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INFLUENCE OF VELOCITY ON THE FREQUENCY SPECTRA OF SMA 11 ROAD SURFACE MEASURED BY CPX METHOD

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ABSTRACT

Noise affects the health of the citizens. Its primary source is transport, especially road transport. Road noise is primarily caused by the vehicle's combustion engine, the contact of the tyre with the road surface, and airflow around the vehicle (depending on the vehicle's velocity). In cities, the most common noise is noise generated by the contact between the tyre and road surface, so-called tyre/road noise. The close-proximity (CPX) method is one of the most objective ways of measuring road surface noise. It uses microphones mounted near the reference tyre so the surrounding environment can't affect the measured noise values.
This paper presents the results from measurements of the reference asphalt surface using the CPX method at the different velocities using all six microphones. The third-octave band spectra for individual microphones were analyzed. The highest differences in trend lines are achieved at frequencies below 1000 Hz. The most significant differences of up to 5.8 dB(A) between the noise spectra values of individual microphones were found at the highest measured velocity for low frequencies.

Keywords: *tyre/road noise, third-octave frequency spectra, CPX method, road pavement, velocity.*

1. INTRODUCTION

Noise is a serious pollutant that not only annoys or disturbs sleep but also negatively affects human health [1]. The dominant noise source in residential areas is traffic, especially road traffic. One of the primary sources of road noise is contact between the tyre and road surface, the so-called tyre/road noise or rolling noise. This noise prevails from a 40 km/h velocity in modern passenger vehicles with combustion engines; in electric motor vehicles, it prevails from a 20 km/h velocity. This type of noise prevails over velocities of around 160 km/h [2, 3]. Engine noise dominates at lower velocities for vehicles with combustion engines, while aerodynamic noise dominates at higher velocities. Tyre/road noise is mainly influenced by the type and condition of the road surface and the velocity of vehicles.
This paper presents the tyre/road noise measurement results on one surface type at three different velocities. The average values from the mandatory and all six microphones with the frequency spectra measured by each microphone are examined.

2. MEASUREMENTS AND METHODS

2.1 CPX method

The measurements were carried out using the CPX method on a dedicated open trailer designed by the Transport Research Centre (CDV). The trailer can be seen in Fig. 1 and complies with the requirements of ISO 11819-2 [4].
The six microphones were mounted according to the standard around the reference tyre (see Fig. 2). Each of the six microphones met the calibration requirements and was equipped with an amplifier and a protective wind cover.
The Uniroyal Tigerpaw 225/60 R16 SRTT passenger car tyre (designated P1 in ISO/TS 11819-3) was used for all measurements. The velocity, air temperature and surface temperature were continuously recorded during all measurements. The obtained values were used for calculation corrections.

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Figure 1. Open CPX trailer used for measurements (designed by CDV).

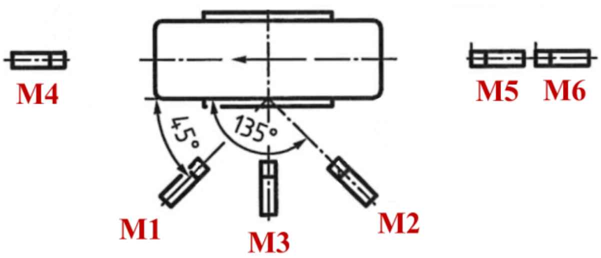

Figure 2. Microphones around the reference tyre (M4 – front optional microphone, M1 – front mandatory microphone, M3 – middle optional microphone, M2 – rear mandatory microphone, M5 – rear optional microphone, M6 – rearmost optional microphone; blue numbers – heights in meters; green numbers – distances in meters) (adjusted from [4]).

2.2 Surface and velocities

Measurements were performed for the surface stone mastic asphalt with maximum grain site 11 mm with increased resistance to permanent deformation (SMA 11 S) at velocities 30, 80 and 130 km/h. The idea of the research was to measure the surface at 80 km/h, which is prescribed by the standard ISO 11819-2, and then use very low and high velocities. The thirty-kilometre option corresponds to the increasing number of zones 30 – limiting velocities from 50 km/h to 30 km/h. As mentioned in the introduction, the noise from rolling tyres starts to dominate in electric motor vehicles from 20 km/h. Thus, it would be advisable to deal more with these low velocities. Velocity 130 km/h is even the maximum velocity allowed for highways in the Czech Republic. The surfaces were older than 10 years and showed no signs of damage (e.g. holes, cracks, etc.).

