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Acoustic evaluation of road surfaces using different Close Proximity testing devices

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ABSTRACT

According to the valid standard, Close Proximity (CPX) method intends to evaluate the influence of road surfaces on traffic noise. Measurements may be carried out with the use of a self-powered vehicle or a special test trailer equipped with testing tyre towed by another vehicle. Two different testing devices took part in the research organized in Poland in order to determine the ranking of road surfaces in terms of acoustic parameters. Two tests (in the year 2018 and 2019) were carried out on 6 different road sections with different wearing courses. Road surfaces were ranked, which enabled comparison of the two measuring systems, based on the same standard. Obtained results revealed some differences within measured values ranging from about -1 dB to +2 dB, which led to ranking changes concerning the best road surface in terms of limitation of traffic noise.

Keywords: Tyre/road noise, Asphalt pavement acoustics, Close proximity method, asphalt, acoustics, tyre,

1. INTRODUCTION

The ongoing civilizational development, present in almost every region of the world, entails continuous changes in the environment. It is connected with the growth of urban areas, which also leads to the development of road transport and communication network. Together with increasing intensity of road transport, which belongs to described changes, this development also brings some disadvantages. Road traffic generates air and water pollution, leads to limitation of green areas and is also a source of noise.

Currently, more and more municipalities all over the world are interested in reduction of noise within cities, towns, villages and animal habitats. According to European law (Environmental Noise Directive 2002/49/EC) it became an obligation to verify the level of noise in the vicinity of roads and railways. Acceptable noise levels for different areas are set in accordance with the law and consequently local administration should prevent the noise generators from exceeding those levels.

A first idea to limit the noise levels near the road network is to use different tyres, reducing noise generated by high-speed traffic. Information about the tyre noise emission is included in tyre's labelling (Sandberg, 2008). Another option is to use special road surfaces (wearing courses) enabling reduction of noise. Porous road surfaces (e.g. porous asphalt) are considered as silent surfaces. Small size aggregate asphalt mixes can also effectively reduce noise emissions (Vaitkus et AL, 2017). To achieve required noise levels, local administration orders Environmental Impact Reports, which contain recommendations applying among others to road surfaces. The report (Ansee Consulting Report, 2016) is an example which obliges the local council to apply road surface reducing noise emissions by 2-6 dB depending on the road section. The construction of the noise reducing road sections took place in 2021. To verify the effectiveness of the applied road surface, there should be reliable assessment method enabling to confirm designed values.

In order to evaluate the road surface acoustic properties, appropriate testing methods were developed and established. Two measurement methods (SPB (Statistical Pass-by method) (ISO 11819-1:1997) and CPX (Close Proximity method) (ISO 11819-2:2017), are widely used throughout the world excluding the United States of America, where the third method – OBSI (On-Board Sound Intensity) (AASHTO T 360-16) dominates.

The Close Proximity method is intended to verify the pavement's noise characteristics at almost any site according to the local requirements. It checks the acoustic effect of maintenance and road surface condition (e.g. damage of the pavement, clogging and the effect of porous asphalt cleaning) and as well as the homogeneity of a wearing course within a road section. In the CPX method two measuring microphones are mounted very close to the test wheel with the reference tyre (one is representing passenger car tyres, the second is 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 a protective 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 chamber (Vieira and Sandberg, 2019). The chamber reduces background noise (most notably the noise from other vehicles and wind noise) and it is constructed so that it does not initiate undesired noise reflections. The CPX method, in contrast to the SPB method, is supposed to take into account only the influence of the road surface on the noise generation phenomenon taking place between tyre and road surface, ignoring the sound propagation effect of a pavement and neglecting other noise sources of a moving vehicle (e.g. engine noise). This is essential for credibility of test results comparing different road surfaces in different parts of the world on during long term observations like those presented in (Hablovicova et al., 2021).

Some researchers declare good correlation between CPX and other methods (Bühlmann, 2019) with minor divergences. There are, however, researches questioning repeatability of the method due to many factors affecting the method. The CPX method is prone to weather conditions, human errors or materials (tyres) wear (Vieira and Sandberg, 2019), which makes the method so complicated that the obtained results may become doubtfully reliable.

The aim of the paper is to compare two different measuring systems available within one standard (ISO 11819-2:2017) in order to objectively assess the road surface noise emissions. This paper focuses on the comparison of the results obtained by different devices regarded as equal. The results shed light on the possible differences in the results obtained while using different testing equipment, which is a valid contribution to ongoing discussion on the assessment methods regarding traffic noise evaluation. The paper also mentions the issue of the tyres used during the tests. The article is the significantly extended version of the conference paper presented at the Internoise 2019 Congress in Madrid (Mioduszewski et al., 2019).

2. Current state of knowledge

All currently used methods are designed to evaluate noise levels coming from road traffic. Assuming that traffic noise problem concerns roads where speed limit exceeds 35-40 km/h, the main noise produced by vehicles comes from rolling tyres (Licitra et al., 2016). The above mentioned methods serve as noise characteristics evaluation of tyre-road interaction, giving possibility to control and consequently limit noise emission by affecting pavement surface layer (wearing course) composition.

In many countries on different road surfaces tests are performed to find out solutions enabling limitation of noise emission. Tests may be carried out in many different ways and may assess different noise generation mechanisms depending on the method used (Mikhailenko et al., 2022).

A previous publication of one of the authors of this paper (Mioduszewski et al., 2016) showed that the CPX method may be used in order to check the homogeneity of road surface. The noise measurement results of different sections differed significantly within the length of one section which was compared afterwards with other road pavement parameters such as evenness, production errors or mix variation. This fact suggests that acoustic measurement can indicate problems with wearing course layer parameters different than just the acoustic characteristic.

It is also getting popular to propose models of acoustic behaviour on the basis of performance of different road surfaces over time. There was proposed in (Licitra et al., 2019) a model of acoustic characteristic changes of rubberized road surfaces over years. The model was based on CPX method results.

The need for low noise road surfaces is clear which makes it essential to have a certain comparability between the results of acoustic road parameters obtained by different measurement methods. Many researches were carried out to pinpoint differences and similarities of different methods' results.

In the publication (Skov, 2016) results from many counties were gathered and compared for 2 testing methods (SPB and CPX). Interesting may seem the comparison between results obtained from different methods with various testing speed, which significantly complicated data analysis.

Other publication (Licitra et al., 2016) contains comparison of CPB (controlled pass-by) and CPX methods. The research aimed to enable to find the correlation between close proximity noise and noise obtained at the receiver outside of the road. Although there were certain obstacles listed that make the task difficult such as e.g. different speed, there were shown the possibilities of developing correction formulas enabling easy translation between results coming from different methods.

