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Factors influencing tyre/road noise under torque

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ABSTRACT

High levels of road traffic noise negatively impact public health in many parts of Europe, especially in cities. The introduction of electric mobility is often seen as one of the best measures to reduce noise exposition in urban environments. Compared to internal combustion engine vehicles (ICEV), there is an increased importance of tyre/road noise for electric vehicles (EV) because of the reduced masking by the powertrain noise. This effect increases further under acceleration. Firstly, it is known that in most cases tyre/road noise is higher under torque than for free rolling. Secondly, in situations which are characterized by increased driving torque, the lack of masking from powertrain noise for EVs is especially evident when compared to ICEVs. The aim of the LIFE E-VIA project is to reduce road traffic noise in cities by providing noise optimized road surfaces and tyres for EVs. Because of the mentioned effects, not only constant speed driving needs to be considered but also accelerated driving. Consequently, within E-VIA noise measurements from an indoor drum and a test track have been used to investigate the impact of different tyre parameters and operating conditions on the change of tyre/road noise under acceleration when compared to free rolling.

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1. INTRODUCTION

High levels of road traffic noise negatively impact public health in many parts of Europe, especially in cities [1, 2]. One of the best ways to reduce noise exposition in urban environments is the introduction of electric mobility. For electric vehicles (EV) there is an increased importance of tyre/road noise because of the reduced masking by the powertrain noise compared to internal combustion engine vehicles (ICEV). Studies have shown that this effect increases further with acceleration, i.e. with tyre torque [3]. Even though also characterized by the occurrence of torque, for normal braking and recuperation, in contrast, only small changes have been observed [4].

There are two main explanations for the increased relevance of tyre/road noise under acceleration. Firstly, there are additional noise generation mechanisms which are of minor importance under normal driving but become relevant with increased torque. These are stick-snap and snap-out phenomena which can appear under torque conditions in addition to the radial block impacts which, together with the road surface, are the main tyre excitation mechanism for free rolling [5]. Both stick-snap and snap-out potentially lead to an additional tangential excitation of the tire structure. These effects are more pronounced for EVs than for ICEVs since the former are typically characterized by higher-power-to-mass ratios and considerably wider RPM ranges at which maximum torque is available. Secondly, in many situations which are characterized by an increase in driving torque, such as sportive open-throttle acceleration, the lack of masking from powertrain noise for EVs is especially evident when compared to typical ICEVs with comparably noisy powertrains under acceleration [4].

Within the LIFE E-VIA project [6] road traffic noise in in urban environments shall be mitigated by providing noise optimized road surfaces and tyres for EVs. Because of the mentioned effects, not only constant speed driving needs to be considered but also accelerated driving. In this study it is investigated to which extend the tyre/road noise generation under acceleration is influenced by tyre and surface properties, or environmental or testing conditions.

2. ACCELERATED PASS-BY NOISE MEASUREMENTS

Pass-by noise measurements have been carried out based on UNECE Regulation 51, Revision 3 [7]. Independent of the type of pass-by (without/with acceleration), only measurements for which the test vehicle passes the microphone position with a speed of 50 km/h ± 1 km/h are considered.

For free rolling (in the following also called *CRS - constant rolling speed*) the used metric is the maximum sound pressure level recorded during the pass-by, $L_{max,\mathrm{CRS}}$. Accelerated pass-bys are conducted for several different accelerations a ranging from roughly 1 $\mathrm{m/s^2}$ to 3 $\mathrm{m/s^2}$. From a polynomial interpolation based on the maximum sound pressure levels of the individual pass-bys, the accelerated pass-by noise level for a reference acceleration of 2 $\mathrm{m/s^2}$, $L_{max}(a = 2\,\frac{\mathrm{m}}{\mathrm{s}^2})$, is estimated, see Figure 1. From this the sound pressure level change under torque follows as

$$\Delta L_{\mathrm{acc}} = L_{max}(2\ \mathrm{m/s^2}) - L_{max,\mathrm{CRS}} \quad . \tag{1}$$

If not specified otherwise,

1. all measurements have been conducted using electrically powered vehicles, and
2. all pass-bys which are analysed in the same evaluation have been measured with the same test vehicle, on the same test track, and under comparable environmental and operational conditions.