3. RESULTS AND DISCUSSION

The results present information on the impact of driving speed on rolling noise near the measuring tyres and the noise distribution in the third-octave band. Using 315–5000 Hz frequencies is sufficient for noise assessment according to the 11919-2 standard. For the results presented in this paper, 50 Hz –10 kHz frequencies are used. Using a third-octave spectrum, the graphs show how the surface noise behaves at low frequencies.
It's important to note that locally measured values may show differences from other locations with similar parameters. However, these differences mostly correspond to measurement uncertainties. For interpreting the results, it should be kept in mind that the inherent uncertainty of one measurement for one location is 1 dB(A).

3.1 $L_{CPX:P1}$ microphones' comparison

The column chart below illustrates the $L_{CPX:P1}$ comparison of noise measured by each microphone at different velocities. The grey circle represents the arithmetic average value of the two mandatory microphones (M1+M2), and the white diamond represents the arithmetic average value of all six microphones. The sequence of the bars in the column chart (Fig. 3) corresponds to the order of the microphones mounted around the tyre in Fig. 2. Thus, the M4 microphone is on the left and the M6 microphone on the right.

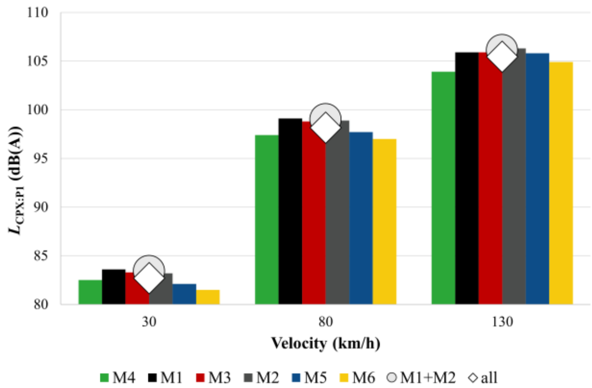

Figure 3. $L_{CPX:P1}$ measured by each microphone; average values from two mandatory (grey circle) and all six (white diamond) microphones at different velocities.

The average noise values of the two mandatory and all six microphones are shown in Tab. 1. The average values of all microphones are always lower than the average values of mandatory microphones for all velocities. This is because of the calculation. The average value of all six microphones is also calculated from the microphones M4, M5, and especially M6, which are located farthest from the tyre. On the other hand, the M1, M2 and M3 microphones are mounted nearest to the tyre. The outermost microphones naturally measure noise levels lower than the ones nearer the tyre. The difference in noise levels is within a relatively tight range of 0.6-0.8 dB(A). However, the values themselves vary considerably. The choice of microphones used for CPX measurement may thus slightly affect the final average $L_{CPX:P1}$ value.

Table 1. Average noise values $L_{CPX:P1}$ from the two mandatory and all six microphones in decibels.

Velocity (km/h)	M1+M2	all
30	83.4	82.7
80	99.0	98.2
130	106.1	105.5

Although the difference between the measured velocities is 50 km/h – between 30–80 and 80–130 km/h – the difference in noise values decreases with increasing velocity for all microphones and their combinations. The difference between the values at 30 and 80 km/h is approximately 15–16 dB(A), and between the values at 80 and 130 km/h is around 7 dB(A).
The numerical differences of $L_{CPX:P1}$ values between the microphones at different velocities are shown in Tab. 2–4 and correspond to the graph in Fig. 3.

Table 2. Differences between $L_{CPX:P1,30}$ microphones' absolute values in decibels.

