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2013 | INNSBRUCK | AUSTRIA
15.-18. SEPTEMBER 2013
NOISE CONTROL FOR QUALITY OF LIFE

Tire-road noise: an experimental study of tire and road design parameters

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ABSTRACT

It is widely known that road traffic noise has negative influences on human health. Hence, as tire-road noise is considered to be the most dominant cause of road traffic noise above 30-50 km/h, a lot of research is performed by the two involving industries: road authorities/manufacturers and tire manufacturers. Usually, the parameters influencing exterior tire-road noise are often examined separately, whereas it is the tire-road interaction which obviously causes the actual noise. An integral approach, i.e. assessing possible measures to reduce tire-road noise from both the road and the tire point of view, is needed to further reduce traffic noise. In a project Silent Safe Traffic, this tire-road interaction is studied in more detail without focusing on either tire or road but looking at the tire-road system. In this publication we present experimental results of tire and road design parameters influencing tire-road noise from a fixed reference tire-road configuration. The influence of tire tread pattern, compound and construction as well as the influence of road roughness, acoustic absorption and driving speed on the exterior tire-road noise, measured by a CPX-set up, is reported.
Keywords: Tire, Road, Measurement.

1. INTRODUCTION

The World Health Organization (WHO), together with the Joint Research Centre of the European Commission has recognized environmental noise as a serious health problem [1]. Road traffic noise constitutes most of the burden of all the environmental noise in western Europe. The European legislative authorities have acknowledged this fact and different road traffic noise regulations are therefore active. The European vehicles need to fulfill limits put on the accelerated Pass By test method as stated in the UN/ECE R51 [2]. Tires need to comply to limits on the Coast By test method mentioned in R661(limits) and R1222 (labeling) [3-4]. The standardized test method ISO 11819-2 (Close Proximity) enable road authorities to put targets and minimize the road contribution to tire-road

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noise [5]. By the ISO 11819-1 (Statistical Pass By) the road authorities can limit the Pass By noise, but the total traffic noise which includes also the amount of vehicles passing by is hard to manage.

The purpose of the above mentioned legislation is to minimize the overall traffic noise. The necessary approach is to label or limit the components separately. In Table 1 the four mentioned legislative methods are summarized together with the four main components specified in the methods: vehicle, tire, road and speed. The component under legislative limit is indicated by an **X** and the testing requirements of the other components are mentioned (-) or explicitly specified.

Table 1 – Overview of legislation methodology

Legislation method	Legislation purpose	Main components specified in method			
		Vehicle	Tire	Road	Speed [km/h]
R51	Vehicle	**X**	-	ISO10844	50 + Open Throttle
R661/R1222	Tire	-	**X**	ISO10844	70 – 90
ISO 11819-1	Road	-	-	**X**	Speedlimit
ISO 11819-2	Road	-	P1,H1 tires	**X**	40,50,80,100

A drawback of this approach is that each component will be separately optimized according to the appropriate standard or legislation. As the legislative process takes many years (up to some decades) often the references are outdated once the legislation is put into force. For example the ISO 11819-2 uses tires with 'old-fashioned' tread patterns and the R51, R661 and R1222 uses the ISO10844 road which is not being used anymore.

Technological improvements of one component are thus not coupled to the latest technology of another component, but to the (outdated) standards. This is especially true for tire-road interaction by which most of the tire and road performances are determined.

In the project 'Silent Safe Traffic' of the University of Twente, Apollo Tyres Global R&D, REEF Infra B.V., Stemmer Imaging B.V. and the province Gelderland follow a more holistic approach and the contribution of both the tire as well as the road design parameters are considered with respect to noise as well as wet grip.

2. OBJECTIVE

In this paper we investigate the influence of tire as well as road design parameters on the overall tire-road noise. This investigation is performed using the Close-proximity (CPX) method which will be shown to have a high correlation with the Coast By method. From a fixed reference tire-road-speed combination subsequently design parameters will be varied keeping the others constant. The design parameters under investigation are: tire tread pattern, road roughness & absorption, tire tread compound, tire construction and driving speed.

