Tire-road noise measurements at the test rig of BASt

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Abstract

The primary source of traffic noise at common road speeds is tire-road noise. Different standards are in use for the noise measurements. In Europe, measurements are taken by the close-proximity method (CPX), while the on-board sound intensity method (OBSI) is used in the USA. Moreover, in Austria another standard named RVS 11.066 is used. The measurements are typically done outside, resulting in restrictions due to ambient conditions. To overcome such limitations the Federal Highway Research Institute (BASt) has developed their own test rig Prüfstand Fahrzeug/Fahrbahn, PFF. This inner drum test rig was built to make in situ acoustic measurements. Due to the stationary wheel, additional measurement instrumentation can be used. On the other hand, one has to deal with some limitations. The inherent noise of the PFF, sound reflections and the influence of the different curvature between tire and the road surface can probably lead to deviations compared to outdoor measurements. Another big issue is the realistic road surface in the test rig. To investigate the properties of the drum test rig, extensive measurements have been performed and the results will be presented.

Introduction

Tire road noise is a main component in traffic noise, especially when driving with constant speed or less engine load at driving speeds of approximately 30 to 110 km/h [1][2]. To characterize tire road noise several standardized measurement methods exist, which can be divided in far and near field methods. In the following, we will concentrate on near field methods. Thereby, the usage of the methods will vary in the countries. In Europe measurements were taken by the close-proximity method (CPX) [3]. Here, two microphones are mounted near the sidewall of the tire in a trailer lined with sound absorbing material. In Austria, additionally the RVS 11.066 [4] is used, having also two microphones in a trailer but on different positions. One position is similar to CPX, near the sidewall of the tire, whereas the other position is behind the wheel. Moreover, in the USA the on-board sound intensity (OBSI) method [5] is used. Here, two intensity probes are placed alongside the leading and trailing edge of the tire. The probes are mounted directly on the vehicle, which is different form CPX and RVS. During the measurements ambient conditions like vehicle speed, temperature, wind speed, etc. have also to be recorded. In Fig. 1 one can see the different measurement positions of the standards.

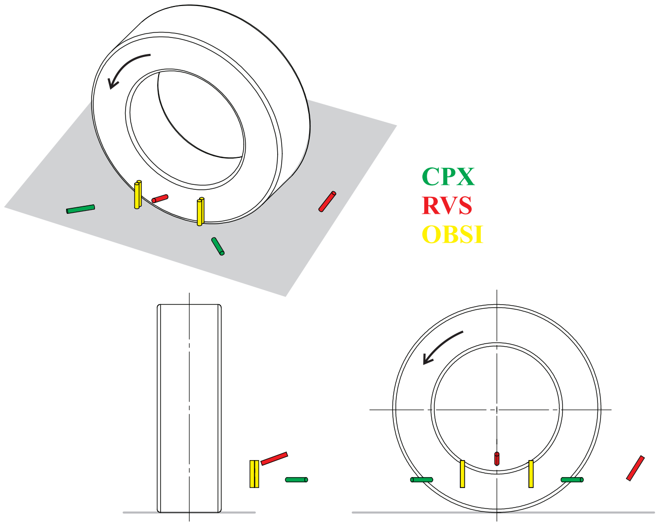

Figure 1: Measurement positions of the different standards.

Comparison of the near field methods

An overview of the conditions which has to be fulfilled for each particular near field method in the measurements is depicted in Tab. 1. Comparing them, one can see that there are less similarities between the standards. Worth mentioning is that in the RVS a PIARC tire with four longitudinal grooves have to be used, whereas the other methods use standardized tires with a tread pattern. According to Tab. 1 the parameters for the measurement campaign at the vehicle-pavement interaction facility (PFF) have been chosen. Thereby the measurements were made with three tires (see Fig. 2), three tire loads (3200, 3530, 4000 N) and ten different speed values (30, 40, 50, 56, 60, 72, 80, 97, 100, 120 km/h). The tire pressure was fixed by 2 bar.

Table 1: Comparison of the standardized near field methods

	CPX	OBSI	RVS
Test speed (km/h)	40, 50, 80, 100 (± 5 %)	40, 56, 72, 97 (± 1.6 km/h)	30, 50, 80, 100 (± 5 %)
Tire load	3200 (± 200 N)	3530 (± 440 N)	4000 (± 500 N)
Tire pressure	2 (± 0.1 bar)	2.07 (± 0.14 bar)	2.3 (± 0.2 bar)
Test section	20 m	134 m (± 3 m)	500 m
A-one third octave	315 Hz – 5 kHz	400 Hz – 5 kHz	250 Hz – 10 kHz
Reference test tire	SRTT 225/60 R16 AV4 195/80 R14	SRTT 225/60 R16	PIARC 165/80 R15

Figure 2: Reference test tires (left) AV4 (middle) SRTT (right) PIARC.