There are also publications presenting methods that are not explained in this paper. Results obtained with CPX method are compared to the results gathered in CB (coast-by) method as a whole spectrum of noise frequencies (Cesbron et al., 2017). It was noted that there is a high correlation between these methods, making it possible to make accurate estimation of the results of the second method by putting results of the first one into a certain formula. Autors in (Knabben et al., 2019) used the CPX method to evaluate Brazilian low noise road surfaces and made comparisons between CPX, CPB and sand patch macro texture measurement method. It was stated that the roughness of road surface may enable prediction of its acoustic result.

Research conducted in the paper (Tonin et al., 2017) revealed differences between American (OBSI) and European (CPX) method of road acoustic performance testing. The tests were compared using CPX open frame trailer and OBSI driven vehicle. The correlation between methods seemed reliable and there were differences only in high frequency range on one open-graded surface, which did not affect the general results.

Similar research was presented in the paper (Buret et al., 2014), where 3 testing methods were compared (OBSI, CPX and SPB). Tests for all road surfaces at 7 sections were carried out 3 times throughout the first year after their construction. The tests showed better correlation between CPX and SPB than OBSI method. The analysis, however, focused more on the road surface performance rather than comparison of methods.

On the other hand, the Danish report (Oddershede, 2013) showed direct and simple relation between CPX and OBSI method's results. According to speed and road type there was just additional value needed to transform results from one test method to achieve results of the second one.

There is also available the literature position (Kragh et al., 2013) showing relation between CPX method results and parameters of road surface such as texture and rolling resistance. The paper (Del Pizzo et al., 2021) proposed monitoring of road noise parameters with sensors placed inside the tyres, making the comparison easier and safer, while using Tyre Cavity Noise as the noise indicator.

In general, all the above mentioned papers revealed rather good correlation between different testing methods. However, it is more important to be sure if pavement acoustic properties obtained while using one method but utilizing different measuring systems or different testing vehicles are fully comparable. Such a comparison is especially important in European countries due to the unification of road pavement requirements all over the Europe. In 2013 Czech Republic researchers published data from a comparison of CPX car method results with CDV trailer method (Krivanek et al., 2014), which is based on self-constructed trailer used in Czech Republic by Transport Research Centre. The authors of that paper were satisfied with comparability of the two methods, even though out of 14 sections they discovered 12 sections having higher noisiness and 2 having lower noisiness obtained from CPX compared to CDV trailer method. They explained it by a difference of used testing tyres which in previous researches have already been found out (Schwanen et al., 2007).

Seven different CPX devices were used for comparison in the research (Lelong et al., 2017). The conclusion of using different CPX devices (including different cars and trailer) was, that there is a good correlation between results as long as there are the same testing tyres applied to the car/trailer. In case of different tyres are used, the correlation between results became not entirely clear, but the ranking of pavements in terms of noisiness was the same for all testing devices.

Even the relation between very similar testing devices may be very important. The results of tests carried out with two CPX trailers built differently or equipped in different tyres were shown in report (Kragh et al., 2010). The differences that could affect the results were e.g. path of the test wheel mounted on a trailer or closed or open chamber (different wind flow). According to (Wehr et al., 2018), the differences in the final CPX level results may be caused by many factors such as air temperature, shore hardness of the test tyre, test vehicle or trailer design, so it is vital to be sure about correction coefficients. Some of them, however, like shore hardness, may be difficult to measure in repeatable way (Vieira et al., 2020).

Similar research was done by (Reinink et al., 2012), where 7 different CPX trailers both with and without an enclosure showed a pretty good repeatability for P1 and H1 standard reference tyres. The tyres, however, become an issue for researchers (Lelong et al., 2020). Recommended tyres are no longer available on the market, which forces researchers to search for alternatives. In the mentioned paper it was also pointed out, that tests are conducted with tyres in deflated state in order to reflect the mechanism in which the tyre works under the heavy load.

Special Round Robin Tests are periodically carried out by many researchers to confirm the reliability of the used methods. This case study, comparing results obtained by different teams and different measuring systems, reported in this article, was carried out in Poland twice: first test in the summer of 2018, the second one in the summer/autumn of 2019. The test wasn't exactly the comparison between two methods as the tyres used in the case study differed in one case from the reference tyres according to the ISO 11819-2 standard.

3. CPX MEASURING SYSTEMS UTILIZED IN THE RESEARCH

The objective of the case study 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.

3.1. 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 measuring system that participated in the case study 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 the standard (ISO/TS 11819-3:2017) but it was the 195/60 R15 88H Michelin Energy Saver+ tyre presented in Fig. 1 (right). It was not possible to mount the standard “P1” tyre due to its improper size (too big). 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 as it was calculated on the basis of original hardness and age of the tyre. 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.

3.2. Polish CPX test trailer

The second CPX measuring system taking part in this case study 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 (ISO/TS 11819-3:2017) – 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 in 2018. During tests performed in 2019 the “H1” tyre became 1 Shore A harder and equalled 68 Shore A, while P1 remained the same as in 2018 (both tyres were stored in cold and dark conditions /refrigerator/ when not used). For the purpose of this paper only the data acquired for the “P1” reference tyre have been used and reported.

4. TEST SECTIONS AND ROAD PAVEMENTS

The first tests took place in 2018 in the vicinity of Krakow in southern Poland. The tests were repeated in the following year on the same road sections excluding the BBTM pavements. Twelve test sections in 2018 and ten in 2019, correspondingly six pairs in 2018 and five in 2019 of nominally the same wearing courses, were selected for this purpose. All of them apart from Slurry Seal Gripfibre (thin emulsion layer) were made in Hot Mix Asphalt (HMA) technology, however they differed in terms of properties. The tested mixes had various air void content or maximum aggregate size. They also differed in age and speed limit. In both years the trailer tests were designed to verify the data provided by self-powered vehicle. Details regarding the characteristics of tested wearing courses are presented in Tab. 1.

