

Comparison of pavement noise properties on selected road sections using different CPX measuring systems: self-powered vehicle and special test trailer

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ABSTRACT

The recently published ISO standard intended to measure the noise properties of road surfaces in a standardized method (ISO 11819-2:2017) precisely defines measurement procedure of the influence of road surface on traffic noise. According to it, two types of test vehicles may be utilized: a self-powered vehicle fitted with one or more test tyres and a trailer towed by a separate vehicle with one or more test tyres mounted on the trailer. The microphones are located in the close-proximity of the test tyre in strictly defined positions.

Round Robin Test using both types of test vehicles was carried out in Poland. The objective was the comparison of noise properties of selected pavements in terms of noise levels obtained when using different CPX measuring systems and to determine if pavement ranking regarding the noise properties is the same. Twelve road sections of six different wearing course mixes were selected for this purpose. Measurements were performed by two independent teams operating two different CPX measuring systems equipped with different test tyres. The RRT results show significant differences in CPX noise levels ranging from -0.9 to $+2.3$ dB. The pavement ranking is generally the same with some exceptions for less noisy road surfaces.

Keywords: Tyre/road noise, Measurement methods, Standards

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1. INTRODUCTION

Traffic noise is an important factor affecting lives of millions of people all over the world and besides the emission of harmful substances into the atmosphere. It is currently one of the most important negative impacts of vehicles and road traffic on the environment. Road surfaces have a direct impact on the noise generated by the tyres running on them (the main and dominant noise source of moving vehicles) as well as on the propagation of noise emitted by all noise sources in the vehicle (tyres, engine, exhaust system, drive system). Thus traffic noise becomes an important factor in terms of proper road surface composition.

To evaluate the road surface acoustic properties appropriate testing methods were developed and established. Two measurement methods, SPB (Statistical Pass-by method) and CPX (Close Proximity method), both already standardized, are widely used throughout the world outside the United States of America, where the third method – OBSI (On-Board Sound Intensity) dominates.

In the Statistical Pass-by method [1] noise emitted by an individual, randomly selected vehicles from the actual traffic stream is measured together with its actual speed. The measured vehicle is categorized into one of three categories: passenger cars, dual-axle trucks and multi-axle trucks. Measurements are performed using a microphone located on the side of the road at a height of 1.2 m, in relation to the road surface level, at a distance of 7.5 m from the centre of the lane. This method takes into account the overall noise of vehicles and also the sound propagation properties of the pavement. It is mainly intended to classify pavements in typical and good condition according to their influence on traffic noise and/or to evaluate the influence of different pavements - at particular sites, irrespective of condition and age - on traffic noise.

The second method, Close Proximity [2], is intended to check a pavement's noise characterization compliance at almost any site according to particular specifications (e.g. for conformity of production) and/or to check the acoustic effect of maintenance and condition (e.g. wear of and damage to pavement, clogging and the effect of cleaning porous pavement) and/or to check the homogeneity of a wearing course of road section. In the CPX method two measuring microphones are mounted very close to the test wheel with a reference tyre (one representing passenger car tyres, the second a proxy for truck tyres). Three main types of test vehicles can be utilized in the CPX method: an open test trailer, a test trailer with chamber and a self-powered vehicle. Most of the existing test vehicles are designed and constructed as special trailers with the measuring wheel(s) and microphones protected by semi-anechoic chambers. The chamber reduces background noise (most notably the noise from other tyres, from other vehicles and wind noise) and must be constructed in such a way that it does not initiate undesired noise reflections. The CPX method, in contrast to the SPB method, in principle takes into account only the influence of the road surface on the tyre/road noise generation phenomenon, ignores the sound propagation effect of a pavement and neglects other noise sources of a moving vehicle.

The On-Board Sound Intensity method [3], similar to CPX one, uses mainly a self-powered vehicle equipped with sound intensity probe close to the test wheel instead of two microphones as in case of CPX method.