Vehicle-Pavement Interaction Facility (PFF)

In corporation with the Federal Highway Research Institute (BASt) tire/pavement noise measurements in the near field of the tire were taken at their vehicle-pavement interaction facility. The test facility was primary designed for acoustic noise measurements, but also rolling resistance measurements can be done. At the measurements the tire and pavement temperatures will also be recorded. In Fig. 3 one can find a schematic drawing of the PFF. Their test facility (inner drum test rig) has an inner diameter of 5.5 m and weights 32 t. The maximum speed of the test rig is 280 km/h and the maximum wheel load which can be applied is 6500 kg. Further information about the PFF can be found in [6]. In the drum different roadway surfaces can be installed by roadway cassettes. During the measurements a safety-walk [7] was installed in the drum.

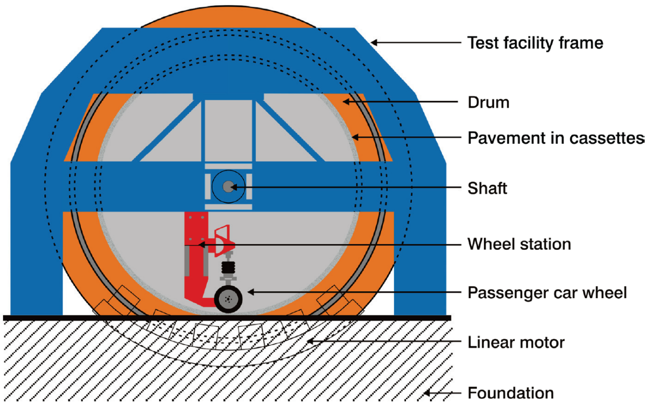

Figure 3: Schematic drawing of the vehicle-pavement interaction test facility (PFF) [6].

Results

Next, selected results of the measurements will be given. Tire/road mechanisms can be divided into vibrational and aerodynamical mechanisms. The contributions of them to the tire/road noise may vary for different tires, roads and operating conditions. Hereby, the first mechanisms mostly occur below 1000 Hz and the others above it. One of the most important vibrational mechanism is the tread impact, which can be influenced by the tread pattern design. The frequencies f_B which are excited by the tread impact can be calculated through [1]

$$f_B = \frac{N}{U} v = \frac{v}{b}, \tag{1}$$

where N is the number of rubber blocks on the tire circumference, U the tire circumference, v the vehicle velocity and b the block length. Due to the fact that the PIARC only has longitudinal grooves, this generation mechanism can be ruled out for it. In the sound pressure level (SPL) spectrum of the AV4 and the SRTT (see Fig. 4) one can find the fundamental frequency of the block impact and some higher harmonics of it. At lower speeds the tread impact frequencies are more dominant and one can also find the second harmonic, whereas at higher speed values just the first harmonic can be seen. If the speed increases, the frequencies will raise up in accordance to (1). Furthermore, a broadband increase over the frequency range of 10 dB can be observed if the speed raises from 40 to 80 km/h. Another increase of speed from 80 to 120 km/h will enlarge the sound pressure levels L_p by further 5 dB. The previously described behavior can be found at both tires, AV4 and SRTT.

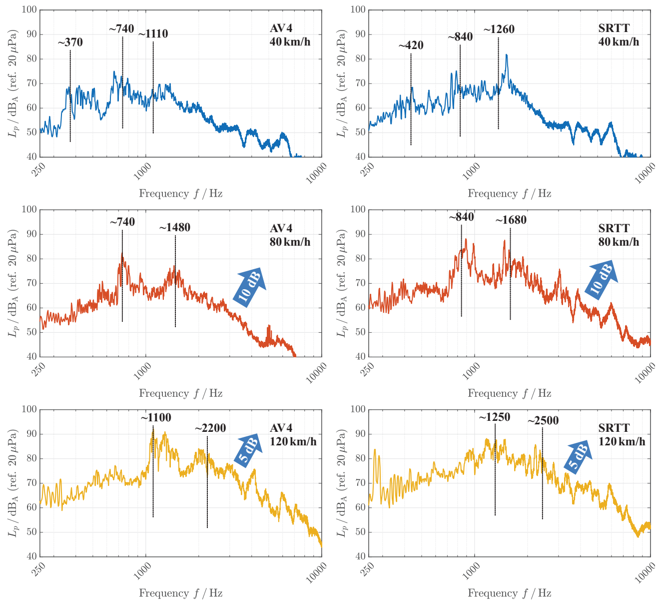

Figure 4: SPL spectra of AV4 and SRTT at tire load 3530 N at the RVS microphone behind the tire.