Tab. 1. *Test sections and wearing course parameters*

Section number	Designation	Mix type	Construction year	Maximum aggregate size	Layer thickness	Air void content	Special feature	Speed limit	Section length	Test years
1	SMA 0/8 N (2010)	SMA	2010	8 mm	4 cm	2.0 – 3.5 %	-	120 km/h	1300 m	2018 2019
2	SMA 0/8 S (2010)	SMA	2010	8 mm	4 cm	2.0 – 3.5 %	-	120 km/h	1300 m	2018 2019
3	SMA 0/8 NW (2016)	SMA	2016	8 mm	4 cm	2.0 – 3.5 %	-	70 km/h	1000 m	2018 2019
4	SMA 0/8 SE (2016)	SMA	2016	8 mm	4 cm	2.0 – 3.5 %	-	70 km/h	1000 m	2018 2019
5	SMA 0/8 N (2017)	SMA	2016	8 mm	4 cm	2.0 – 3.5 %	Rubber addition	120 km/h	1700 m	2018 2019
6	SMA 0/8 S (2017)	SMA	2016	8 mm	4 cm	2.0 – 3.5 %	Rubber addition	120 km/h	1700 m	2018 2019
7	SMA 0/12.8 L1 (2005)	SMA	2005	12.8 mm	4 cm	3.0 – 4.0 %	-	100 km/h	750 m	2018 2019
8	SMA 0/12.8 L2 (2005)	SMA	2005	12.8 mm	4 cm	3.0 – 4.0 %	-	100 km/h	750 m	2018 2019
9	SSGF 0/5 L1 (2017)	Slurry Seal Gripfibre	2017	5 mm	1 cm	-	Polymer modified emulsion layer with fibres	100 km/h	500 m	2018 2019
10	SSGF 0/5 L2 (2017)	Slurry Seal Gripfibre	2017	5 mm	1 cm	-	Polymer modified emulsion layer with fibres	100 km/h	500 m	2018 2019
11	BBTM 0/8 N (2015)	BBTM	2015	8 mm	3 cm	7.0 – 10.0 %	Rubber modified binder	90 km/h	1000 m	2018
12	BBTM 0/8 S (2015)	BBTM	2015	8 mm	3 cm	7.0 – 10.0 %	Rubber modified binder	90 km/h	1000 m	2018

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. 11 and 12 as well as SMA sections no. 5 and 6. Slurry Seal Gripfibre (sections no. 9 and 10) was applied on SMA 0/12.8 to postpone cracks propagation and to improve skid resistance. Slurry Seal Gripfibre influence on the section with SMA 0/12.8 was widely described in the paper (Nowoświat et al., 2020).

5. 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 with the speed of 80 km/h. Air temperature during the measurements was within the range from 22 up to 35 °C in 2018 and from 16 up to 25 °C in 2019. All the divergences could have affected final results of the tests to some extent.

5.1. 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.

In this procedure at first the energy-based average of the front and the 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 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 in 2018 and 66-67 Shore A in 2019 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 up to 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.

5.2. 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 car”. The designation for Polish CPX test trailer was “PL trailer”.

The calculated sound pressure levels for both measuring systems for all tested sections were presented in Tab. 2. The calculated differences between both systems were also shown in Fig. 3.

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

Test section	Measurements 2018 CPXP [dB(A)]		*CPXP difference [dB(A)]*	Measurements 2019 CPXP [dB(A)]		*CPXP difference [dB(A)]*
	FR car	PL trailer	*FR car - PL trailer*	*FR car*	*PL trailer*	*FR car - PL trailer*
SMA 0/8 N (2010)	99,6	99,4	0,2	99,2	99,2	0,0
SMA 0/8 S (2010)	99,9	99,5	0,4	99,7	98,8	0,9
SMA 0/8 (2010) average	***99,8***	***99,5***	***0,3***	***99,5***	***99,0***	***0,4***
SMA 0/8 NW (2016)	98,3	98,4	-0,1	98,4	98,5	-0,1
SMA 0/8 SE (2016)	97,1	98,0	-0,9	97,4	97,6	-0,2
SMA 0/8 (2016) average	***97,7***	***98,2***	***-0,5***	***97,9***	***98,1***	***-0,2***
SMA 0/8 N (2017)	97,9	98,3	-0,4	97,7	97,9	-0,1
SMA 0/8 S (2017)	97,8	98,3	-0,5	98,0	98,0	0,1
SMA 0/8 (2017) average	***97,8***	***98,3***	***-0,5***	***97,9***	***97,9***	***0,0***
SMA 0/12.8 L1 (2005)	103,4	101,1	2,3	103,1	101,2	2,0
SMA 0/12.8 L2 (2005)	102,3	100,5	1,9	102,1	100,7	1,5
SMA 0/12.8 (2005) average	***102,9***	***100,8***	***2,1***	***102,6***	***100,9***	***1,7***
SSGF 0/5 L1 (2017)	97,9	97,1	0,8	98,3	97,3	1,0
SSGF 0/5 L2 (2017)	97,7	95,9	1,8	96,9	96,6	0,4
SSGF 0/5 (2017) average	***97,8***	***96,5***	***1,3***	***97,6***	***96,9***	***0,7***
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***	-	-	-

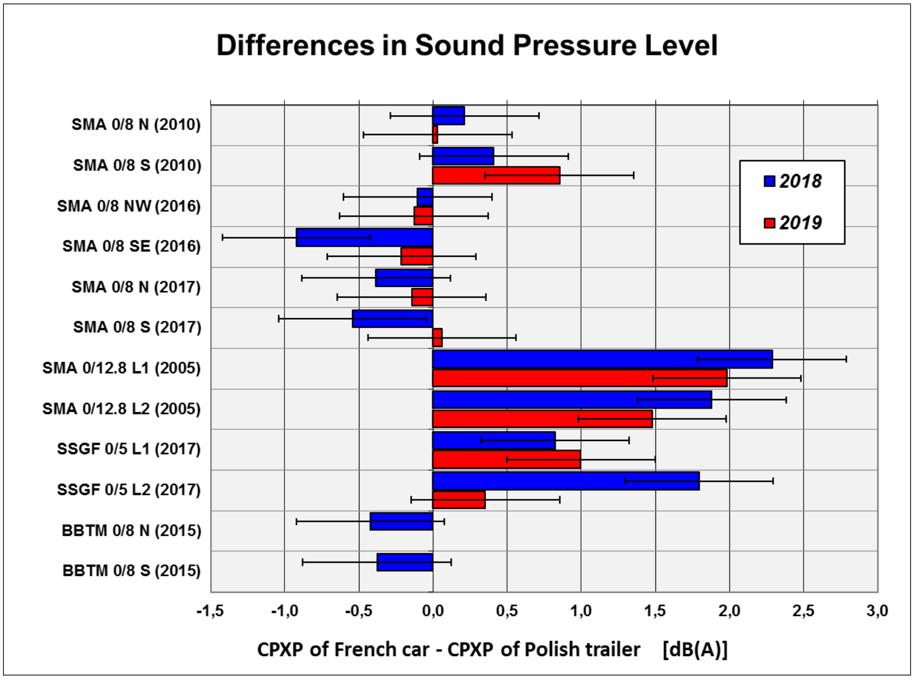


Fig. 3. *Differences in CPXP levels between the measuring systems*

The obtained results reveal that the differences in noise levels measured by both CPX systems are differentiated and inconsistent. But when comparing year-to-year results for the same test pavement, the trend of differences has been maintained.

For BBTM 0/8 (2015) and SMA 0/8 (2017) test sections the results are almost the same – consistently the CPXP values calculated for French CPX car were about 0.4 dB lower than values for Polish CPX trailer. The measurements in 2019 showed even smaller differences – within a measurement error. 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 0.3 dB) can be observed for a similar SMA 0/8 (2016) pavement. In case of this test section the difference measured between two subsections for French car in 2018 was much higher (1.3 dB) than for Polish trailer (0.4 dB).