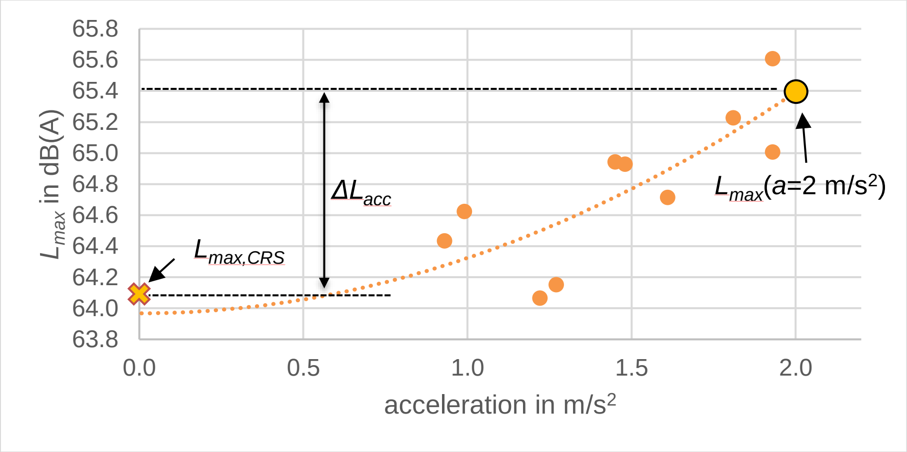


Figure 1: Example for the evaluation of accelerated pass-by measurements.

3. TYRE/ROAD NOISE UNDER FREE AND ACCELERATED ROLLING

Figure 2 shows the results of pass-by noise measurements for six different summer tyres. There is no systematic relation between the constant speed noise levels and the accelerated noise levels. For example, T1 is the most silent tyre without acceleration but at the same time the sound pressure level for this tyre increases by ca. 3 dB(A) for an acceleration of 2 m/s^2. Consequently, T1 is the second loudest tyre at this acceleration. In contrast, T6 is the loudest tyre for free rolling (ca. 2,5 dB(A) louder than T1) but the pass-by noise levels decrease slightly under acceleration, resulting in T6 not only being among the two most silent tyres at 2 m/s^2 but it also now being 1 dB(A) less noisy than T1. A similarly low sound pressure level increase under torque conditions can also be observed for tyre T4.

For all other tyres ΔL_{acc} is in the range of roughly 1 dB(A) to 2 dB(A). Overall, there is significant change of relative noise level differences between the tyres depending on the driving conditions without/with torque.

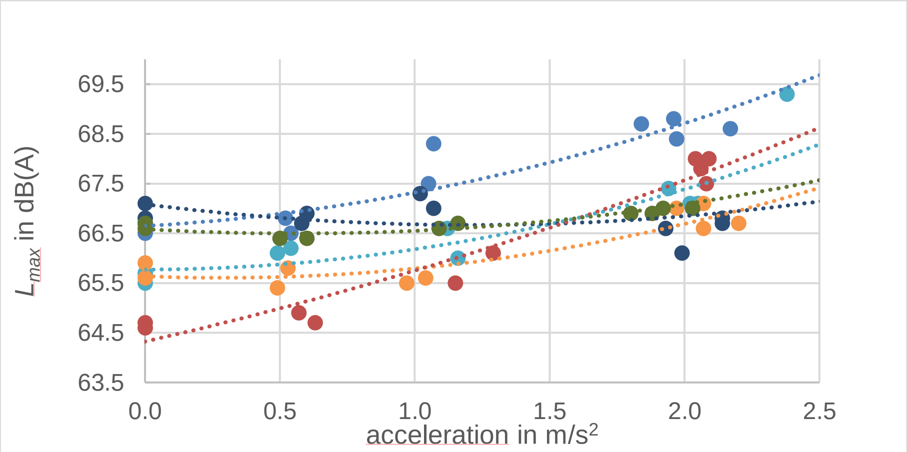


Figure 2: Pass-by measurements without/with acceleration for six different summer tyres: T1, T2, T3, T4, T5, T6.

