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Transportation Research Procedia 14 (2016) 2678 – 2687

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

Impact of potential and dedicated tyres of electric vehicles on the tyre-road noise and connection to the EU noise label

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Abstract

With the advent of electric vehicles and their significant lower propulsion noise emission it is possible to assess the tyre-road noise trough cruise-by measurements with an increased accuracy, even at speeds where a combustion engine propulsion system would usually disturb the measurement results. The European project FOREVER (Future OpeRational impacts of Electric Vehicles on European Roads) funded by CEDR between 2013 and 2014, aimed to provide data and information on the potential future noise impacts of electric vehicles (EVs) and hybrid electric vehicles (HEVs) on national roads, more specifically (i) the noise levels generated by electric/hybrid vehicles, (ii) how these vehicles can be effectively included in noise prediction models, and (iii) the likely noise impacts for residents as the number of electric/hybrid vehicles on national roads increases. Within work package 3 of the project, concerned with the noise emission of tyres used on EVs and HEVs, nine different sets of tyres have been selected and compared by carrying out pass-by measurements based on the standard ISO 11819-1. Special attention has been paid to potential and dedicated tyre sets which meet the demands for low energy consumption and a low rolling resistance to optimize the range of electric vehicles. The results have been analysed in order to reveal differences between single tyre sets and to quantify the influence of the tyres on the tyre-road noise. In a second part of the work, the EU tyre labels have been considered. The tyre labels have been introduced by the European Community for informing and helping consumers to choose products according to energy efficiency, safety in wet braking conditions and exterior rolling noise. Minimum requirements are also set in type-approval legislation. In the FOREVER project the exterior noise labels of the nine selected tyres have been compared with the results of the pass-by noise measurements performed on a common real-life road surface. Discrepancies observed on tyre ranking between both approaches have been discussed. Investigations within the concept of "low-noise tyres"

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Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.443

have been put forward accordingly. Finally, outcomes for the modelling of rolling noise from electric vehicles in the European noise assessment method CNOSSOS-EU, which is recommended for strategic noise mapping in Europe, have been given. As a complement to the EV propulsion noise component previously specified in the FOREVER project, it turns out that no correction term is required for EV rolling noise. In this paper, the main content as well as the outcomes of work package 3 of the project FOREVER are presented.

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Keywords: Electric vehicle; tyre-road nosie; EU tyre label; CNOSSOS-EU

1. Introduction

Electric cars are among the fastest growing vehicle groups in the field of motorized individual transport in multiple European countries. Due to targeted promotion of electric vehicles (EVs) in form of tax benefits for the purchase of an EV and free parking spaces in cities, e.g. according to Statistics Norway (2014), Norway’s vehicle stock had a share of 1.5 % of EVs by the end of 2014. With increasing range and decreasing charging time, it is expected that the global number of EVs will further grow within the next years. With the omission of the internal combustion engine and the corresponding exhaust system, EVs offer the potential of reducing traffic noise in urban areas, as pointed out by Jabben (2012). However, multiple studies (e.g. Czuka (2014), Altinsoy (2013)) have proved that the missing noise of the combustion propulsion system can hamper the auditory detectability of EVs, especially at driving speeds below 30 km/h and in presence of urban background noise.

While acoustic-related investigations on EVs have been mainly focused on traffic safety and noise emissions in urban situations, little research has addressed the potential noise impacts on roads under the jurisdiction of National Road Authorities (NRAs), where speed limits are likely to be high. The European project FOREVER (Future OpeRational impacts of Electric Vehicles on European Roads) funded by CEDR (Conference of European Directors of Roads) between 2013 and 2014, aimed to provide data and information on the potential future noise impacts of electric vehicles (EVs) and hybrid electric vehicles (HEVs) on national roads. More specifically, the project had three key objectives: the identification of noise emission levels from EVs and HEVs, how these vehicles can be effectively included in the noise prediction model CNOSSOS-EU (Kephalopoulos, (2012)) and furthermore, the quantification of noise emissions of tyres used on hybrid and electric vehicles.