Also for the PIARC the same enhancement in the SPL arises (see Fig. 5). Due to the longitudinal grooves of the PIARC, pipes will be formed between the tire and the road surface. This aerodynamical mechanism is here much more pronounced than at the SRTT and AV4, where it can not be found that clear. The resonance frequencies f_n for these pipes are given by [8]

$$f_n = \frac{nc}{2(L + 0.8d)}, \tag{2}$$

where n denote an integer number, c the speed of sound, L the pipe length and d the pipe diameter. In dense surfaces (like the safety walk) this effect is more significant than for porous surfaces. The contact patch area

A, which should be the basis of the estimation of L is provided by [1]

$$A = \frac{F_V - kx}{p_i}, \tag{3}$$

with F_V the tire load, k the stiffness of the carcass, x the vertical deflection and p_i the internal tire pressure. A typical value for kx is $\approx 0.15F_V$. In Fig. 5 the estimated value for the pipe resonance is depicted.

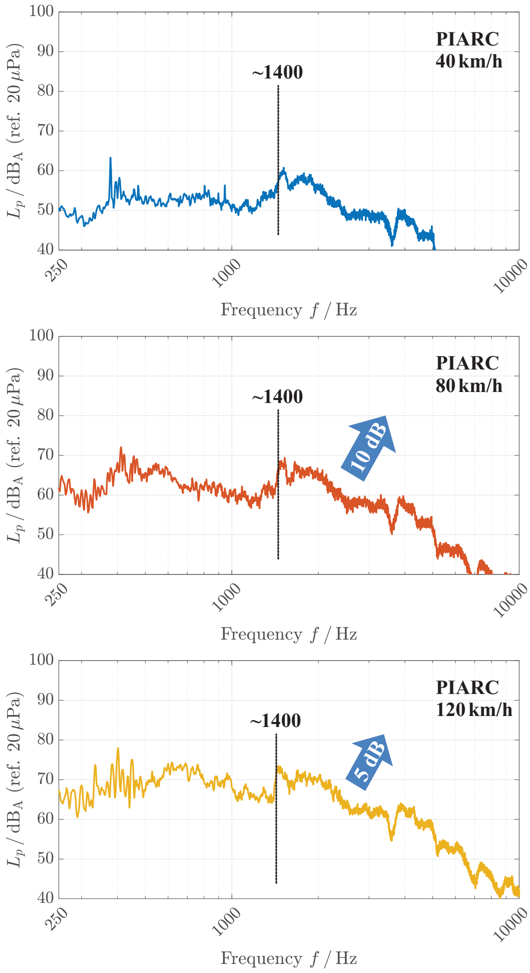

Figure 5: SPL spectra of PIARC at tire load 3530 N at the RVS microphone behind the tire.

Next, CPX results of the three different tire types and loads at various speeds will be given (see Fig. 6). Here, the SRTT shows a neglectable influence of the tire load at the different speed values. The same holds for the PIARC above the one-third octave center frequency of 630 Hz. Especially, the one-third octave level at 400 Hz shows a relatively strong dependency on the tire load. Interestingly, the one-third octave level of the AV4 at 800 Hz and 80 km/h is higher at a lower tire load. Apart from that, the tire load shows less influence on the one-third octave levels. Because of the tire load independence on the one-third octave levels at the investigated speeds the SRTT may be the most suitable tire for the standardized measurement methods. In Fig. 7 a comparison of the near field standards is depicted. Due to the fact that CPX and OBSI have nearly the same measurement positions