Table 1: Example for the temperature influence on the accelerated pass-by noise levels.

Measurement	**Air temp. in °C**	**$L_{max,\mathrm{CRS}}$ in dB(A)**	**$L_{max}(2\mathrm{m/s^2})$ in dB(A)**	**ΔL_{acc} in dB(A)**
1	34,9	64,1	65,3	1,2
2	15,6	64,3	64,4	0,1

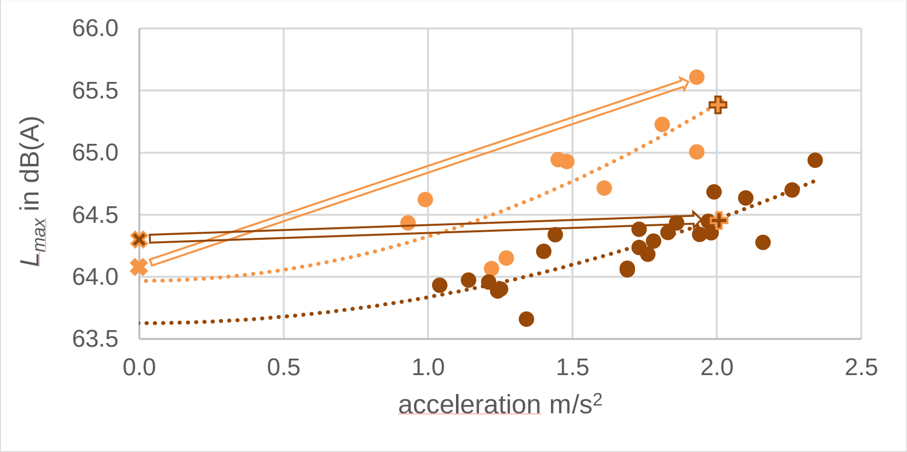


Figure 3: Temperature influence on the accelerated pass-by levels for 34.9 °C and 15.6 °C. × $L_{max,CRS}$, + $L_{max}(2\ \mathrm{m/s^2})$, ⋯ polynomial interpolation.

4. FACTORS INFLUENCING TYRE/ROAD NOISE UNDER TORQUE

4.1. Air temperature

In a large set of conducted measurements an influence of the air temperature on the sound pressure level change under acceleration could be observed. In Table 1 and Figure 3 an example for this is shown in which pass-by noise levels for identical samples of a summer tyre were measured at different air temperatures of 34.9 °C (measurement 1) and 15.6 °C (measurement 2). The constant speed sound pressure levels differ by only 0.2 dB(A) between the two measurements. This is within the expected measurement uncertainty. Under acceleration, however, the sound pressure level increase is 1.2 dB(A) for the measurement performed with warmer ambient temperature, while there is no significant level increase for the colder measurement.

In other words, a moderate temperature increase of roughly 20 °C, which easily can be observed during a sunny test day in spring or autumn, has a major impact on if and to which extent, pass-by noise levels increase under acceleration. To facilitate the comparability of accelerated pass-by noise measurements it is thus of importance to assure that testing is conducted at comparable air temperatures.

4.2. Test vehicle

Figure 4 and Figure 5 give an impression of the possible influence of the test vehicles on the pass-by noise measurements. For this, six different summer tyres were measured with two different test vehicles on the same test track and under similar environmental conditions. The cars were comparable electric vehicles from the same market segment from two different manufacturers.

Figure 4 shows that for free rolling there is a generally good correspondence between the measurement results for both test vehicles. For the sound pressure level change under acceleration there is, as depicted in Figure 5, a considerably worse agreement between the vehicles. The measurement results are distributed in a cross-shape. Each cross-arm signifies a set of tyres for which there is small range of values of ca. 0.5 dB(A) for one vehicle, and a larger range of values of 1.5 dB(A) (vertical cross arm) and 2.5 dB(A) (horizontal cross arm) for the other vehicle. Which vehicle is characterized by the large, and which by the small range of values varies with each cross arm.