The present paper covers the content of FOREVER’s work package 3 (Gasparoni et al. (2015)), which took a comprehensive look at the noise emission of potential and dedicated tyres for electric cars. In total nine different sets of tyres have been chosen with respect to the EU tyre label ratings and the specific demands of electric vehicles. By performing pass-by measurements based on the standard ISO 11819-1 with EVs, the tyre-road noise has been assessed with an increased accuracy due to the significantly lower propulsion noise emission of EVs. Subsequently, these measurement results obtained on a common real-life road surface have been analysed and compared with the EU tyre labels for exterior rolling noise. Discrepancies observed on the tyre ranking between both approaches have been discussed by considering the concept of “low-noise tyres”. Finally, the outcomes of FOREVER’s work package 2 for the modelling of rolling noise from electric vehicles in the European noise assessment method CNOSSOS-EU, which is recommended for strategic noise mapping in Europe, have been given.

2. Impact of potential and dedicated tyres for electric cars on the tyre-road noise

A common procedure for determining the exterior noise emissions of a vehicle in motion is the so-called controlled pass-by (CPB) measurement method, which is based on the standard ISO°11819-1. The results of these measurements take into account the noise emitted by the vehicles’ propulsion system as well as the noise caused by the tyre-road interaction. Due to the significantly lower contribution of the propulsion system of an EV, it is possible to determine the tyre-road noise and furthermore the influence of the tyre with increased accuracy.

2.1. Potential and dedicated tyres for electric vehicles

For the analysis and quantification of the influence of different potential and dedicated tyres for electric cars on rolling noise, nine different sets of tyres have been selected. Since the focus of the project FOREVER was on national roads, only tyres suited for electric cars that are more likely to appear on highways have been considered for the investigations. Therefore, the electric car Renault Fluence Z.E., which is suited for common driving speeds on highways, has been chosen. According to Euro NCAP, the vehicle can be classified as a “small family car”.

For the selection of potential tyres for the chosen electric car, multiple considerations have been taken into account. In order to ensure a high range with one single battery charge, a low rolling resistance between the tyre and the road surface, which leads to less energy dissipation, is advantageous. The rolling resistance rating provided by the EU tyre label has been used as the primary selection criterion for potential tyres for EVs. The second selection criterion represented the tyre label rating for wet grip, whereas a lower rating implies a shorter braking distance. In total, 8 different sets of tyres have been selected with dimension to fit on the Renault Fluence Z.E.

While several dedicated tyres were available for EVs within the vehicle class “supermini” on the market by the end of 2013, no exclusively dedicated tyres were available for the Renault Fluence Z.E.. However, the vehicle is shipped with a standard set of tyres, which is assumed to be well suited for this EV. In addition, one set of dedicated tyres has been selected for a different EV of the vehicle class “supermini”, the Renault ZOE.

The final selected nine sets of tyres, abbreviated by the letters A to I, are listed in table 1. The tyres A to H have been mounted on the Renault Fluence Z.E., whereas tyre B represents the used standard tyre model on this EV. Tyre I with its smaller dimensions has been used with the Renault ZOE.

Table 1. Set of tyres selected for the measurements. The EU label is in the format “Rolling Resistance/Wet Grip/Noise Emission”.

Abbreviation	Brand	Model	Dimensions	EU Label
A	Dunlop	Sport BluResponse	205/55 R16 91H	B/A/68
B	Goodyear	Efficient Grip	205/55 R16 91H	C/C/68
C	Kumho	Ecowing ES 01 KH27	205/55 R16 91V	B/B/67
D	Pirelli	Cinturato P1 Verde	205/55 R16 91H	B/B/70
E	Toyo	NANOENERGY 2	205/55 R16 91V	A/C/70
F	Bridgestone	Ecopia EP150	205/55 R16 91H	B/B/69
G	Michelin	ENERGY SAVER	205/55 R16 91W	B/A/70
H	Hankook	Kinergy Eco K425	205/55 R16 91H	B/B/70
I	Michelin	ENERGY E-V	195/55 R16 91Q	A/A/70

2.2. Measurement procedure

The rolling noise caused by the selected tyres has been determined by performing controlled pass-by measurements based on the standard ISO 11819-1. As depicted in figure 1, the test vehicle drives with constant speed from position C to C’ on the test surface. The distance between the measurement microphone at point P in a height of 1.2 m and the center of the driving lane equals 7.5 m. The distance between the line from A and A’ to the line from B and B’ indicates the test surfaces’ minimum length, which has to be at least 20 m. Since the test road, made of asphalt concrete with 11 mm chipping size (AC11), was located between two fields, the criterion of a similar sound absorbing material up to 3.75 m to the microphone position was not completely fulfilled.