Nowadays it is very important to be sure if noise measurement results obtained using different methods are comparable. Numerous researches focused on this subject [4, 5, 6, 7, 8, 9] finally presenting, in general but not always, a rather good correlation between the methods. Even more important is to be sure if pavement acoustic properties measured using the same method but utilizing different measuring systems or different test vehicles are fully comparable. Such comparison is especially important in European

countries because of the unification of road pavement requirements all over the Europe. Special Round Robin Tests are periodically carried out by researchers [10, 11, 12, 13] to confirm the reliability of the used method. A dedicated Round Robin Test, reported in this paper, was also conducted in Poland in the summer of 2018.

2. CPX MEASURING SYSTEMS UTILIZED IN ROUND ROBIN TEST

The objective of the Round Robin Test (RRT) performed on Polish roads was to compare the noise properties of selected pavements in terms of noise levels obtained when using different measuring systems and to determine if the pavement ranking regarding the noise properties is the same. Two different CPX measuring systems, self-powered vehicle and special test trailer, operated by different crews (French and Polish respectively) took part in the test.

2.1. French CPX test car

Measuring systems directly mounted on a self-powered test vehicles have been developed and still are very popular in France. Such typical system consists of three microphones (two side and one rear) attached to a test car in the close proximity of one of its wheels (usually a right rear wheel) equipped with test tyre. The CPX measuring system that participated in the RRT in Poland, property of EUROVIA Management – Centre de Recherche, was mounted on a Renault Scenic passenger car – see Fig. 1 (left).



Fig. 1. CPX measuring system no. 1 – French car Renault Scenic (left) and the test tyre used – Michelin Energy Saver+ (right)

The test tyre was not the reference one according to ISO/TS 11819-3:2017 [14] but it was the 195/60 R15 88H Michelin Energy Saver+ tyre presented in Fig. 1 (right). The tyre inflation pressure was 230 kPa. The load of the test wheel resulted from the actual load on the rear axle of the vehicle and it was approximately 3170 N. The estimated tyre tread hardness was 65 Shore A. For the purpose of this paper, only the noise data acquired by the two side microphones placed in ISO mandatory positions have been used and reported.

2.2. Polish CPX test trailer

The second CPX measuring system taking part in this RRT was a special test trailer developed and built in the Gdansk University of Technology (Poland) named Tiresonic Mk4 – see Fig. 2 (left). Two standard reference tyres were used – one representing passenger car tyres, designated “P1”, and the second – a proxy for truck tyres, designated “H1” in the ISO Technical Specification [14] – see Fig. 2 (right).



Fig. 2. CPX measuring system no. 2 – Polish test trailer Tiresonic Mk4 (left) and the test tyres used – two ISO reference tyres P1 and H1 (right)

The inflation pressure for both reference tyres was the same – fixed to 200 kPa in cold condition. The test wheel load was 3200 N. The tread rubber hardness was 67 Shore A for both reference tyres. For the purpose of this paper only the data acquired for the “P1” reference tyre have been used and reported.

3. TEST SECTIONS AND ROAD SURFACES

The Round Robin Test took place in the last week of July and in the first week of August 2018 in the vicinity of Krakow in southern Poland. Twelve test sections (six pairs of nominally the same pavements) were selected for this purpose. All of them were made in Hot Mix Asphalt (HMA) technology, however they differed in terms of HMA properties. The tested mixes had various air void content or maximum aggregate size. They also differed in age and speed limit. Details regarding the characteristics of tested wearing courses are shown in Tab. 1.