3. EXPERIMENTAL SET-UP

3.1 CPX set-up

The CPX set-up used is developed within the 'CCAR' project with TNO and the University of Twente and is shown in Figure 1. The self-induced wind noise plays a role only below 350 Hz for driving speeds up to 80 km/h and structural vibrations have no effect on the microphone signals [7].

Figure 1 – CPX measurement set-up.

The correlation between the CPX set-up and the Coast By method from R661 is examined by measuring simultaneously with both set ups 224 different tire-speed-road combinations mentioned in Table 2. The correlation between the front-rear averaged CPX Sound Pressure Level (SPL) and the Coast By level according to R661 is shown in Figure 2.

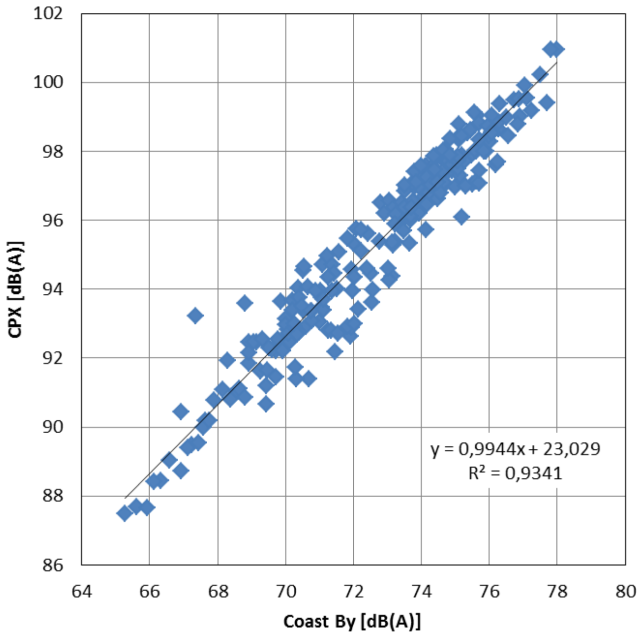

Figure 2 – Correlation of SPL measured by the CPX and Coast By method.

As can be seen from the figure there is a high correlation (R^2 = 0,93) between both measurement set-ups over all measured sound pressure levels ranging from 65 to 78 dB(A). Also the slope is almost unity indicating that the noise phenomena in both methods are the same. As such the results obtained through the CPX set-up can be used to predict the Coast By results.

The advantage of the CPX set-up over the Coast By method in the fact that only one tire needs to be measured and the set-up travels along with the tire. This gives more and better data-processing possibilities like tire tread order analysis via the coasting down method [8].

3.2 Experimental programs

The developed CPX set-up is used in four additional experimental research programs. Within these research programs the influences of the following tire and road design parameters are investigated: tire tread pattern, road & speed, tire construction and tire compound. In table 2 an overview of the performed research programs is given.

Table 2 – Overview experimental research programs

Investigated parameter	Tire variants	Road variants	Speed variants	Total variants
CPX – CB correlation	7	2	16	224
Tire tread pattern	16	1	2	32
Tire, Road & Speed	8	41	5	1640
Tire compound	6	1	2	18
Tire construction	14	1	2	28
Total				1942

To relate the programs a reference configuration is chosen: a slick tire (235/45R17) on ISO10844 road surface at 80 km/h. Tire and road design parameters are varied subsequently and reported below relative to this reference. The tire design parameters are manufactured by Apollo Vredestein B.V. and for the road design parameters the Kloosterzande test tracks has been used [9]. As the reference is a low noise configuration higher noise values thus indicate the potential of noise reduction still left within that design parameter.

4. RESULTS

4.1 Tire Tread pattern

Grooves in the tire tread pattern are needed for water storage and storage during rainy conditions preventing hydroplaning to happen at low speeds. The drawback of this geometrical tire roughness is that it generates a contact force variation resulting in vibrations and noise.

To study the influence of tire tread pattern design parameters like amount of tread blocks, block angle, etc. 16 tire tread pattern variants are tested and analyzed. These research tires give insight into the physics, but don’t indicate how much noise reduction potential is still left in the existing tire population.