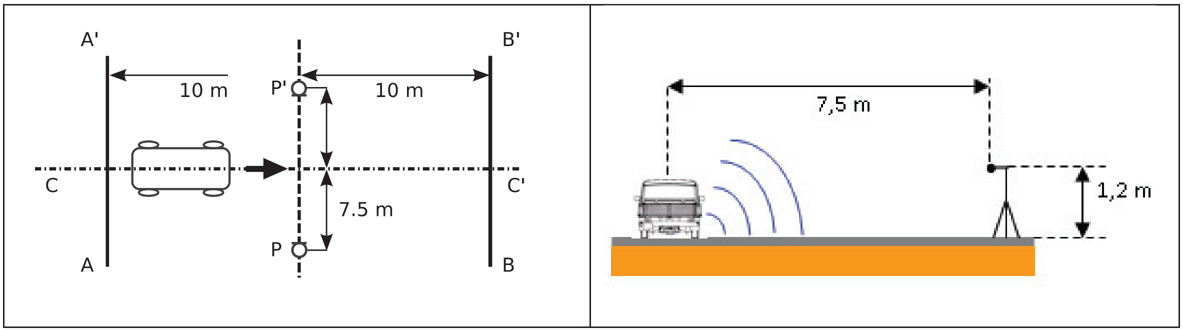

Fig. 1. (left) birds-eye view of the measurement set-up; (right) side view of the measurement set-up.

The measurement set-up has been applied to determine the maximum A-weighted sound pressure level (L_{AFmax}) during the pass-by for constant driving speeds between 10 and 130 km/h according to:

$$L_{AFmax} = 10\ log_{10}\left(\frac{p_{AFmax}^2}{p_0^2}\right) \quad (1)$$

On all measurement results, a temperature correction to the reference air temperature of 20 °C as used in CNOSSOS-EU has been applied:

$$L_{AF}(20°C) = L_{AF}(T) + 0.08\ dB(A)/°C \cdot (T - 20°C) \quad (2)$$

Before each measurement run with a single set of tyres started, the vehicle was driven for half an hour to ensure typical operation conditions for the tyres. Since tyre I mounted on the Renault ZOE was investigated in a separate measurement campaign, multiple aspects of the measurement set-up were different. The test track was not the same, but except that the road allowed lower driving speeds, all other parameters such as pavement and the surface in the vicinity of the road were similar. Furthermore, the dimensions of tyre I (195/55/R16) are smaller, compared to the dimensions of tyres A to H (205/55/R16). Classified as a supermini, the Renault ZOE is a smaller car than the Renault Fluence Z.E.

2.3. Results and analysis

Pass-by measurements with electric vehicles at low speeds require a very low background noise, as experienced in previous investigations by Czuka (2014). Therefore, each measurement was checked whether the background noise level was at least 3 dB below the vehicle noise level – otherwise the measurement was discarded. The results have been analysed in terms of overall maximum pass-by levels and as octave band levels at the time of the maximum of the overall pass-by level. In addition, depending on the distribution of the results, a regression with a 1st or 2nd-order polynomial function has been computed.

Figure 2 shows the maximum pass-by noise levels (L_{AFmax}) for all investigated tyres after performing a logarithmic regression with a 1st-order polynomial function. Due to the logarithmic scaling of the horizontal axis, the regression functions have the shape of straight lines. The lowest coefficient of determination equals to 0.987, which indicates that the overall maximum pass-by level of this EV is mainly influenced by the tyre-road noise. The maximum difference between two tyres at low pass-by speeds can be found between tyre A and I (the latter was measured under different conditions) and equals to 3.6 dB at 19 km/h. At 66 km/h, the tyres have the smallest deviation with a maximum difference of 2.2 dB. At higher speeds the deviations increase slightly and equals to 2.4 dB at a speed of 120 km/h.