	M4	M1	M3	M2	M5	M6
M4	---					
M1	1.1	---				
M3	0.8	0.3	---			
M2	0.7	0.4	0.1	---		
M5	0.4	1.5	1.2	1.1	---	
M6	1.0	2.1	1.8	1.7	0.6	---

Tab. 2 shows the difference in noise values for a 30 km/h velocity. M1 and M6 have the highest difference between microphones, over 2 dB(A). The microphone pairs M5+M6 and M4+M5 and the trio M1+M2+M3 show considerable similarity with absolute difference of 0.6 dB(A), 0.4 dB(A) and for the trio in the range 0.1–0.4 dB(A). Explanation can be seen in Fig. 2, i.e. it is due to the positioning of the microphones. The lowest noise value was measured with microphone M6, 81.5 dB(A).
Tab. 3 shows the differences in noise values for a velocity of 80 km/h. Even at this velocity, the highest difference is in the noise values measured by the M1 and M6 microphones. The trend in the similarity of the noise values measured by the microphones at this velocity is comparable to the previous lower velocity. At this velocity, the noise levels of the M4 and M6 microphones show better similarity than the M5 and M6 microphones. The lowest value was again measured with microphone M6, 97.0 dB(A).

Table 3. Differences between $L_{CPX:P1,80}$ microphones' absolute values in decibels.

	M4	M1	M3	M2	M5	M6
M4	---					
M1	1.7	---				
M3	1.4	0.3	---			
M2	1.5	0.2	0.1	---		
M5	0.3	1.4	1.1	1.2	---	
M6	0.4	2.1	1.8	1.9	0.7	---

Tab. 4 shows the differences in noise values for a velocity of 130 km/h. There has already been a change in trend from the two lower velocities. The M4 microphone shows the most significant difference in noise values compared to almost all other microphones. The lowest noise value of 103.9 dB(A) was measured with the M4 microphone. This is because the microphone is placed in front of the tyre.

Table 4. Differences between $L_{CPX:P1,130}$ microphones' absolute values in decibels.

	M4	M1	M3	M2	M5	M6
M4	---					
M1	2.0	---				
M3	2.0	0.0	---			
M2	2.4	0.4	0.4	---		
M5	1.9	0.1	0.1	0.5	---	
M6	1.0	1.0	1.0	1.4	0.9	---

Most of the rolling noise mechanisms are mainly associated with the trailing edge of the tyre, e.g. horn effect or tangential vibrations caused by stick-snap adhesion. Fewer mechanisms are present in the leading edge of the tyre, e.g. radial vibrations associated with impact mechanisms and aerodynamic mechanisms caused by air-pumping [2]. At high velocities, such as 130 km/h, the mechanisms on the trailing edge and sidewall of the tyre are amplified. This is probably why the lowest noise level was measured with the M4 microphone. Porous (open) surfaces have lower noise values measured by M5 and M6 microphones compared to impervious (closed) surfaces, which include SMA 11 S [5].

3.2 Third-octave band spectra

The following figures show the noise values measured by individual microphones for each frequency of the third-octave band between 50 Hz and 10 kHz. The frequencies 50–500 Hz are designated as low, 630–1600 Hz as midrange, and higher frequencies as high.

Fig. 4 shows that mandatory microphones M1 and M2 recorded similar noise values at 30 km/h velocity. Their difference is minimal, up to 0.5 dB(A) at most frequencies. However, the range of values measured by the individual M1–M6 microphones is quite significant. For low frequencies, the differences range from 1.5–5.4 dB(A) with a maximum at 80 Hz, for midrange frequencies the range is 1.4–3.9 dB(A) with a maximum at 630 Hz, and for high frequencies it is 1.8–3.3 dB(A), with microphones at 8–10 kHz achieving a difference of over 3 dB(A).

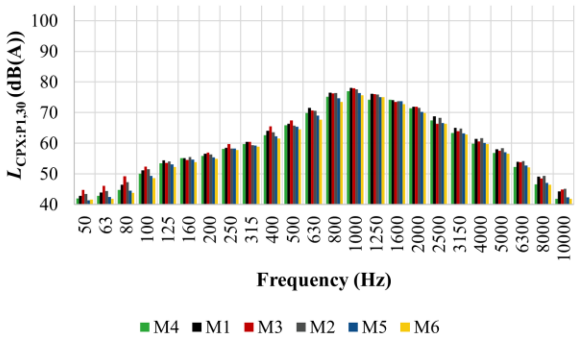

Figure 4. Third-octave band noise values of individual microphones at 30 km/h velocity.