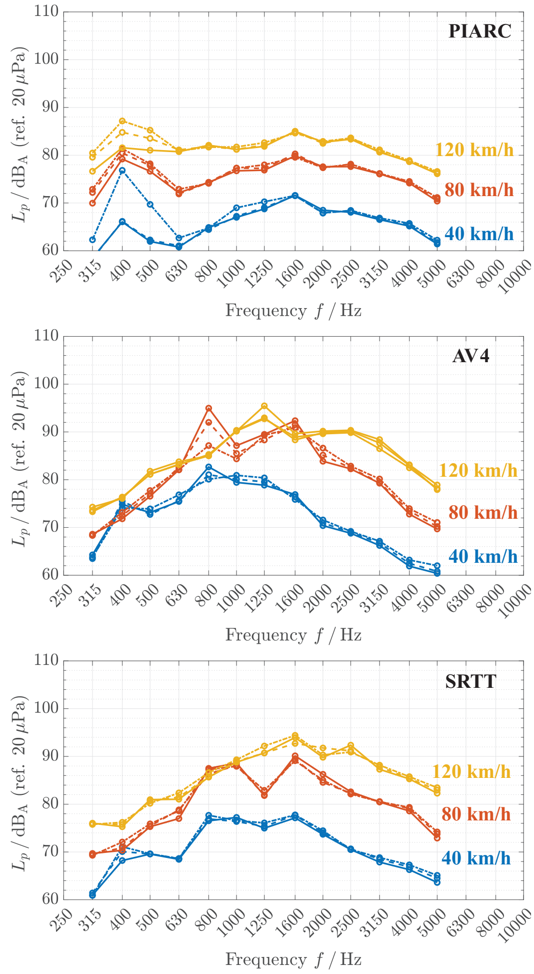

Figure 6: CPX results of the three tires, different speeds and tire loads (solid) 3200 N (dashed) 3530 N (dashed-dotted) 3530 N.

the difference of the levels is relative small. However, the RVS levels are much higher. This can be attributed to the horn effect [8]. The geometry between tire and road surface is shaped like an exponentially horn. Through the impedance jump due to the change of the geometry the radiated sound will be amplified. Since the microphone in the RVS is positioned behind the tire, in the horn throat, higher levels will occur. Now, comparing the CPX and OBSI one-third octave levels one can observe an interesting behavior. In the higher frequency range approximately above 1600 Hz the CPX levels are slightly higher than OBSI.

Conclusion

Known tire/road noise mechanisms have been observed in the results of the measurements at the vehicle-pavement interaction facility (PFF) of BASt. Moreover, the tread pattern impact can be concluded to be a big contributor to tire/road noise. Comparing the different near field methods, the RVS levels are higher than CPX and OBSI, while CPX and OBSI provide nearly the same levels. Next, the results obtained at the PFF should be compared to outdoor measurements to see if same results can be achieved. It should also be mentioned that

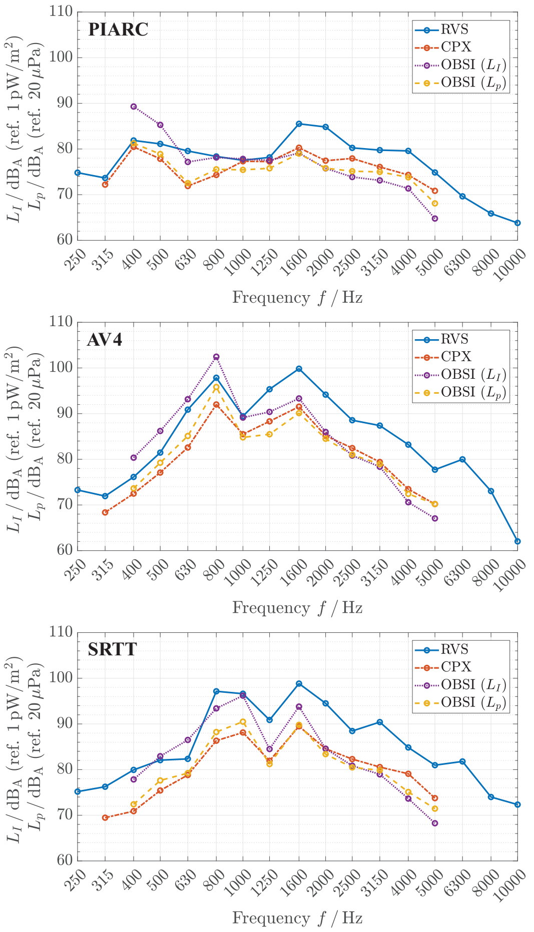

Figure 7: Comparison of the standardized near field methods at 80 km/h and 3530 N.

the measurements were made on a safety walk, so the results may differ on real road surfaces.

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