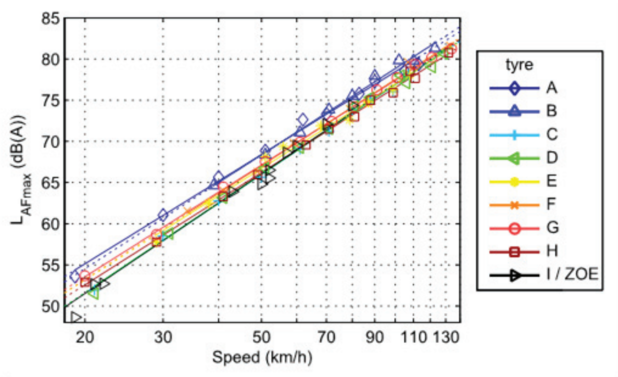

Fig. 2. Maximum pass-by noise levels for the investigated tyres - the symbols mark the individual measurements used for the regression, dotted lines are extrapolated.

The spectral analysis in form of octave band levels at the time of the overall maximum pass-by level can be found in figure 3. Since a 1st-order polynomial regression function leaded to very low coefficients of determination at low-frequency octave bands, a 2nd-order polynomial has been used for 125 Hz and 250 Hz. The sound pressure levels at low speeds in these octave bands are responsible for the better fit of a 2nd-order polynomial. A possible explanation to this could be the influence of the noise emitted by the electric propulsion system at low speeds. For the remaining octave bands levels, a 1st-order polynomial leaded to satisfying coefficients of determination.

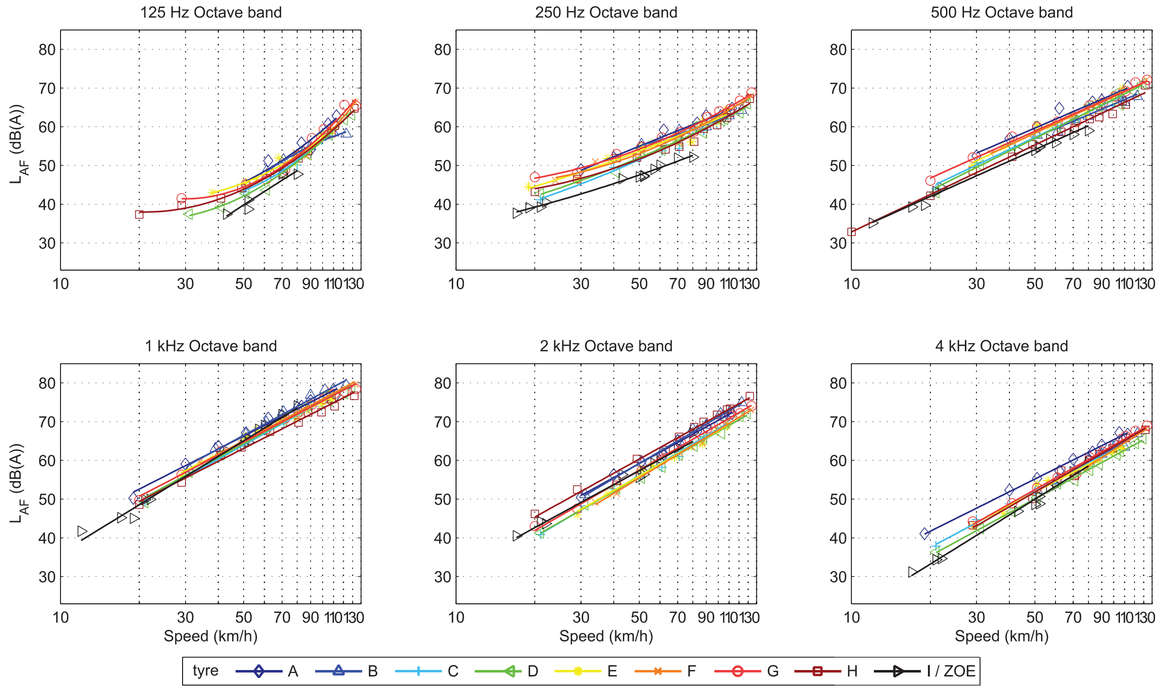

Fig. 3. Octave band levels for the investigated tyres – for the 125 and 250 Hz band, the regression has been computed with a 2nd-order polynomial function.