Tab. 1. Test sections and wearing course parameters

Section number	Designation	Mix type	Pavement age	Maximum aggregate size	Layer thickness	Air void content	Special feature	Speed limit	Section length
1	BBTM 0/8 N (2015)	BBTM	3 years	8 mm	3 cm	7.0 – 10.0 %	Rubber modified binder	90 km/h	1000 m
2	BBTM 0/8 S (2015)	BBTM	3 years	8 mm	3 cm	7.0 – 10.0 %	Rubber modified binder	90 km/h	1000 m
3	SMA 0/8 N (2010)	SMA	8 years	8 mm	4 cm	2.0 – 3.5 %	-	120 km/h	1300 m
4	SMA 0/8 S (2010)	SMA	8 years	8 mm	4 cm	2.0 – 3.5 %	-	120 km/h	1300 m
5	SMA 0/8 NW (2016)	SMA	2 years	8 mm	4 cm	2.0 – 3.5 %	-	70 km/h	1000 m
6	SMA 0/8 SE (2016)	SMA	2 years	8 mm	4 cm	2.0 – 3.5 %	-	70 km/h	1000 m
7	SMA 0/8 N (2017)	SMA	1 year	8 mm	4 cm	2.0 – 3.5 %	Rubber addition	120 km/h	1700 m
8	SMA 0/8 S (2017)	SMA	1 year	8 mm	4 cm	2.0 – 3.5 %	Rubber addition	120 km/h	1700 m
9	SMA 0/12.8 L1 (2005)	SMA	13 years	12.8 mm	4 cm	3.0 – 4.0 %	-	100 km/h	750 m
10	SMA 0/12.8 L2 (2005)	SMA	13 years	12.8 mm	4 cm	3.0 – 4.0 %	-	100 km/h	750 m
11	SSGF 0/5 L1 (2017)	Slurry Seal Gripfibre	1 year	5 mm	1 cm	-	Polymer modified emulsion layer with fibres	100 km/h	500 m
12	SSGF 0/5 L2 (2017)	Slurry Seal Gripfibre	1 year	5 mm	1 cm	-	Polymer modified emulsion layer with fibres	100 km/h	500 m

Apart from the information visible in the table, there are some information concerning road's special function that may be important in the analysis process. Rubber addition to certain mixes was introduced to improve pavement acoustic characteristics on BBTM sections no. 1 and 2 as well as SMA sections no. 7 and 8. Slurry Seal Gripfibre (sections no. 11 and 12) was applied on SMA 0/12.8 to inhibit cracks propagation and to improve skid resistance.

4. ROUND ROBIN TEST RESULTS

It should be noted at the beginning of the analysis that the CPX measurements were performed by two independent teams operating two different measuring systems equipped with different test tyres. The test speed was also different – the French team conducted all measurements with the speed of 70 km/h (later extrapolated to 80 km/h) while the Polish team at 80 km/h. Air temperature during the measurements was within the range from 22 up to 35 °C.

4.1. Data preparation procedure

All the raw data independently acquired during measurements by two teams have been processed by one person (the first author of this paper) according to the analysis procedure given in the Annex C (*Detailed explanation of the calculation procedure*) of the ISO 11819-2:2017 standard [2].

In this procedure first the energy-based average of front and rear microphone SPLs was calculated in each one-third-octave band. Then to the overall level (SPL), calculated for a 20 m long segment from the one-third-octave-band levels ranging from 315 Hz to 5000 Hz, test system (for test trailer only) and speed corrections (to the reference speed of 80 km/h) were applied. The obtained values were then normalized to the reference air temperature of 20 °C and, in case of the test trailer only, to the reference tyre rubber hardness of 66 Shore A. Because the exact value of the tread hardness of Michelin test tyre was unknown (it was estimated to be about 65 Shore A based on measurements performed in late 2016 when 63 Shore A was measured) as well as the hardness correction coefficient for this tyre is unsure and the estimated hardness was only 1 Shore A different from the reference value, it was decided to skip the hardness correction for this test tyre. Then after obviously disturbed segments being discarded the A-weighted sound pressure levels for each segment were averaged over the entire section length giving a CPX level.

4.2. CPXP levels

The CPXP levels indicate the acoustic performance of the tested road surfaces for light vehicles as the used “P1” tyre only (or Michelin passenger car tyre) was analysed for the purpose of this paper. One should remember that the test tyres used by two teams differed and could have significant impact on measured noise levels.

In the analysis presented below the results obtained using the French CPX test car were designated by “FR CPX car”. The designation for Polish CPX test trailer was “PL CPX trailer”.

The calculated sound pressure levels for both measuring systems for all tested sections were presented in Tab. 2 and also shown in Fig. 3. Also the average CPXP values calculated for nominally the same pavement when measured in both directions on a road at the same location were shown in this table.

