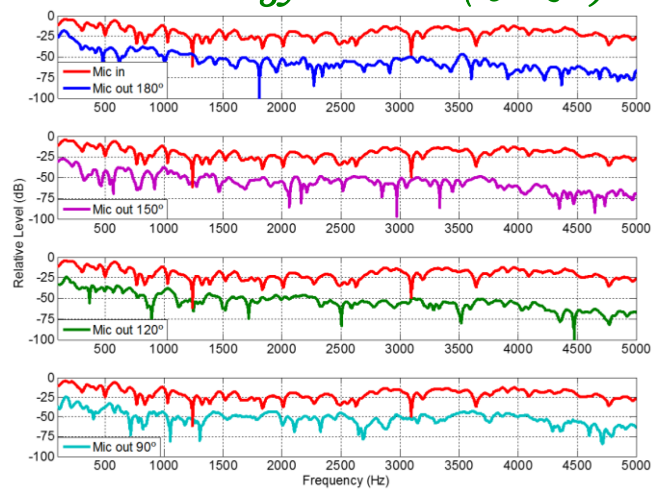

Figure 10. Transfer functions between the loudspeaker and inner microphone (red), and between the loudspeaker and outer microphones at different angles.

Figure 11 shows the frequency dependence of TL through the engine hood for different angles. The FFT spectrum has been converted to 1/3 octave bands.

From the 1/3 octave band spectra, the overall TL at each angle

$$TL_{overall}(\theta) = 10log\left[\sum_{f_i} 10^{0.1\,TL\,(\theta,f_i)}\right], \quad (7)$$

can be calculated.

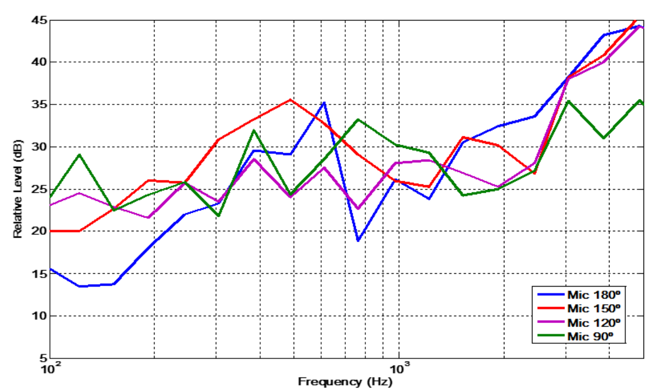

Figure 11. Frequency dependence of TL through the engine hood for different angles

Table 1 shows the angle dependence of the engine hood TL of a passenger car in frequency bands between 100 Hz - 5 kHz. Fig. 12 shows the angle dependence $TL_{overall}$ at the positions (0°-180°). It is appreciated high level at 0° instead of 180°, due to the internal components inside of the engine compartment.

Table 1. Angular dependence of Engine hood TL in the range frequency from 100 Hz to 5 kHz

Theta (°)	(100 Hz - 5 kHz)
	TL (dB)

0	22.6
30	27.4
60	26.5
90	24.3
120	24.0
150	24.8
180	17.2
Overall (0-180º)	25.1

There are frequencies at which TL are lower. For the case of frequency about 150-200 Hz for the most positions, this suggest that resonances inside the engine hood occur at these frequencies.

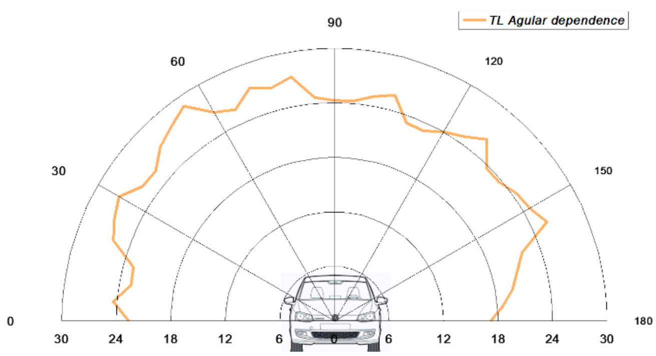

Figure 12. Angular dependence of the overall TL through the engine hood of a passenger car

Conclusions

This work has reported a measurement technique of noise reduction through the engine hood of a vehicle. The Sound Transmission Loss with inverse filtering was used as a metric to characterize the noise reduction. It is calculated from the log-spectra of the transfer functions between a loudspeaker inside the engine compartment and microphone inside and microphones outside the engine hood. Measurements of TL was carried out in 37 points surrounding the hood surface over a semicircle and it has been analyzed and characterized the angular dependence of the transmission loss through the hood of a passenger car. Effective attenuation was found as the frequency is increased, finding the overall equivalent TL, is around 25 dB, this level is going to be dependent of the components inside of the engine hood and the internal cover of mineral wool having under the hood. We conclude that this method is handy and useful to measure the TL of vehicles compartments.

Acknowledgments

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Biography

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