For other 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 – 0.9 dB with an average of 0.4 dB). The highest difference between both measuring systems (from 1.5 up to 2.3 dB, with an average of 1.9 dB) was noted for the oldest tested sections with SMA 0/12.8 (2005). The difference was about 0.4 dB higher in 2018 compared to 2019. In this case the differences measured over both years between two subsections were almost twice as high (1.0 dB) for French car than for Polish trailer (0.6 dB). In contrast to this, the measured by French CPX car difference between two subsections of SSGF 0/5 (2017) in 2018 was negligible, only 0.2 dB, while the Polish CPX trailer measured a significant difference of 1.2 dB for this pavement. In 2019 this difference increased up to 1.4 dB for French CPX car and decreased to 0.7 dB for Polish CPX trailer. The differences in CPXP levels obtained by two CPX measuring systems for this test section in 2018 were from 0.8 up to 1.8 dB, with an average of 1.3 dB and they were half smaller (from 0.1 up to 1.0 dB, with an average of 0.7 dB) in 2019.

Comparing the results of this case study to those obtained by (Vieira et al., 2020) some resemblance may be observed. The test carried out in 2020 with use of 4 different CPX trailers with standard tyres H1 and P1 revealed differences in mean results of different testing devices. Those ranged up to the level of 1,57 dB for H1 tyre and 1,29 dB for P1 tyre which was assumed to be comparable to the ISO 11819-2:2017 standard uncertainty values.

5.3. Pavement ranking

Considering the already known inconsistency and various differences in noise levels measured by both CPX devices it is vital to verify if the ranking of tested pavements (from the quietest to the loudest) was the same for both CPX measuring system used. Taking into account that significant differences in CPXP levels were noted between subsections for a part of tested pavements, the ranking has been prepared for all twelve selected test sections (presented in Tab. 3) as well as for the same six wearing courses with counting average for the same road surfaces' sections (shown in Tab. 4).

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

Test section	Measurements 2018				Measurements 2019			
	CPXP [dB(A)]	Ranking position	CPXP [dB(A)]	Ranking position	CPXP [dB(A)]	Ranking position	CPXP [dB(A)]	Ranking position
	by FR CPX car		by PL CPX trailer		by FR CPX car		by PL CPX trailer	
SMA 0/8 N (2010)	99,6	9	99,4	9	99,2	7	99,2	8
SMA 0/8 S (2010)	99,9	10	99,5	10	99,7	8	98,8	7
SMA 0/8 NW (2016)	98,3	8	98,4	7	98,4	6	98,5	6
SMA 0/8 SE (2016)	97,1	1	98,0	3	97,4	2	97,6	3
SMA 0/8 N (2017)	97,9	5	98,3	4	97,7	3	97,9	4
SMA 0/8 S (2017)	97,8	3	98,3	5	98,0	4	98,0	5
SMA 0/12.8 L2 (2005)	102,3	11	100,5	11	103,1	10	101,2	10
SMA 0/12.8 L1 (2005)	103,4	12	101,1	12	102,1	9	100,7	9
SSGF 0/5 L1 (2017)	97,9	4	97,1	2	98,3	5	97,3	2
SSGF 0/5 L2 (2017)	97,7	2	95,9	1	96,9	1	96,6	1
BBTM 0/8 N (2015)	98,0	6	98,4	6	-	-	-	-
BBTM 0/8 S (2015)	98,1	7	98,5	8	-	-	-	-

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

Test section	Measurements 2018				Measurements 2019			
	CPXP [dB(A)]	Ranking position	CPXP [dB(A)]	Ranking position	CPXP [dB(A)]	Ranking position	CPXP [dB(A)]	Ranking position
	by FR CPX car		by PL CPX trailer		by FR CPX car		by PL CPX trailer	
SMA 0/8 (2010)	99,8	5	99,5	5	99,5	4	99,0	4
SMA 0/8 (2016)	97,7	1	98,2	2	97,9	3	98,1	3
SMA 0/8 (2017)	97,8	3	98,3	3	97,9	2	97,9	2
SMA 0/12.8 (2005)	102,9	6	100,8	6	102,6	5	100,9	5
SSGF 0/5 (2017)	97,8	2	96,5	1	97,6	1	96,9	1
BBTM 0/8 (2015)	98,0	4	98,4	4	-	-	-	-

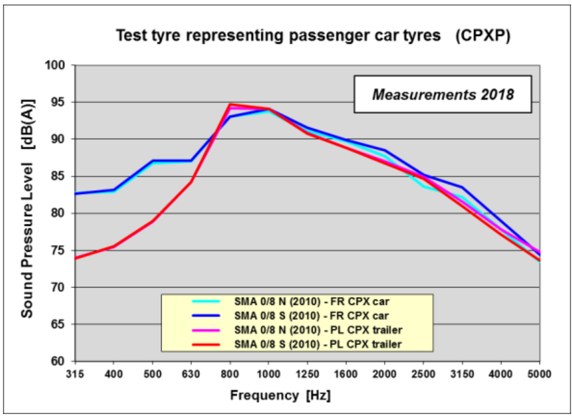
Analysing the ranking performed for all 12 (10 in 2019) tested sections (shown in Tab. 3) it can be observed that there is differentiation for the quietest test sections. In the ranking according to the results obtained by French CPX car the quietest test section in 2018 is SMA 0/8 SE (2016), which is only the 3rd quietest section in ranking according to Polish CPX trailer (both years) and the 2nd in repeated by French crew measurements in 2019. The 2nd quietest test section in 2018 ranking corresponds to the quietest one (SSGF 0/5 (2017)) in all other rankings. It should be pointed out that differences in CPXP levels between the six successive test sections in the 2018's ranking by French car (positions from 2 to 7) are very small – only 0.1 dB between single results: 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 2018's ranking obtained from the Polish trailer's results, 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. In the 2019's rankings the differences in CPXP levels between the successive test sections (positions from 2 to 6) for both teams are higher and are about 0.3 dB. With only one exception (test section SSGF 0/5 L1 (2017) which is 5th in French CPX car ranking and 2nd for Polish CPX trailer), the results correspond to each other. Test sections of the SMA 0/8 (2010) pavement are inverted. At the other end of ranking, for the loudest sections, one can observe the same order of test sections in both 2018's rankings starting from position 9 up to 12 and for 2019's rankings for the last two positions 9 and 10.

