44º CONGRESO ESPAÑOL DE ACÚSTICA
ENCUENTRO IBÉRICO DE ACÚSTICA
EAA EUROPEAN SYMPOSIUM ON ENVIRONMENTAL ACOUSTICS AND NOISE MAPPING

ON THE ROLLING NOISE OF PASSENGER CAR TYRES

PACS: 43.50.-Lj

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ABSTRACT

The acoustic and mechanical comfort in passenger cars is becoming more and more important. Whereas the number of cars is continuously increasing – which implicitly results in higher overall noise emission – the respective legal regulations are becoming more stringent. However, abiding by these objective limits does not necessarily imply a better interior noise performance, since the subjective perception of acoustic signals varies depending on their spectral composition. In this article, the main mechanisms of tyre/road noise are summarised, and the current EU regulations for road vehicles are presented, with special emphasis on C1 class tyres.

RESUMEN

El confort acústico y mecánico en vehículos de pasajeros se está volviendo más y más importante. Mientras que el número de automóviles está aumentando constantemente – lo que aumenta implícitamente la emisión de ruido - las regulaciones legales son cada vez más estrictas. Sin embargo, cumpliendo con estos valores límites objetivos no implica directamente una mejor calidad de ruido neumático interior, ya que la percepción subjetiva de las señales acústicas varía dependiente de su composición espectral. En este artículo, se resumen los principales mecanismos del ruido neumático/pavimento y se presentan las actuales normas de la UE en vehículos de carretera, con especial énfasis en los neumáticos de clase C1.

BACKGROUND

Traffic noise has become a major pollutant of the outdoor urban environment with direct implications on public health. Noise exposure can affect the individual's concentration and, depending on its level and dosage, can cause a temporary threshold shift. Acute noise effects may also develop into clinical symptoms like permanent threshold shift, tinnitus, or even insomnia [3]. This has led the responsible authorities to apply certain measures to mitigate traffic noise pollution.

In this regard, the EU tyre labelling regulation 1222/2009 [8] provides a first step towards reducing traffic noise. It stipulates that manufacturers comply with the limits for external rolling noise (along with fuel consumption and wet grip) of each tyre that is intended to be sold in the EU as of November 2012. Accordingly, tyres are classified by A (green, best performance) to G (red, worst performance) for the overall performance. Moreover, with the noise classification on the tyre label (loudspeaker symbol with one to three sound waves), the customer gets a better overview of the acoustical tyre behaviour.

Now the question is: Are these EU regulations sufficient for ensuring a quiet and comfortable ride? In this report, we first recapitulate the main mechanisms of tyre/road noise and then shed some light on the advantages and limitations of the EU legal regulations concerning tyre noise.

TYRE NOISE GENERATION MECHANISMS

A schematic of a tyre on a surface is shown in Fig. 1, along with the main excitation mechanisms. For frequencies below about 300 Hz, structure-borne noise, instigated by the tyre and suspension vibrations, is the dominant factor (relevant mainly for interior noise). Above 600 Hz, air-borne noise dominates (relevant both for interior and exterior noise).