Using the Apollo R661 database an average SPL of 73.7 dB(A) with a standard deviation of 1,6 dB(A) is calculated. This standard deviation of 1.6 dB(A) indicates the margin in which noise can be reduced without comprising safety.

In Figure 3 an example from the research programs is shown. The figure shows three commercial tires: winter (tyre 2), two summer (tyre 1,3) together with the slick (tyre 4). It can be seen that that the lowest commercial tire measured here is only 0.8 dB(A) higher than the slick tire. The mentioned safety requirements for hydroplaning prevent the noise to be reduced much more as indicated in earlier publications [10].

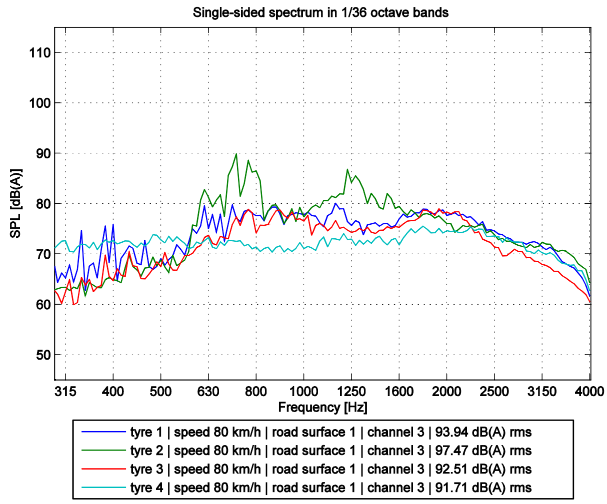

Figure 3 – Frequency spectrum of commercial winter tire (2), summer tire (1,3) and slick tire (4).

4.2 Road roughness & absorption

The noise reduction potential of the road is investigated by the 41 Kloosterzande test tracks. The average road noise for the slick at 80 km/h is found to be 91.0 dB(A) with a standard deviation of 2.7 dB(A). According to this standard deviation the noise reduction potential seems to be a bit more. A maximum difference is found of 5.6 dB(A). This effect can be explained by the two main road design parameters: road roughness and sound absorption.

The road needs to be rough for the same safety reasons as in the tread pattern case. Phillips et al [9] discriminated between positive and negative roughness. The roughness coming into contact with the tire is defined as positive roughness and the other as negative roughness. The positive roughness establishes real physical tire-road contact during rain (similar to the tread blocks) and hence need to be considered also as the impact source for noise. The negative roughness behaves as the tread grooves in which water can be stored and can (especially for open asphalts) be used for sound absorption.

The influence of positive roughness is considered by comparing roads with constant absorption coefficient [10]. In Figure 4 the results of three non-absorbing roads are shown: ISO10844 (road surface 1), SMA 0/11 (road surface 21) and surface dressing 11/16. The last one representing the worst case with a major difference of 10 dB(A) can be found. For the regular optimized road SMA 0/11 the potential noise reduction is with 3 dB(A) much less. The results indicate furthermore that also the road infrastructure should be maintained properly as wear and raveling increase the noise.

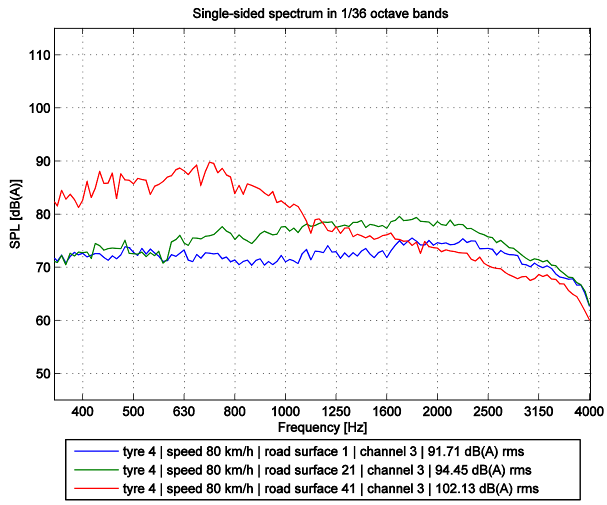

Figure 4 – Frequency spectrum of slick tire on ISO10844 (1), SMA 0/11 (21) and surface dressing 11/16 (41).