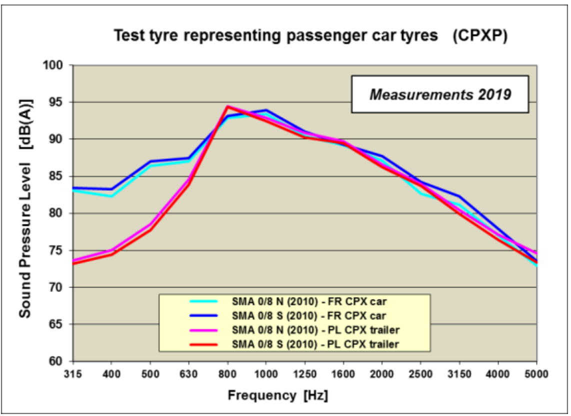
Similar conclusions can be drawn for the rankings shown in Tab. 4 which have been performed for the six in 2018 and five in 2019 pavement types when averaging nominally identical wearing course subsections. Inconsistency can be observed in 2018's pavement ranking positions 1 and 2 and full compliance 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. The 2019's rankings are exactly the same.

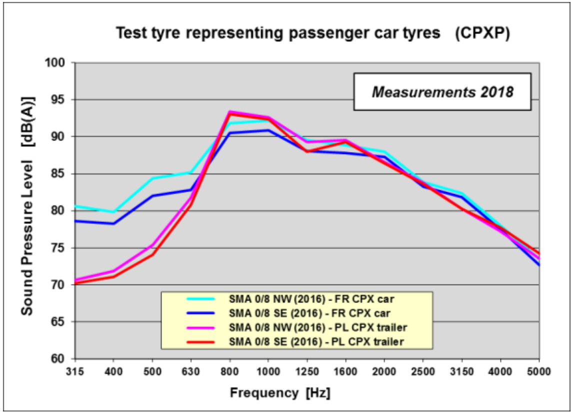
5.4. Noise frequency spectra

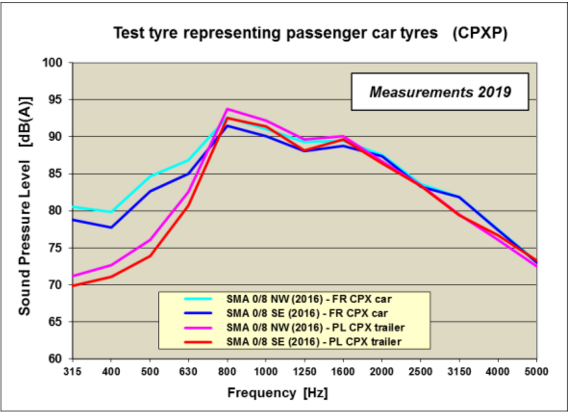
During the research, all noise data were collected as the A-weighted one-third-octave-band levels in the frequency spectra range from 315 Hz to 5000 Hz. Performing the noise frequency spectra analysis, one should remember that the measuring systems used in this RRT were equipped with different test tyres. 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 was used in the Polish CPX trailer.

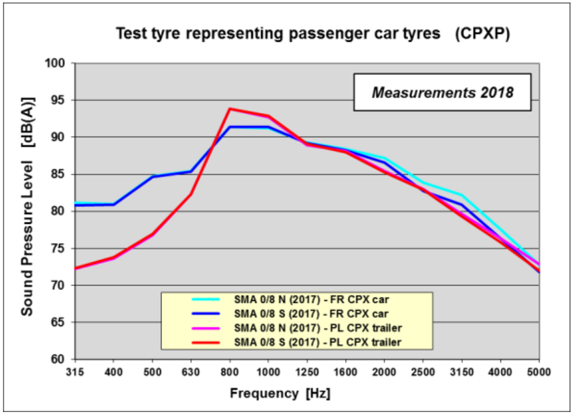
The noise frequency spectra obtained by both CPX measuring systems during the two trial campaigns for all test sections were presented in Fig. 4.


Test tyre representing passenger car tyres (CPXP)
Measurements 2018
Sound Pressure Level [dB(A)]
100
95
90
85
80
75
70
65
60
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
Frequency [Hz]
SMA 0/8 N (2010) - FR CPX car
SMA 0/8 S (2010) - FR CPX car
SMA 0/8 N (2010) - PL CPX trailer
SMA 0/8 S (2010) - PL CPX trailer


Test tyre representing passenger car tyres (CPXP)
Measurements 2019
Sound Pressure Level [dB(A)]
100
95
90
85
80
75
70
65
60
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
Frequency [Hz]
SMA 0/8 N (2010) - FR CPX car
SMA 0/8 S (2010) - FR CPX car
SMA 0/8 N (2010) - PL CPX trailer
SMA 0/8 S (2010) - PL CPX trailer


Test tyre representing passenger car tyres (CPXP)
Measurements 2018
Sound Pressure Level [dB(A)]
100
95
90
85
80
75
70
65
60
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
Frequency [Hz]
SMA 0/8 NW (2016) - FR CPX car
SMA 0/8 SE (2016) - FR CPX car
SMA 0/8 NW (2016) - PL CPX trailer
SMA 0/8 SE (2016) - PL CPX trailer


Test tyre representing passenger car tyres (CPXP)
Measurements 2019
Sound Pressure Level [dB(A)]
100
95
90
85
80
75
70
65
60
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
Frequency [Hz]
SMA 0/8 NW (2016) - FR CPX car
SMA 0/8 SE (2016) - FR CPX car
SMA 0/8 NW (2016) - PL CPX trailer
SMA 0/8 SE (2016) - PL CPX trailer


Test tyre representing passenger car tyres (CPXP)
Measurements 2018
Sound Pressure Level [dB(A)]
100
95
90
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400
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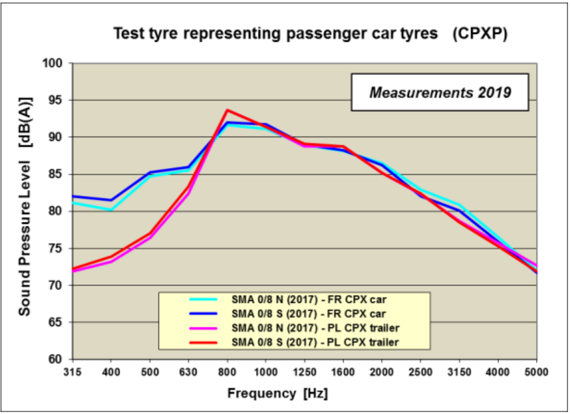
630
800
1000
1250
1600
2000
2500
3150
4000
5000
Frequency [Hz]
SMA 0/8 N (2017) - FR CPX car
SMA 0/8 S (2017) - FR CPX car
SMA 0/8 N (2017) - PL CPX trailer
SMA 0/8 S (2017) - PL CPX trailer