Consequently, it must be assumed that an assessment of the accelerated pass-by noise levels cannot be done purely based on the tyre, rather the combined tyre/vehicle system needs to be considered.

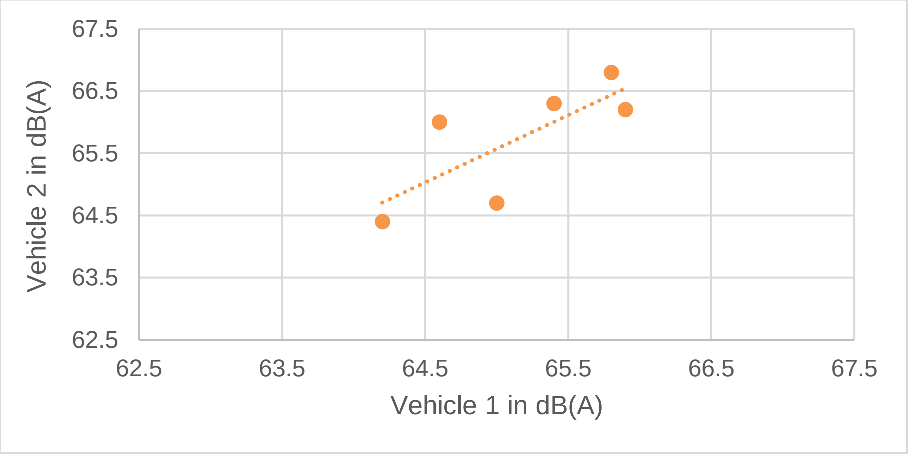


Figure 4: Free rolling - $L_{max,\mathrm{CRS}}$ for each test vehicle. ⋯ linear regression all data points.

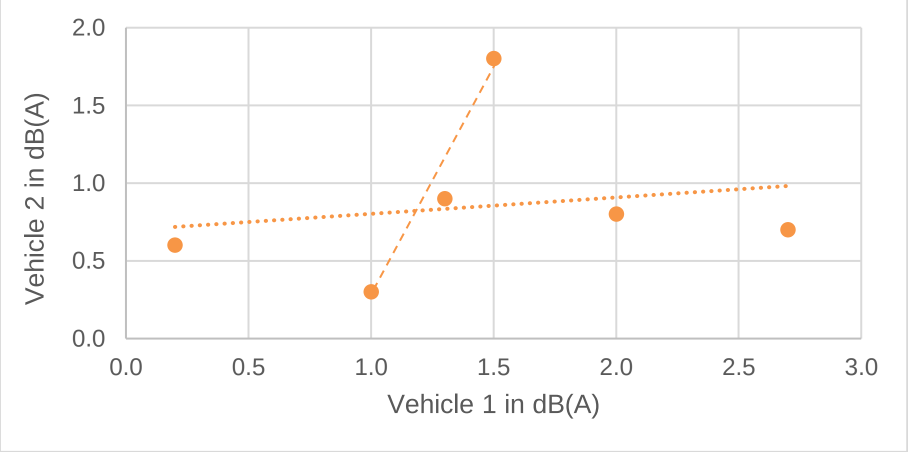


Figure 5: Acceleration: ΔL_{acc} for each test vehicle. ⋯ and - - - linear regressions for data points forming horizontal and vertical “cross-arms” of data (see text).