Tab. 2. CPXP levels for all tested sections depending on the measuring system used

Test section	CPXP [dB(A)]		CPXP difference [dB(A)]
	FR CPX car	PL CPX trailer	FR car - PL trailer
BBTM 0/8 N (2015)	98.0	98.4	-0.4
BBTM 0/8 S (2015)	98.1	98.5	-0.4
BBTM 0/8 (2015) average	98.0	98.4	-0.4
SMA 0/8 N (2010)	99.6	99.4	0.2
SMA 0/8 S (2010)	99.9	99.5	0.4
SMA 0/8 (2010) average	99.8	99.5	0.3
SMA 0/8 NW (2016)	98.3	98.4	-0.1
SMA 0/8 SE (2016)	97.1	98.0	-0.9
SMA 0/8 (2016) average	97.7	98.2	-0.5
SMA 0/8 N (2017)	97.9	98.3	-0.4
SMA 0/8 S (2017)	97.8	98.3	-0.5
SMA 0/8 (2017) average	97.8	98.3	-0.5
SMA 0/12.8 L1 (2005)	103.4	101.1	2.3
SMA 0/12.8 L2 (2005)	102.3	100.5	1.9
SMA 0/12.8 (2005) average	102.9	100.8	2.1
SSGF 0/5 L1 (2017)	97.9	97.1	0.8
SSGF 0/5 L2 (2017)	97.7	95.9	1.8
SSGF 0/5 (2017) average	97.8	96.5	1.3

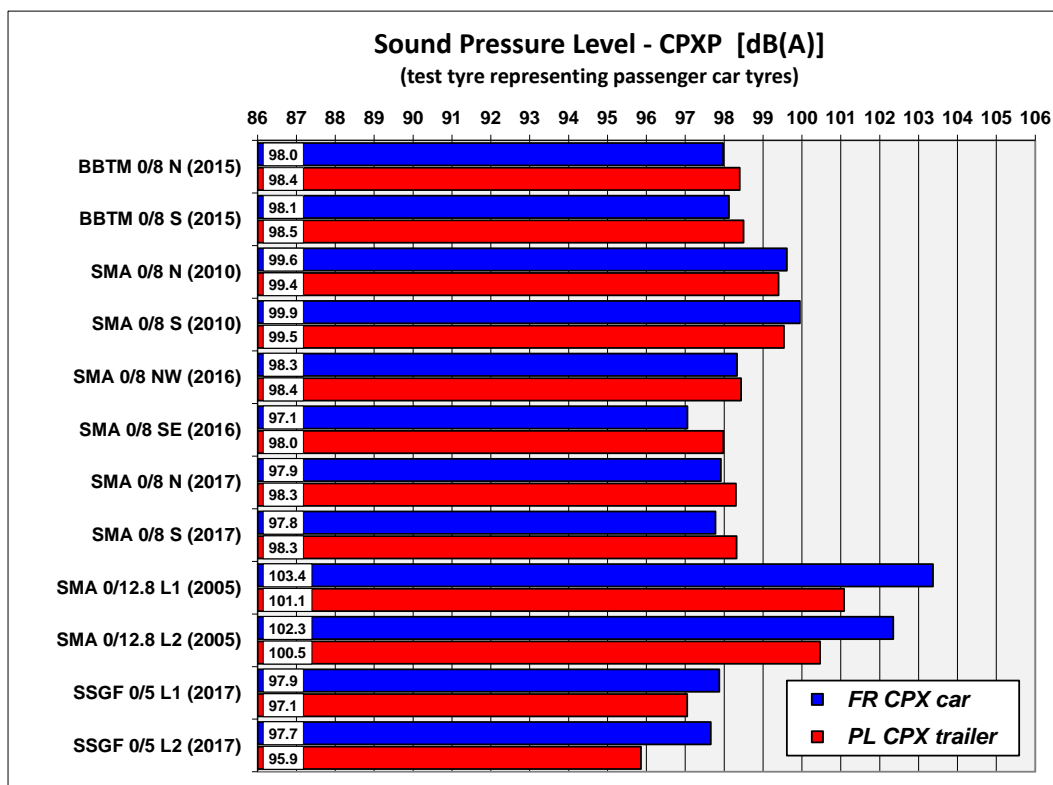


Fig. 3. CPXP levels for all tested sections depending on the measuring system used

Analysing the obtained results it can be observed that the differences in noise levels measured by both CPX systems are differentiated and inconsistent.