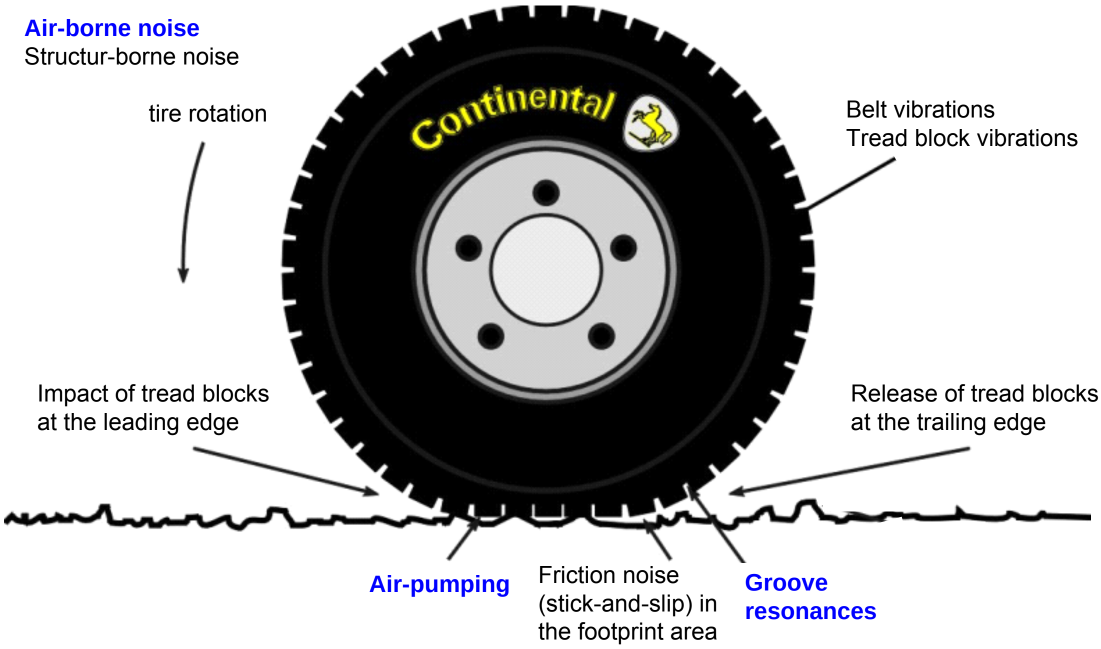

Figure 1. Tyre schematic indicating the main excitation mechanisms upon the interaction of the tyre with the road surface.

All these excitation mechanisms are caused by the interaction of the tyre tread pattern with the road surface. These vibrations are induced in the tyre structure (e.g., radial and tangential vibrations), in the air column within the tyre (cavity mode), and in the surrounding air that is "trapped" in the grooves (pipe and Helmholtz resonators). Table 1 shows an overview of the main noise generation mechanisms and their causes [1,4,6,10].

Tyre vibration	Cause
Radial tyre vibrations	Radial belt vibrations and pattern elements hitting (on the leading edge) and leaving (on the trailing edge) the contact patch.
Tangential tyre vibrations	Tangential forces in the contact patch.
Sidewall vibrations	Tread vibrations transported to the sidewall and radiated thereof.
Tangential stick/slip vibrations	Tangential displacements of the tyre on the road due to reduced friction in the footprint area.
Adhesion stick/snap	Occurs on relatively clean road surface when the tyre tread surface gets sticky (e.g., due to hot asphalt). This may take place in winter tread compounds at high temperature.
Cavity mode	Resonating air-column within the tyre (membrane filled with air). For a rolling tyre, two cavity modes of adjacent frequencies arise [1]: $f_{cavity} = (ic/\lambda) \pm (s^*i + \Delta f)$, where i = 1,…,n; c is speed of sound; λ wavelength; s: number of revolutions per second; $\Delta f \approx 0.5$ Hz (frequency shift)
Air-pumping	Air displacement into and out of groove cavities or between the tyre tread and the road surface due to entering and leaving the contact patch.
Pipe resonance	Air displacement in grooves ($\lambda/2$ and $\lambda/4$ pipe resonators) upon the contact of the tread pattern with the road surface.
Helmholtz resonators	Air displacement into/out of connected air cavities in the tyre tread pattern and the road surface.

Table 1. Overview on the main mechanisms of tyre/road noise [1,4,6,10].

LEGAL LIMITS FOR PASSENGER CAR TYRES

Regarding the acoustical tyre performance, the EU tyre label stipulates that a tyre noise on certified ISO surface (ISO 10844:2011 [5]) lies within well-defined limits. The measured noise level [in dB(A)] is calculated in accordance with UNECE Reg. 117 [9] in an outdoor coast-by test.

For passenger car tyres of class C1 (tyre classification as defined in Article 8 of Regulation (EC) No 661/2009 [7]), the noise coast-by measurement is performed at a speed of 80 km/h with the engine switched off during recording (Fig. 2, left). To obtain the value exactly at this reference speed, at least 8 measurements (4 lower and 4 higher than 80 km/h) are carried out in the range of 70 to 90 km/h with an accuracy of ± 1 km/h. The level at 80 km/h is then determined by a regression analysis [2] and used for the tyre approval testing[1]. Other restrictions concerning meteorological conditions (wind speed: v_{wind} < 5 m/s, air temperature: 5°C ≤ T_{air} ≤ 40°C; test surface temperature: 5°C ≤ T_{surface} ≤ 50°C) must also be met for testing [2].