The negative road roughness exhibits an extra noise reduction potential. Interconnecting holes in porous asphalts enables pressure variations to travel inside the road and minimize the SPL. Noise phenomena like air pumping, but especially the sound reflecting properties are reduced enormously. To show the potential of sound absorption, Figure 5 shows the results of three roads are shown: ISO10844 (road surface 1), porous 2/6 (road surface 15) with on average 20% sound absorption and double layered porous 25 mm 2/6 on top of a 45 mm 11/16 (road surface 16) with around 35% sound absorption. Unfortunately the last two also have a 10 dB (ref 1 μm) higher texture amplitude) generating thus more road excitation.

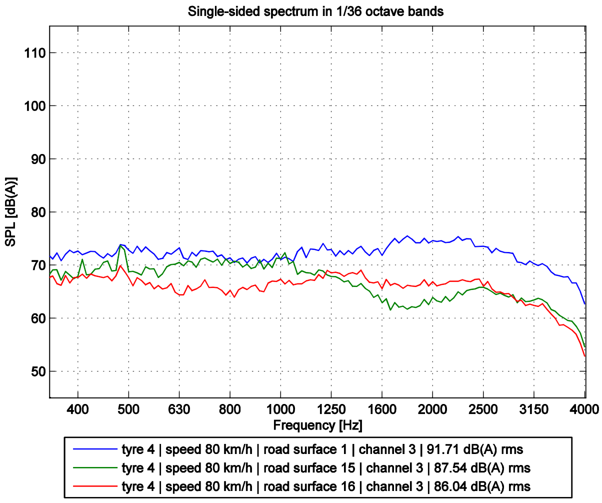

Figure 5 – Frequency spectrum of slick tire on ISO10844 (1),

SMA 2/6 (15) and 25mm SMA 2/6 on top of 45 mm 11/16 (16).

Despite the 10 dB higher texture amplitude and thus more road excitation of the two SMA road surfaces there is still a noise reduction of 4.2 and 5.7 dB(A) with respect to the ISO10844 surface. Depending on the road construction, the noise reduction potential may even be more. The main advantage of the porous asphalts is also that during rain water is stored and flows outwards beneath the top layer and is directly removed from the tire-road contact patch giving an enormous improvement in the safety aspects like braking, friction and increased visibility due to reduced splashing. The main technological challenge is to solve the reduced life time of these open asphalts.

4.3 Tire tread compound

In most tire-road noise publication the shore A hardness is used as measure for the tire's tread hardness. A more physical parameter is the stiffness and storage moduli. These mechanical properties for rubber are a function of the strain, frequency, temperature and history. The stiffness (E'), of the tread compound is a measure for how much the tire will deform due to the contact force. The loss modulus (E'') is as a measure for the compound's hysteresis reducing the travelling distance of vibrational waves. Their respective ratio tan(δ) = E'/ E'' is a combination of both and often used as a design parameter in rubber compounding.

Six tires with extreme different tread compounds have been manufactured and a mono blocked tire was hand cut. The mechanical properties are measured separately by a Dynamical Mechanical Analyzer. The average tan(δ) over the tread block impact frequency range was determined. The averaged tan(δ) versus the averaged Sound Pressure Level at CPX locations for four tires is shown in Figure 4. As can be seen, a higher tan(δ) reduces the noise and a maximum effect of around 1.5 dB(A) is achieved. Less stiff tire compounds have less steering / handling performance and comprises safety. A higher hysteresis at the tread impact frequency range often implies also having more hysteresis at low frequencies and as such increased rolling resistance [11].