Test tyre representing passenger car tyres (CPXP)
Measurements 2019
Sound Pressure Level [dB(A)]
100
95
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85
80
75
70
65
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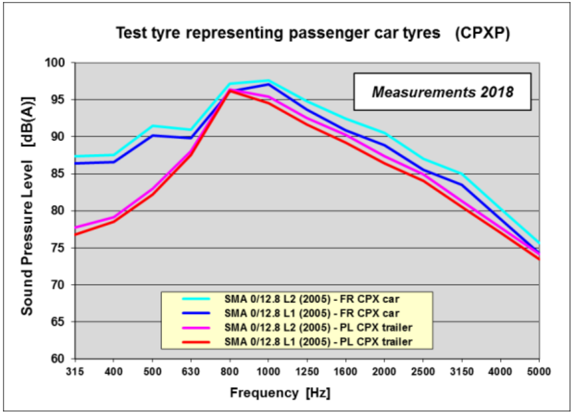
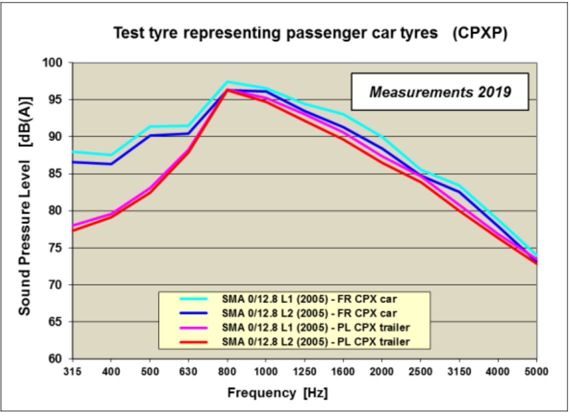
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
Frequency [Hz]
SMA 0/8 N (2017) - FR CPX car
SMA 0/8 S (2017) - FR CPX car
SMA 0/8 N (2017) - PL CPX trailer
SMA 0/8 S (2017) - PL CPX trailer


Test tyre representing passenger car tyres (CPXP)
Measurements 2018
Sound Pressure Level [dB(A)]
100
95
90
85
80
75
70
65
60
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
Frequency [Hz]
SMA 0/12.8 L2 (2005) - FR CPX car
SMA 0/12.8 L1 (2005) - FR CPX car
SMA 0/12.8 L2 (2005) - PL CPX trailer
SMA 0/12.8 L1 (2005) - PL CPX trailer


Test tyre representing passenger car tyres (CPXP)
Measurements 2019
Sound Pressure Level [dB(A)]
100
95
90
85
80
75
70
65
60
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
Frequency [Hz]
SMA 0/12.8 L1 (2005) - FR CPX car
SMA 0/12.8 L2 (2005) - FR CPX car
SMA 0/12.8 L1 (2005) - PL CPX trailer
SMA 0/12.8 L2 (2005) - PL CPX trailer

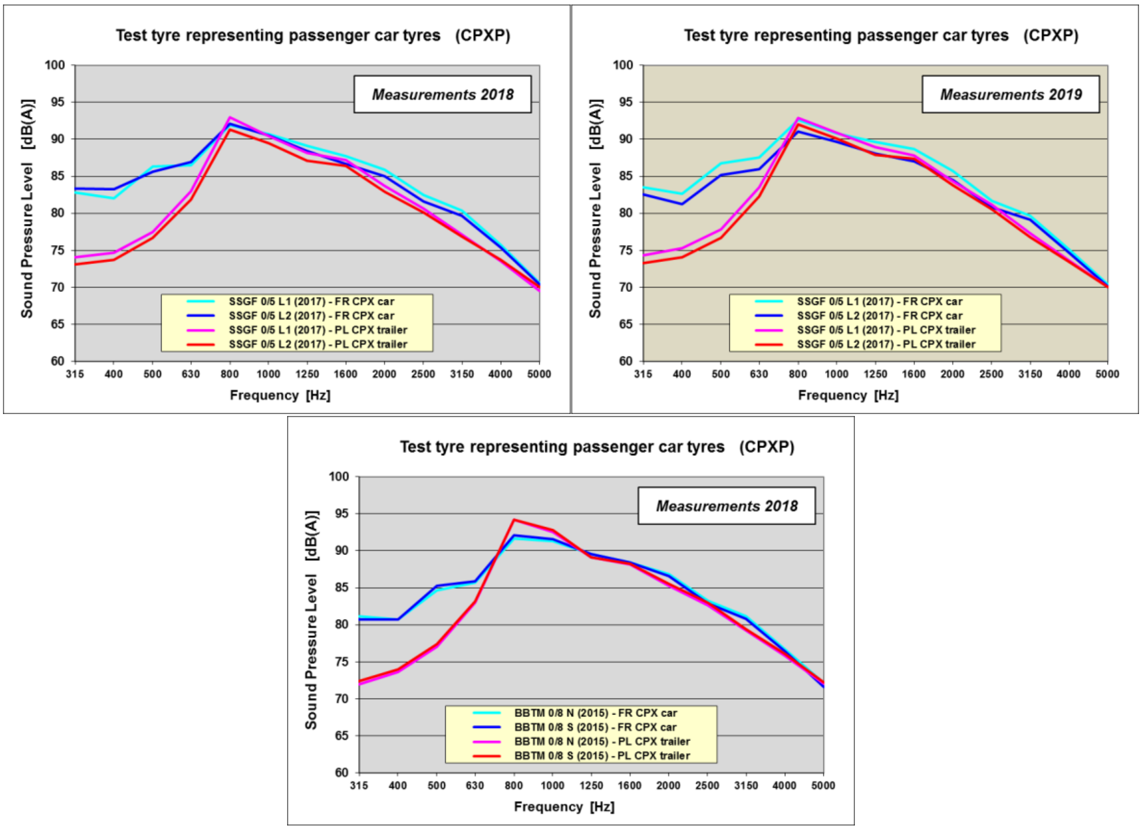


Fig. 4. *Noise frequency spectra obtained by both CPX measuring systems for all test sections during measurements performed in 2018 and 2019*

Analyzing the obtained frequency spectra it can be noted that in the high frequency range, above 1250 Hz, frequency characteristics were similar for all test sections with the exception of only two pavements, SMA 0/12.8 (2005) and SSGF 0/5 (2017) where higher levels (1.5 ÷ 2.0 dB on the average) were observed for French car. In the medium frequency range (800 – 1250 Hz), in case of 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 contrast to the above mentioned convergences, significant differences were observed for all the test sections in the low frequency range i.e. below 800 Hz. Frequency spectra characteristics obtained by French car are much higher than by Polish trailer. In few cases differences exceed 10 dB. Their shape is also quite similar for all tested pavements. The cause may be a disturbing noise derived from car’s engine, muffler system of the vehicle affecting measurement results or tyre characteristics. Thus, additional measurement runs in 2019 were performed at one of the test sections to find out the reason. Comparative tests were conducted when the French CPX car was cruising (about 2300 rpm) and during coast-by but with its engine idling (800 rpm) because it was not safe to switch it off when driving on public and trafficked road. The obtained results were presented in Fig. 5. No differences in noise frequency spectra were noted between both cases which suggests that the tyre characteristics impact (not the car engine influence).