For BBTM 0/8 (2015) and SMA 0/8 (2017) test sections they are almost same – consistently the CPXP values calculated for French CPX car were about 0.4 dB lower than values for Polish CPX trailer. Also lower values measured by French car, but with higher spread between subsections (from 0.1 up to 0.9 dB, with an average of 0.5 dB) can be observed for a similar SMA 0/8 (2016) pavement. In case of this test section the measured difference between two subsections for French car was much higher (1.3 dB) than for Polish trailer (0.4 dB).

For the other half of tested pavements CPXP levels obtained for French CPX car were higher than for Polish measuring system. Among them, the smallest difference was noted for SMA 0/8 (2010) pavement (0.2 – 0.4 dB). The highest difference between both measuring systems (from 1.9 up to 2.3 dB, with an average of 2.1 dB) was noted for the old SMA 0/12.8 (2005). In this case the measured difference between two subsections was almost twice as high (1.0 dB) for French car than for Polish trailer (0.6 dB). Contrary to this, the measured by French CPX car difference between two subsections of SSGF 0/5 (2017) was negligible, only 0.2 dB, while the Polish CPX trailer measured a significant difference of 1.2 dB for this pavement. The differences in CPXP levels obtained by two CPX measuring systems for this test section were from 0.8 up to 1.8 dB, with an average of 1.3 dB.

4.3. Pavement ranking

Considering the already known inconsistent and various differences in noise levels measured by both CPX devices one can be curious if the ranking of tested pavements (from the most quiet to the loudest one) was the same independently on CPX measuring system used. Taking into account, that significant differences in CPXP levels were noted between subsections for a half of tested pavements, the ranking has been prepared for all twelve selected test sections (presented in Tab. 3) as well as for the six pavement types averaging the subsections of nominally the same road surfaces (shown in Tab. 4).

Tab. 3. Ranking of test sections depending on the measuring system used

Test section	CPXP [dB(A)]	Ranking position	CPXP [dB(A)]	Ranking position
	by FR CPX car		by PL CPX trailer	
BBTM 0/8 N (2015)	98.0	6	98.4	6
BBTM 0/8 S (2015)	98.1	7	98.5	8
SMA 0/8 N (2010)	99.6	9	99.4	9
SMA 0/8 S (2010)	99.9	10	99.5	10
SMA 0/8 NW (2016)	98.3	8	98.4	7
SMA 0/8 SE (2016)	97.1	1	98.0	3
SMA 0/8 N (2017)	97.9	5	98.3	4
SMA 0/8 S (2017)	97.8	3	98.3	5
SMA 0/12.8 L1 (2005)	103.4	12	101.1	12
SMA 0/12.8 L2 (2005)	102.3	11	100.5	11
SSGF 0/5 L1 (2017)	97.9	4	97.1	2
SSGF 0/5 L2 (2017)	97.7	2	95.9	1

Tab. 4. Ranking of tested pavements depending on the measuring system used

Test section	CPXP [dB(A)]	Ranking position	CPXP [dB(A)]	Ranking position
	by FR CPX car		by PL CPX trailer	
BBTM 0/8 (2015)	98.0	4	98.4	4
SMA 0/8 (2010)	99.8	5	99.5	5
SMA 0/8 (2016)	97.7	1	98.2	2
SMA 0/8 (2017)	97.8	3	98.3	3
SMA 0/12.8 (2005)	102.9	6	100.8	6
SSGF 0/5 (2017)	97.8	2	96.5	1

Analysing the ranking performed for all 12 tested sections (shown in Tab. 3) one can observe differentiation for the most quiet test sections. In the ranking according to the French CPX car results the most quiet test section is SMA 0/8 SE (2016), which is only 3rd quiet section in ranking according to Polish CPX trailer. The 2nd quiet test section in this ranking corresponds to the most quiet one (SSGF 0/5 (2017)) in the ranking by Polish trailer. It should be pointed out, that differences in CPXP levels between the six successive test sections in the ranking by French car (positions from 2 to 7) are very small – only 0.1 dB or less: 97.7, 97.8, 97.9, 97.9, 98.0, 98.1 dB and thus the exact position of a particular test section in the ranking should be considered with an accuracy of ± 1 or even ± 2 positions due to overall CPX measurement precision (estimated to be 0.3 dB). Also in the ranking by the Polish trailer, the CPXP level values obtained for the five successive test sections at positions from 4 to 8 are within a very small range of 0.2 dB (98.3 – 98.5 dB). Thus, taking this into account, it can be assumed that the test section ranking from position 4 to 8 is the same for both CPX measuring systems. At the other end of this ranking, for loud test sections, one can observe the same order of test sections in both rankings starting from position of 9 up to 12.