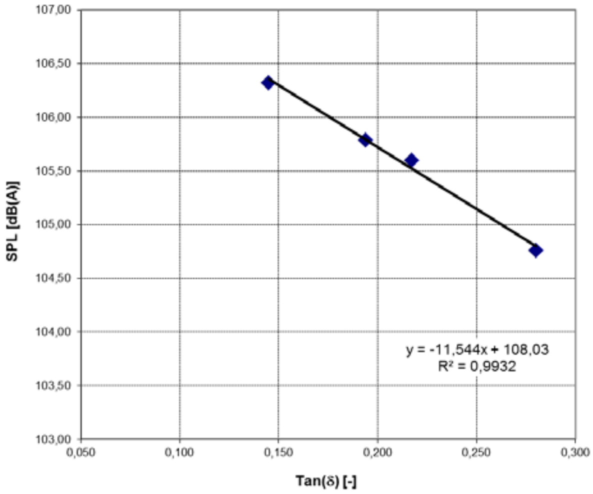

Figure 6 –Correlation of SPL measured at CPX with averaged tan(δ).

4.4 Tire construction

Roughly 90% of the tire stiffness originates from the air pressure inside the tire-rim cavity. The margin for the tire construction influencing the stiffness is therefore limited. Fifteen different tire construction variants with hand cut mono block pattern are tested. All have an increase at tread pattern impact frequency range and some have a (lesser) decrease at the other (road impact) frequency ranges. The maximum difference found was 2 dB(A). Saemann reported a maximum influence of tire construction including changing from summer to winter compound (!) of around maximum 3 dB(A) [12].

4.5 Driving speed

The last main influencing factor is the driving speed which follows the logarithmic relation:

$$SPL = A + B\log(V) \quad (1)$$

where A is about 16 and B is about 24 and V is the speed.

The tires are tested at 5 different speeds from 40 up to 120 km/h. In Figure 7 the frequency spectrum of the slick tire at the coarse surface dressing 11/16 (road surface 41) is shown at these five different speeds. From the figure it can be seen that much noise reduction can be achieved by lowering down the (maximum) driving speed. Tire-road noise already reduces 3 dB(A) when driving speeds are lowered from 120 to 100 km/h.

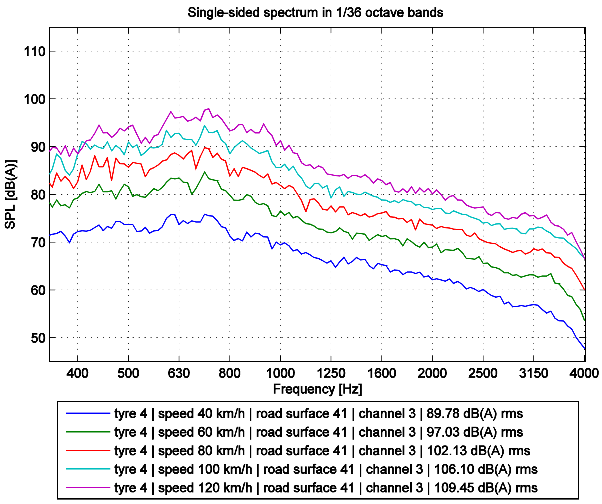

Figure 7 – Frequency spectrum of slick tire on surface dressing 11/16 (41) at five speeds.

5. CONCLUSIONS

The CPX set-up can used to represent the tire-road noise perceived at Coast By locations. The advantage of the first set-up is that it travels with the tire and better and more post-processing possibilities are available.

The experimental results are summarized in Table 3. It shows that most noise reduction potential of the separate design parameters are often already applied in commercial available tires and roads. A further optimization for noise often comprises the safety or the lifetime properties of tire or road. An integral and holistic approach is therefore needed in order to further optimize the tire-road configuration as it is the interface between both where all performances originate.

Table 3 – Noise reduction potential: A summary of the experimental results

Parameter	Noise reduction potential
Tread pattern	~ 1-2 dB(A)
Road roughness	~ 3 dB(A)
Road sound absorption	~ 6 dB(A)
Tire tread compound	~ 1 dB(A)
Tire construction	~ 2 dB(A)
Driving speed	~ 3 dB(A)

ACKNOWLEDGEMENTS

The presented work is part of the project "Stil Veilig Wegverkeer" in the framework of GO and funded by the “Europees Fonds voor Regionale Ontwikkeling” of the European Union together with Regio Twente and Province Overijssel. Apollo Tyres Global R&D B.V. is gratefully acknowledged for the permission to publish.

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