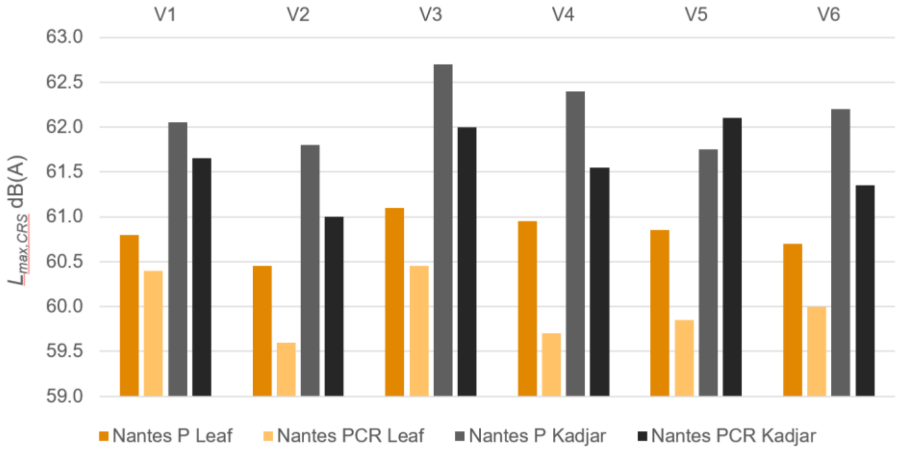


Figure 6: E-VIA measurements for free rolling with prototype tyres (V1-V6) on prototype road surfaces (P/PCR - without/with crumb rubber).

4.3. Road surface

Within the E-Via project two prototypes of a low-noise optimized road surface were built at Université Gustave Eiffel’s test track in Nantes, France [4]. These are surfaces of type very thin asphalt concrete with maximum aggregate sizes of 6 mm (VTAC 0/6). One of these variants was without crump rubber (P), the other one with crumb rubber (PCR) in the mixture. The mean profile depth *MPD* is 0.39 mm and 0.30 mm for the P and PCR surfaces, respectively. The absorption is around 0.1 or lower for frequencies below 2 kHz. In the 1-kHz and 1.25-kHz third octave bands the P surface has a noticeable lower absorption than the PCR surface. Between 2 kHz and 4 kHz, in contrast, the P surface has higher absorption coefficients of 0.20 to 0.25 than the PCR surface with ca. 0.12 to 0.18.

The measurements were conducted using six prototype tyres which had been designed as technology demonstrators. Besides an electric Nissan Leaf, a Renault Kadjar with internal combustion engine was additionally used as test vehicle.

Results for free rolling are shown in Figure 6. For the ICEV Renault Kadjar the measured sound pressure levels are in all cases higher than those for the EV Nissan Leaf. This is as expected because of the additional powertrain noise. The difference between Kadjar and Leaf is on average 1.5 dB(A). Independent of this test vehicle influence, it can be observed that, with one exception (Kadjar with tyre V5), the pass-by noise levels on the PCR surface with crumb rubber are 0.5 dB(A) to 1.3 dB(A) lower than those on the P surface without crumb rubber.

A significantly different picture is obtained for pass-by noise levels with full acceleration which are shown in Figure 7(a). In contrast to the free rolling results the Leaf is now for all but one surface/tyre combination (V5/PCR) louder than the Kadjar. This is despite the lack of a significant increase in powertrain noise during acceleration of the Leaf when compared to the Kadjar. Likely, it is caused by the differences in the maximum acceleration which is achieved under wide-open throttle. This is 1.4 m/s^2 for the Kadjar but 4 m/s^2 for the Leaf.

Focussing on the road surface influence in a third of all cases the PCR pavement is now the louder surface. Concentrating on the measurements with the Leaf, the PCR surface is in 50 % of the cases by approximately 0.5 dB(A) louder than the P surface.

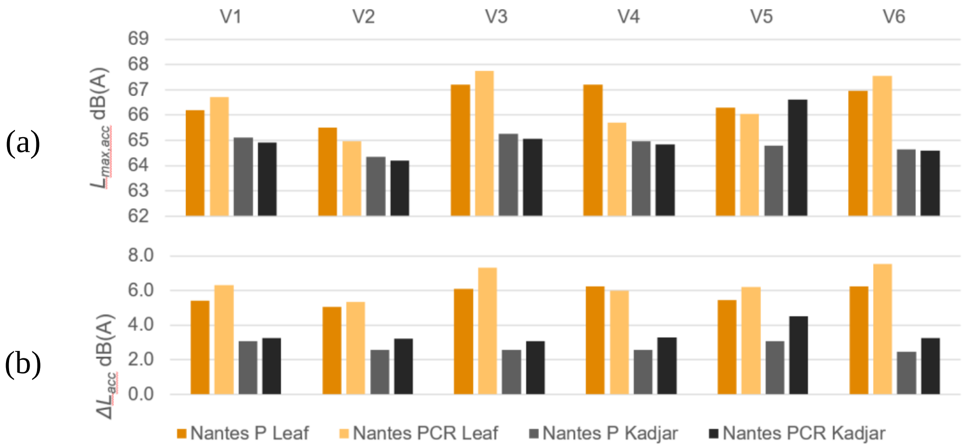


Figure 7: E-VIA measurements for full acceleration with prototype tyres (V1-V6) on prototype road surfaces (P/PCR - without/with crumb rubber). (a) Maximum pass-by levels under acceleration. (b) sound pressure level change under acceleration.