Similar conclusions can be drawn for the ranking shown in Tab. 4 that has been performed for the six pavement types when averaging the subsections of nominally the same road surfaces. Inconsistency can be observed in pavement ranking positions 1 and 2 and full compliance for positions from 3 to 6. But one should also notice that pavements at positions 1 to 3 in ranking by French car and at positions 2 and 3 in the ranking by Polish trailer differ only by 0.1 dB.

4.4. Noise frequency spectra

During the Round Robin test, all noise data were collected as the A-weighted one-third-octave-band levels in the frequency spectra range from 315 Hz to 5000 Hz. Performing the noise frequency spectra analysis one should remember that the measuring systems used in this RRT were equipped with different test tyres. The French CPX car used the 195/60 R15 88H Michelin Energy Saver+ tyre, while the P225/60 R16 97S Uniroyal Tigerpaw – Standard Reference Test Tyre (SRTT) specified in the ISO/TS 11819-3:2017 [13] was used in the Polish CPX trailer.

The noise frequency spectra obtained by both CPX measuring systems for all test sections were presented in Fig. 4.

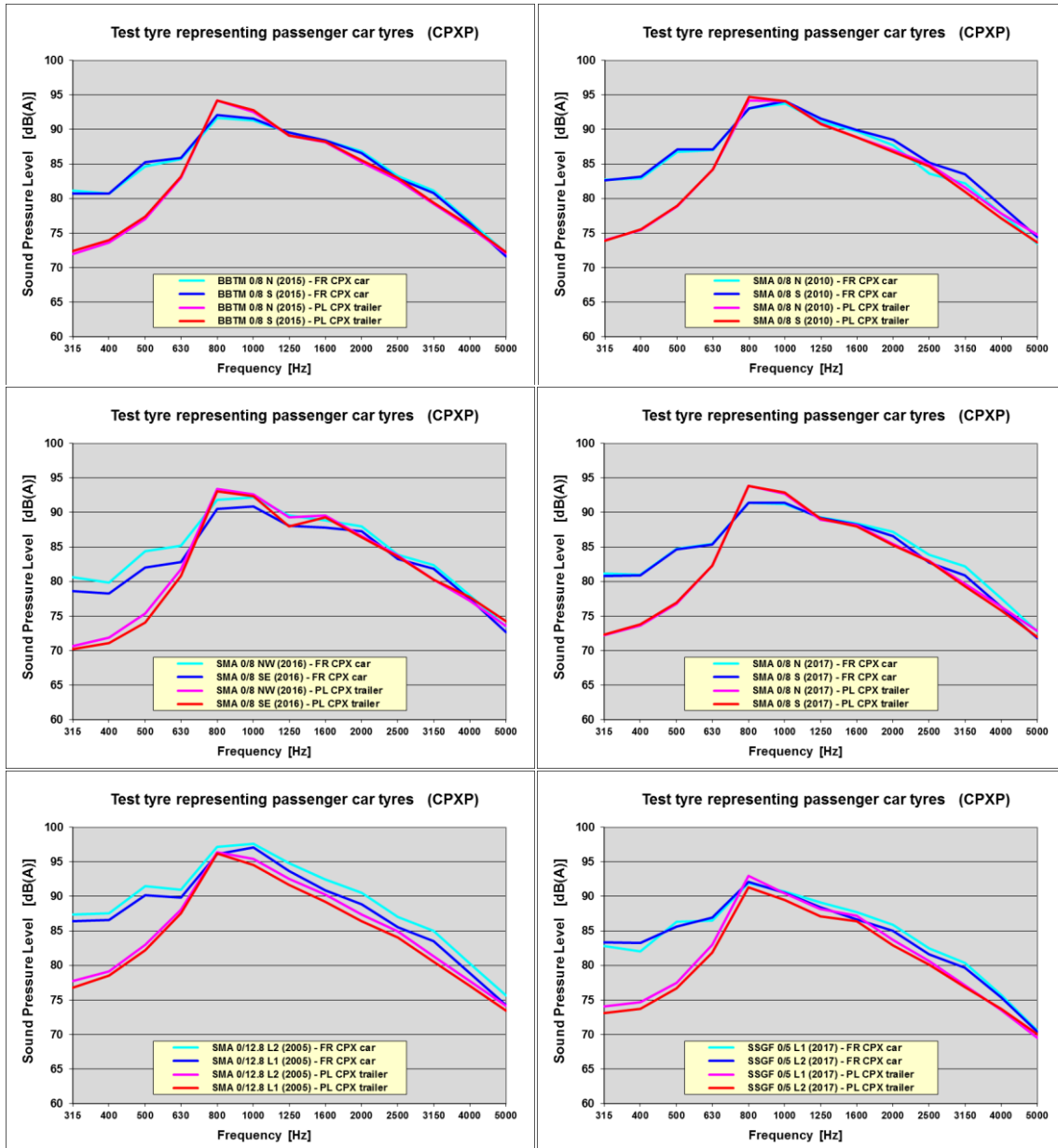


Fig. 4. Noise frequency spectra obtained by both CPX measuring systems for all test sections

Significant differences in the low frequency range, below 800 Hz, can be observed for all the tested road surfaces. Frequency spectra characteristics obtained by French car are incredibly higher than by Polish trailer. In few cases differences exceed 10 dB. Their shape is also quite similar for all tested pavements. Most probably the cause can be a disturbing noise derived from power unit or/and muffler system of the vehicle affecting measurement results. Unknown is also condition of the microphone wind screens used. Contaminated with dust could affect the measurement results due to loss of shielding performance. A similar phenomenon was observed and described in [11] but an aerodynamic noise was pointed to be the possible cause in that case.

In the medium frequency range (800 – 1250 Hz), in case of first four pavements, the BBTM and three SMA 0/8, one can observe 1.5 ÷ 2.5 dB higher levels measured by Polish trailer. For the 5th pavement, rather old SMA 0/12.8 (2005), the levels are about 1.5 dB higher for French car. For the last case, SSGF 0/5 (2017), no significant differences were observed within this frequency range.