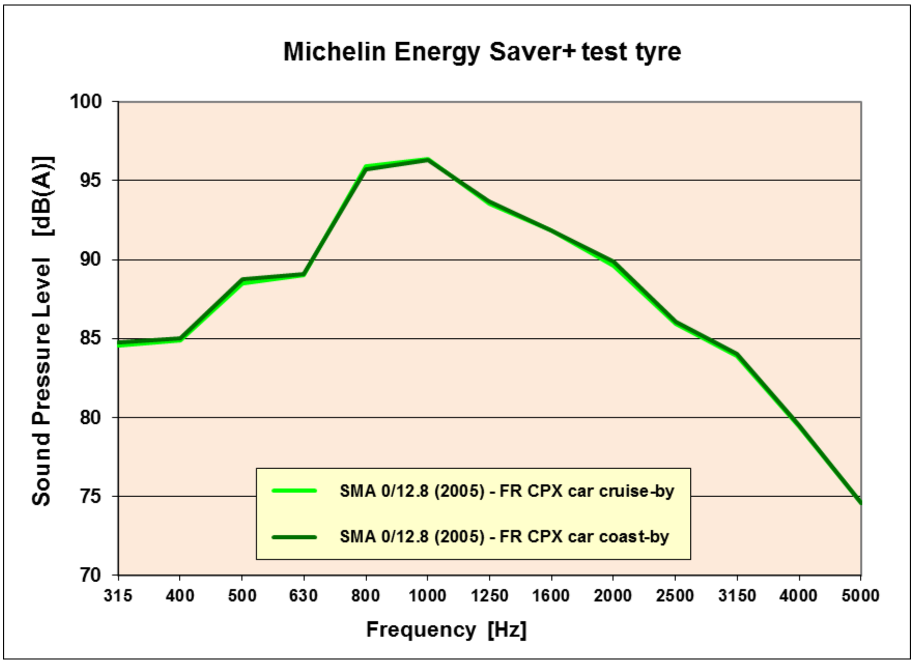


Fig. 5. *Results of the experiment to establish the influence of test vehicle power unit or/and muffler system on measured noise frequency spectra*

Full compliance of measured spectral characteristics in both cases means that the causes should be connected with the construction of the wheel arch and its impact on the measured noise. Such a problem was foreseen by the ISO standard and therefore the test system correction determined according to the Annex A “Certification of the test vehicle” of the ISO 11819-2:2017 standard have to be applied. As mentioned in chapter 5.1 the test system correction of French CPX car was unknown and it was not applied when calculating this RRT measurement results. It is also planned to perform the certification procedure of the French CPX car.

Another cause of the obtained differences between both measuring systems, French CPX car and Polish CPX trailer, can be the different test tyre used. This issue was already indicated in (Lelong et al., 2017). In the RRT, the “P1” reference tyre according to the ISO 11819-3:2017 was used by the Polish CPX trailer while the Michelin Energy Saver+ tyres were fitted and measured on French CPX car.

The comparison of the two different types of test tyres utilized in this research was done during measurements performed on a test section with SMA 0/8 wearing course located in Gdansk (northern Poland) using the Polish CPX trailer. Two Michelin Energy Saver+ and two SRTT tyres were tested. The obtained sound pressure levels were shown in Fig. 6 while the frequency spectra were presented in Fig. 7.

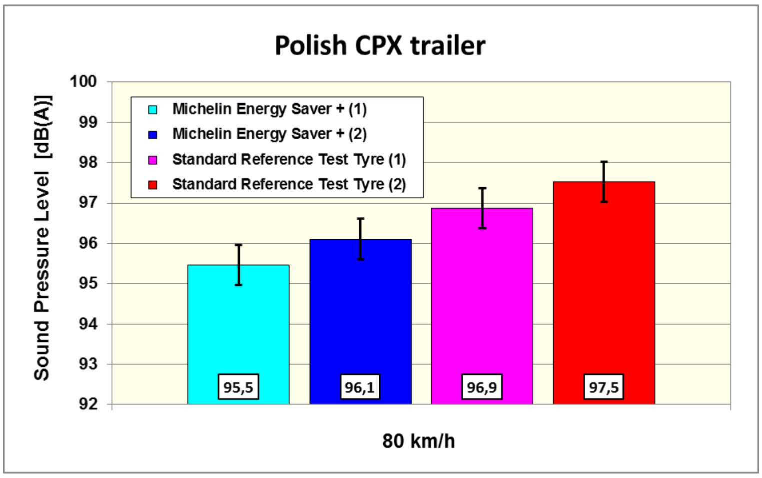


Fig. 6. *Sound pressure levels of Michelin Energy Saver+ and SRTT tyres*

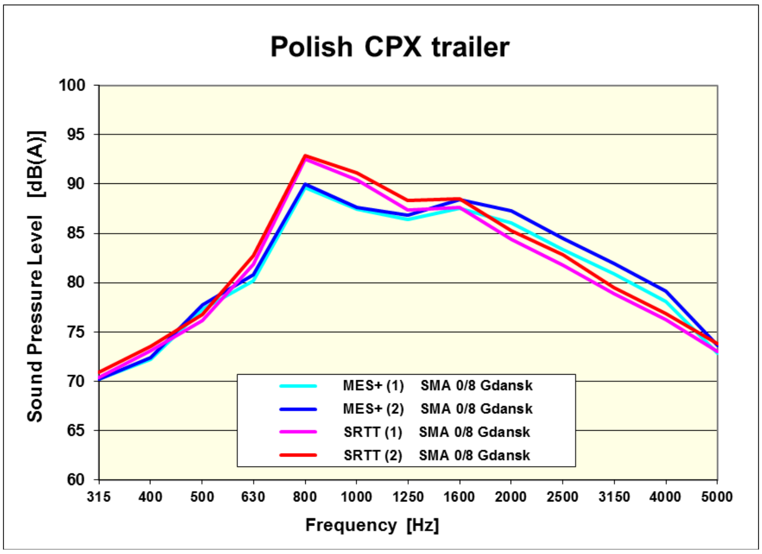


Fig. 7. *Noise frequency spectra of Michelin Energy Saver+ and SRTT tyres*

The shapes of frequency spectra in medium and high frequency range for all tested tyres do not differ significantly from the ones obtained on SMA 0/8 pavements which are reported in this case study and presented in Fig. 4. However, for the low frequencies (630 Hz and below) the values recorded for Michelin Energy Saver+ tyres were much lower when tested on Polish CPX trailer than on French CPX car. They were fully comparable with values of the tested SRTT tyres. This finding supports conclusion formulated above, saying that the differences in low frequency range may be connected with the construction of the testing vehicle and its impact on the measured noise. The authors of (Campillo-Davo et al., 2019) confirm that use of a passenger car in CPX method results in an increase of low frequency noise emission due to aerodynamic noise. In the article this effect was minimised by the adoption of the new modified test frame supporting microphones. Also the authors of (Ji et al., 2020) experimented with modification of microphone setup at the CPX car. Concluding, the calibration of test vehicle and application of device-related correction of frequency spectra would be recommended in case of French CPX car.