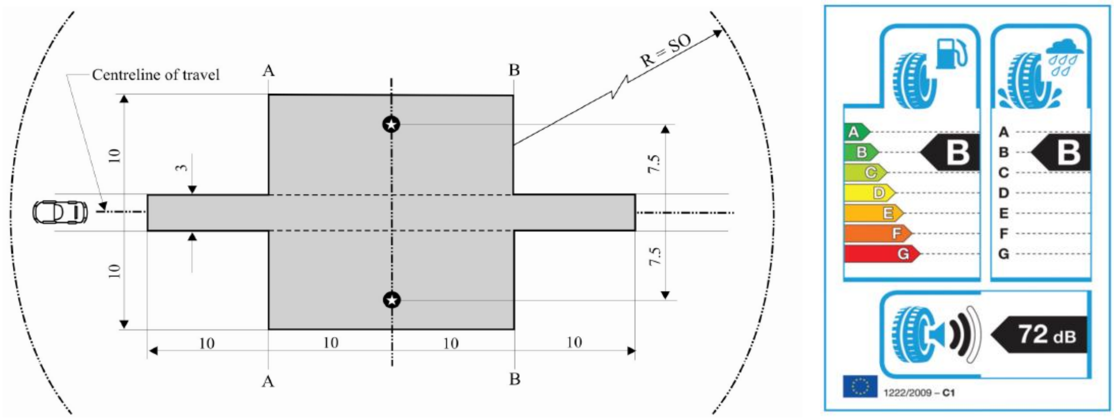

Figure 2. Left: a highly schematic representation of the noise coast-by test [9]. The shaded part represents the test area that is passed by the test vehicle. Two microphones are mounted, each (7.5 ± 0.05) m away from the reference line (centre line of the test track) and (1.2 ± 0.02) m above the ground. Source: Directive 2001|43|EC [2]. Right: example of a label for a C1 class tyre. Source: Reg. 122|2009 [8].

The tyre noise performance is represented by a loudspeaker symbol on the label (Fig. 2, right), with:

-  one black wave: meaning that the tyre is at least 3 dB(A) below the future limits of 661/2009 which will come into effect as of November 2016;
-  two black waves: meaning that the tyre lies between the future limit and 3 dB below, i.e., the tyre meets the imminent 661/2009 limits that will apply in the future.
-  three black waves: meaning that the tyre is above the future European limits of 2016.

All tyre classes (C1, C2, and C3) must meet the rolling noise requirements listed in Reg. No 661|2009 (Annex II [7]). While different countries may have different regulations, Table 2 shows the EU values for C1 class tyres, which are designed primarily for vehicles of categories M1, N1, O1 and O2.

[1] Note that for class C3 tyres, measurements are performed in a speed range of 60 to 80 km/h, and the legal value is taken by interpolation at 70 km/h.

Whereas these legal requirements (objectively measured values) pave the way for a reduced overall sound pressure level emitted from a certain tyre, they do not say much about the spectral composition of the emitted noise. Hence, the subjective comfort of the passengers in the car is not addressed by the legal limits. This is true especially for low-frequency sound and vibration (say below 50 Hz), which can adversely affect the psycho-physiological well-being of humans, as known from experiments using vibratory chairs (i.e., chairs equipped with a vibration accelerator).

Tyre class	Nominal section width: w (mm)	Limit values in dB(A)
C1A	w ≤ 185	70
C1B	185 < w ≤ 215	71
C1C	215 < w ≤ 245	71
C1D	245 < w ≤ 275	72
C1E	w > 275	74

Table 2: Legal values for class C1 tyres (valid since November 2012), depending on the nominal section width of the tyre [7]. C1 tyres are primarily used for standard passenger cars (e.g., vehicle category M1 with ≤ 9 seats including driver's seat and a power-to-mass ratio ≤ 120 kW/ton). Note that for reinforced (extra load) tyres, the limit values are 1 dB(A) higher. For more details on tyre classes C2 and C3, please refer to the EU tyre labelling regulation 1222/2009 [8].

OUTLOOK

The current legal requirements for tyre noise were presented for C1 class tyres. These requirements set the limits for exterior rolling noise (cf. tyre l-3(em)-20s4 (0550c3-10(.)(lu)dpa)-5(e)-3(d)-97-5(f)

[2] Directive 2001|43|EC of the European Parliament and of the Council of 27 June 2001 amending Council Directive 92|23|EEC relating to tyres for motor vehicles and their trailers and to their fitting. Official Journal of the European Communities.

[3] European environment agency (2010). "Good practice guide on noise exposure and potential health effects". EAA Technical report No. 11/2010.

[4] Graf R.A.G., Kuo C.-Y., Dowling A.P., Graham W.R. (2002). "On the horn effect of y tyre/road interface, Part 1: Experiment and Computation". Journal of Sound and Vibration 256, 417-431.

[5] ISO 10844: 2011 Acoustics – Specification of test tracks for measuring noise emitted by road vehicles and their tyres.

[6] Kuijpers A., van Blokland G. (2001). "Tyre/road noise models in the last two decades: a critical evaluation", internoise (The Hague).

[7] Regulation (EC) No 661/2009 of the European Parliament and of the council of 13 July 2009 concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefor. Official Journal of the European Union.

[8] Regulation (EC) No 1222/2009 of the European Parliament and of the Council of 25 November 2009 on the labeling of tyres with respect to fuel efficiency and other essential parameters. Official Journal of the European Union.

[9] Regulation No R117 of the Economic Commission for Europe of the United Nations (UN/ECE): Uniform provisions concerning the approval of tyres with regard to rolling sound emissions and to adhesion on wet surfaces and/or to rolling resistance.

[10] Sandberg U, Ejsmont J.A. (2002). Tyre/road noise reference book. Informex, Harg, SE-59040 Kisa, Sweden.