In the high frequency range, above 1250 Hz, only for the last two pavements, SMA 0/12.8 (2005) and SSGF 0/5 (2017), higher levels (1.5 ÷ 2.0 dB on the average) were observed for French car. In other cases frequency characteristics were similar.

5. CONCLUSIONS

Acoustic measurements, especially those using the close proximity measuring systems are prone to many factors. It applies to not only weather conditions, but also to measuring devices. The research confirms, that differences in terms of construction of measuring device and tyres used plays an important role in the process of obtaining final results. Although the results obtained using both measuring systems showed substantial compliance, they revealed also some important differences.

The following conclusions can be drawn on the basis of the performed Round Robin Test:

- Obtained differences in noise levels measured by both CPX systems are differentiated and inconsistent and they vary from -0.9 up to 2.3 dB.
- Inconsistency for low noise test sections, a general compliance for normal and full compliance for loud ones can be observed in pavement ranking according to both teams.
- Very small differences, within the measurement error, were noted for both measuring systems for test sections placed in the middle of the ranking.
- Significant differences in noise frequency spectra, sometimes over 10 dB, can be observed in the low frequency range for all the tested road surfaces (most probably due to a disturbing noise derived from power unit or/and muffler system), smaller differences (-1.5 ÷ 2.5 dB) in medium frequency range and rather similar levels in the high frequency range with two exceptions.

Concluding, the measuring system does not only affect the values of calculated noise levels but also it may affect the assessment process of the road surface (changes in ranking). Such situation is unique within European Standards. It is rare situation, that one standard enables to use two kinds of measuring systems (test trailer and self-powered vehicle) significantly different from each other. In order to correctly use both systems, they should be precisely compared, and have obvious correlation which unfortunately does not occur in this case. Otherwise, those differences in terms of using two different measuring systems may result in unreliability in comparison between tests carried out by various testing teams according to the same standard.

6. ACKNOWLEDGEMENTS

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