It was also interesting for the authors to find out if the former used (in 2017) Michelin Energy Saver test tyre shows similar characteristics of frequency spectra. Comparison of the tread patterns of both Michelin tyres is presented in Fig. 8.

Fig. 8. *Test tyres used in 2017 by the French CPX car: Michelin Energy Saver+ (left) and Michelin Energy Saver (right)*

Comparative tests of the influence of different Michelin tyres used by the French CPX car on measured sound pressure levels and noise frequency spectra were carried out on two consecutive days in July 2017 on four test sections with SMA 0/8 pavement (sections 1, 2, 5 and 6 given in Tab. 1). The results are presented in Fig. 9 (sound pressure levels) and in Fig. 10 (frequency spectra).

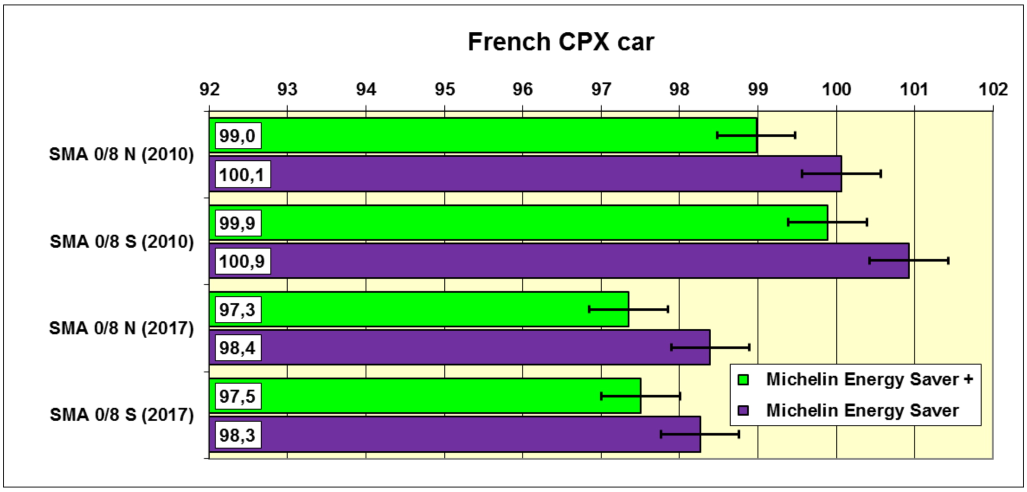


Fig. 9. *Sound pressure levels of the different Michelin tyres used by the French CPX car*

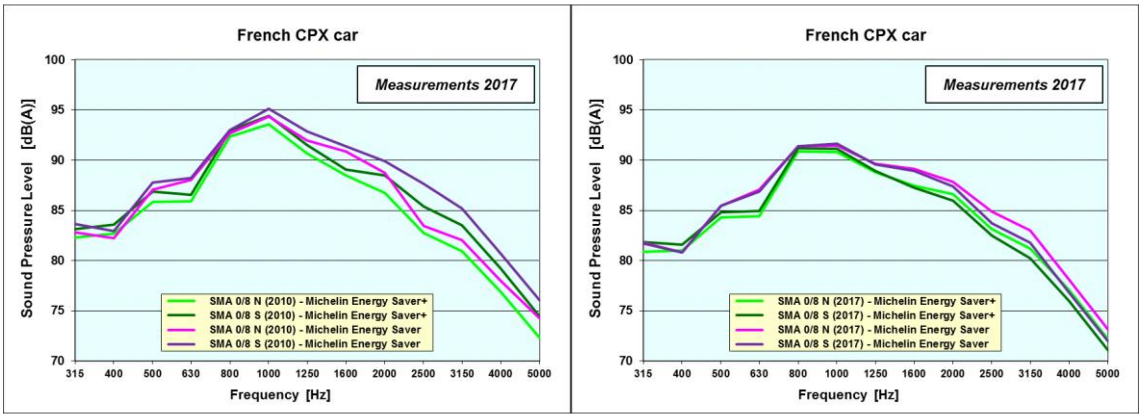


Fig. 10. *Noise frequency spectra of the different Michelin tyres used by the French CPX car*

Systematic difference in measured sound pressure levels can be observed between the two Michelin tyres for all test sections. The old Michelin Energy Saver tyre is of about 1.0 dB louder than the new one. But the shape of frequency spectral characteristics remains almost unchanged. Rather high values in the low frequency range, below 800 Hz, were measured for both Michelin tyres regardless of the test section. Almost no differences were noted for medium frequencies. In the high frequency range (above 1250 Hz) one can observe up to 1.5 ÷ 2.5 dB higher levels for the old Michelin tyre. Concluding this experiment, the main issue was still not explained and a comparison of Michelin Energy Saver+ tyre with the “P1” standard reference tyre is planned to be arranged in the nearest future.

6. CONCLUSIONS

Acoustic measurements, especially those using the close proximity measuring systems are prone to many factors. It applies not only to weather conditions, but also to measuring devices. This research confirms that differences in terms of construction of measuring device and tyres used play 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 study:

- 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 in 2018 and from -0,2 up to 1,9 dB in 2019, which is consistent with results of analogical test presented in (Lelong et al., 2017) and (Vieira et al. 2020) where reported differences reached up to respectively 2 dB and 1,5 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, smaller differences (-1.5 ÷ 2.5 dB) in medium frequency range and rather similar levels in the high frequency range with two exceptions. Low frequency differences are expected to be caused by difference in measuring device (tyre, microphone, closed trailer). There is a need of test vehicle certification and applying test system correction in case of French CPX car.
- It was excluded that differences between those testing methods may be affected by speed of engine rotation.
- Change of testing wheel in CPX car method affected the results, but the shape of noise frequency spectra graph remained similar.

The differences listed above arise most probably because of the difference in tyres used in both devices but also due to omission of calibration of French CPX system. It, however, should not affect the ranking of test sections. If two different tyre types change the ranking it may imply that CPX test results may not have reflection in the noise levels around the road and does not reflect the consumer tyres which was confirmed in the paper (Licitra et al., 2017) and which triggered works on the opportunistic measuring system (Van Hauwermeiren et al., 2021). Nevertheless, it is planned to repeat this research in 2023 provided the same tyre type will be used in both experiments to confirm the observations.

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

7. ACKNOWLEDGEMENTS

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