The difference between the values measured by the mandatory microphones is also minimal at 80 km/h. A difference of 2.8 and 2.4 dB(A) can be observed between the mandatory microphones at 63 and 80 Hz in Fig. 5. The range is around 1.3 dB(A) at 50 and 400–630 Hz frequencies. The difference is up to 0.7 dB(A) at other frequencies. The range of measured values between individual microphones is 2.1–4.0 dB(A) for low frequencies with a maximum at 500 Hz, for midrange frequencies the range is 1.5–4.2 dB(A) with a maximum at 630 Hz and for high frequencies it is 1.4–2.8 dB(A). The decrease from 1 kHz has the same characteristic as the 30 km/h velocity.

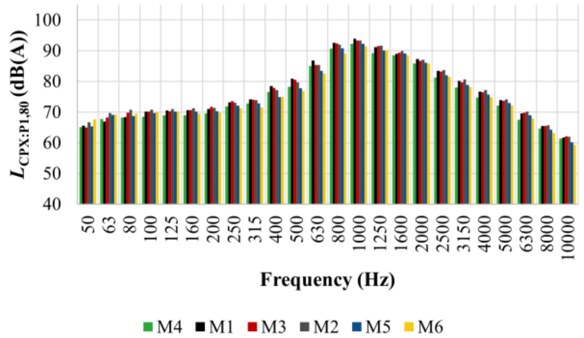

Figure 5. Third-octave band noise values of individual microphones at 80 km/h velocity.

The difference in the noise values measured by the mandatory microphones for a velocity of 130 km/h can be observed at low frequencies up to 250 Hz (see Fig. 6). From them, higher values were measured by the M2 microphone. The difference varies from 4.6 to 5.6 dB(A) at a 50–160 Hz frequency range. The range of measured values between the individual microphones is 2.4–5.8 dB(A), for low frequencies with a maximum at 100 Hz, for midrange frequencies the range is 1.8–3.8 dB(A) with a maximum at 1250 Hz and for high frequencies it is 1.4–3.8 dB(A), where values of 3.7 and 3.8 d(BA) are achieved at 2500 and 3150 Hz. The decrease from 1 kHz has the same characteristic as the previous two velocities.

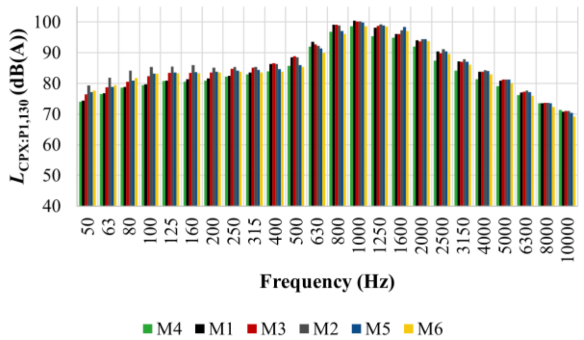

Figure 6. Third-octave band noise values of individual microphones at 130 km/h velocity.

The same trend of third-octave spectra with a peak at 1000 Hz was also found for other asphalt surfaces [6, 7]. Noise below 1000 Hz is caused by impact mechanisms mainly caused by radial vibrations [2] between the tyre and the road. This is why there are visible changes in noise levels at these frequencies at different velocities. The higher the velocity, the greater the vibrations.

3.3 Data fitting

The average $L_{CPX:P1}$ noise values of all six microphones for the three velocities were plotted on a dot plot and interleaved with a trend line. Linear interlacing can be used for smaller velocity ranges [8], but using a logarithmic trendline is preferable for this range [9, 10] (see Fig. 7). This is most useful when the data change rate increases quickly and then levels out. This corresponds to the acoustic behavior of surfaces as the velocity increases.

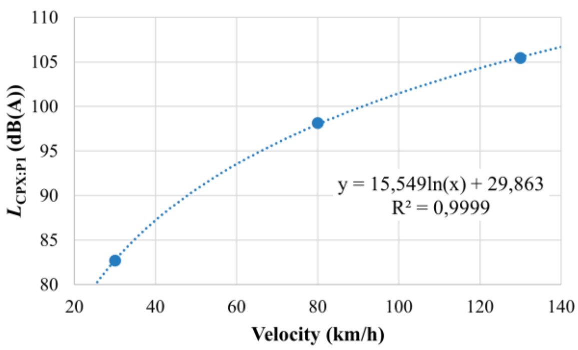

Figure 7. $L_{CPX:P1}$ for all microphones.