An even more pronounced effect can be observed in Figure 7(b) which shows the actual sound pressure level change under acceleration ΔL_{acc}. Except for the Leaf with tyre V4, the increase is always higher on the PCR pavement with crumb rubber than on the P surface without.

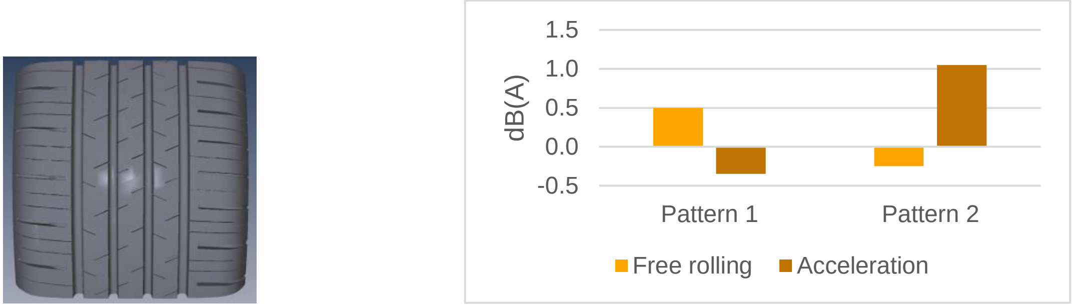
Like the results for the different summer tyres which have been presented in Section 3, it can also for the road surfaces be said that the most silent pavement for free rolling is not necessarily also the most silent pavement with acceleration.

4.4. Tyre pattern

Based on the measurements at the test track in Nantes which have been presented in the previous section, it is also possible to investigate the influence of tyre pattern properties on the sound pressure level change under acceleration. For this the serial production tyre shown in Figure 8(a) was chosen as reference. Based on this two pattern variants with different shear-to-radial-stiffness ratios as shown in Table 2 were evaluated. For these, the averaged sound pressure level differences to the reference under free rolling and with full acceleration are shown in Figure 8(b). Similarly to the other shown examples, also here a discrepancy between pass-by noise levels at constant speed and under acceleration can be observed: pattern 1 with the higher shear stiffness is louder than the reference for free rolling, but more silent under acceleration. The pattern with the lower shear stiffness, pattern 2, in contrast, is more silent than the reference at constant speed but louder under acceleration. This signifies that also for measures on the tyre it has to be independently considered which influence these have on the respective pass-by noise levels without and with acceleration.

Table 2: Pattern variations.

	ratio shear stiffness/ radial stiffness
Pattern 1	> Reference
Pattern 2	< Reference



(a) (b)

Figure 8: (a) Serial production reference tyre. (b) Sound pressure level differences to reference for patterns 1 and 2. Average for P and PCR road surfaces and Leaf/Kadjar test vehicles.

4. CONCLUSIONS

Based on the presented results the following can be generally concluded for accelerated pass-bys:

- It is not possible to consider tyre and vehicle independent of each other. Quite contrary, they need to be considered as one combined system for pass-by measurement purposes.
- The sound pressure level change in comparison to free rolling depends to a large extent on environmental conditions, in particular the air temperature, and the road surface.

With respect to the development of a low-noise optimized tyre for electric vehicles within the framework of the E-Via project this means that the optimization process needs to consider the interaction of vehicle, road surface and tyre design for both free rolling and under acceleration. Only such an approach can guarantee that a reduction of tyre/road noise will be achieved under the assumed urban traffic conditions.

5. ACKNOWLEDGEMENTS

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