The graph in Fig. 8 plots the third-octave band spectra from $L_{CPX:P1}$ values shown in Fig. 7. The lower dots indicate values for a velocity of 30 km/h, the middle for a velocity of 80 km/h, and the upper for a velocity of 130 km/h. Measured values at one velocity were divided into frequencies up to 1 kHz and from 1 kHz – 1 kHz is marked with a yellow dot in the graph. The dots were interleaved with the best-fitting trend lines according to the R^2 reliability value. The reliability values for the different interleavings are shown in Tab. 5. At a velocity of 30 km/h, the noise level increases logarithmically up to 1 kHz and then decreases exponentially. However, there is only a slight difference between the exponential and logarithmic decrease. At a velocity of 80 km/h, the noise level increases linearly, but considering the little difference, it could also increase exponentially. The decrease in noise from 1 kHz onwards is then logarithmic. At a velocity of 130 km/h, the noise level increases exponentially up to 1 kHz, but considering the little difference, it could also increase linearly. The decrease in noise from 1 kHz onwards is then logarithmic.

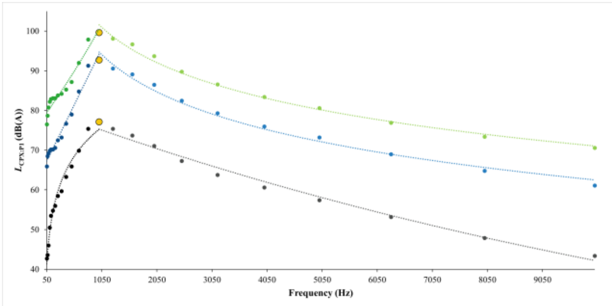

Figure 8. Third-octave band average noise values from all six microphones; lower dots for velocity 30 km/h, middle dots for velocity 80 km/h, and upper dots for velocity 130 km/h.

Table 5. R^2 values for different trendline types.

Trendline type	Velocity (km/h)		
	30	80	130
50–1000 Hz			
Linear	0.9134	0.9770	0.9466
Exponential	0.8738	0.9751	0.9474
Logarithmic	0.9803	0.8283	0.8333
1–10 kHz			
Linear	0.9676	0.9525	0.9344
Exponential	0.9885	0.9733	0.9560
Logarithmic	0.9811	0.9887	0.9915

4. CONCLUSION

The CPX method is the recommended method for assessing road surface noise. The method procedure is determined by the standard ISO 11819-2. The fundamental measuring velocities are 50, 80, and 110 km/h. The noise level is usually presented as a single number. This L_{CPX} number is obtained by calculating the noise levels at each frequency of the third-octave band spectrum.

The paper dealt with noise assessment of the SMA 11 S road surface at three velocities using six microphones of the CPX method. The results are shown as third-octave band frequency values, as well as average values calculated from them.

First, the surface noise was measured at a 80 km/h velocity. Two extreme velocities were chosen to assess the behavior of the CPX method outside the defined conditions – a low velocity of 30 km/h and a high velocity of 130 km/h.

There is an equally large difference between the measured velocities (between 30–80 and 80–130 km/h, it is 50 km/h). However, the difference in L_{CPX} noise values decreases with increasing velocity for all microphones, from about 15 dB(A) to 7 dB(A). This is related to the logarithmic increase in noise with increasing velocity. The lowest noise level is usually measured with the M6 microphone rearmost from the tyre, but at 130 km/h, the lowest noise level was measured with the M4 front microphone. This is related to the fact that the lowest noise levels were measured for almost all frequencies.

The highest noise difference between microphones of over 5 dB(A) was measured for low frequencies at 130 km/h. The highest difference between the mandatory M1 and M2 microphones was also measured at the highest velocity and for low frequencies. These events are associated with the radial vibrations caused by the impact mechanism. At the lowest velocity, the noise increases logarithmically up to 1 kHz; at higher velocities, it is a linear/exponential increase. The decrease in noise levels between 1 and 10 kHz is then more or less logarithmic.

5. ACKNOWLEDGMENTS

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