3. Comparison between pass-by measurements and the EU exterior tyre noise label

In this section, the results obtained from the measurement campaigns carried out in work package 3 of the FOREVER project will be compared to the EU tyre label for exterior rolling noise. Furthermore, the concept of “low-noise tyres” will be discussed.

3.1. The EU tyre noise label

The EU tyre label for exterior noise is determined by the tyre manufacturers (or their representative) for type approval according to the procedure described in the UN (ECE) regulation No. 117. The measurement conditions and the method for light vehicle tyres include the following specifications:

- The road surface shall be in accordance with ISO 10844:2011. The sound field on the test site shall meet semi-free field conditions.
- The vehicle is fitted with four identical tyres.
- The A-weighted maximum sound pressure level (time weighting = FAST) is recorded at vehicle coast-by (engine off, gear at neutral) on microphones located 7.5 m from the track centre line and 1.2 m above the ground.
- Temperature corrections are applied, according to the test surface temperature, to normalize to the reference 20 °C.
- A minimum of eight measurements on each vehicle side is required, with test speeds ranging from 70 to 90 km/h.
- A regression equation relating the maximum noise level to log(speed) is determined, and the noise level at the reference speed 80 km/h is inferred.
- The final result is reduced by 1 dB(A) to take account of measuring inaccuracies and rounded down to the nearest whole value.

The EU noise labels of the 8 tyres fitted to the Renault Fluence Z.E. and the specific tyre fitted to the Renault ZOE, listed in table 1, are compared with the noise levels measured on the AC11 road surface (see section 2), calculated from the regression equations at the reference speed of 80 km/h.

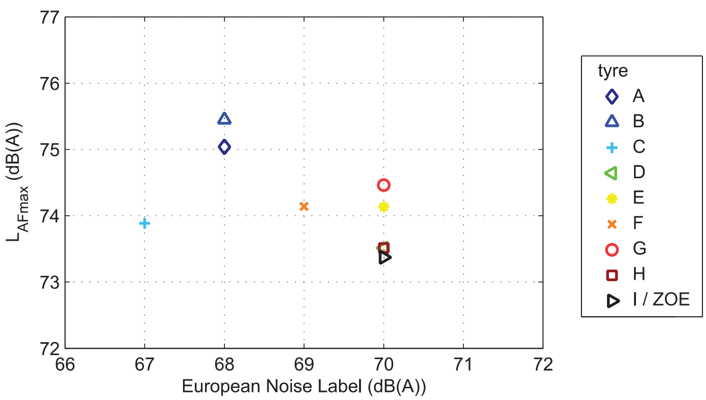

Fig. 4. Noise levels measured at 80 km/h on AC11 compared with the EU noise labels, for the 8 tyre types fitted to the Fluence Z.E. and 1 tyre fitted to the ZOE (black).

The noise measurements at 80 km/h are spread on a reduced noise scale in relation to the EU labels: the tyre labels range over 4 label values from 67 to 70 dB(A)) while the measured noise levels are contained within an interval width of approx. 2 dB(A). Furthermore, it turns out that the EU labels do not properly render the tyre ranking given by the noise measurement on the AC11 surface: the tyre with the lowest label and those with the highest labels yield similar noise levels, whereas the largest noise levels are due to tyres with an intermediate label.

The lack of a common trend can be noticed between noise labels and the actual noise levels. A possible cause is that the ISO surface used for the EU noise label is a smooth surface, which does not excite many vibrations on a tyre. This may also explain why the mean of the EU Noise Label is lower.

Other recent studies pointed out a similar behaviour, underlying a lack of representability of the exterior noise EU labels with actual noise levels on operational road surfaces, for instance Kragh (2013), which reports a study involving 31 different tyres tested on Nordic road surfaces and Swieczko-Zurek (2014) where 12 tyres were tested either on a drum with road replicas or by the CPX method on road surfaces. The adequacy of the ISO surface for inferring tyre ranking on actual roads is questioned.

3.2. Investigating the concept of "low-noise" tyres

The concept of low-noise tyres has not yet been clearly defined, as underlined by Berge (2012). It can be stated as referring to tyres granted with a noise label either 1 dB or 2 dB under the type approval limit value, or even 3 dB lower than the limit value which corresponds to a noise rating with a 1-wave pictogram. The impact of one or the other definition of a low-noise tyre within the tyre set previously measured will be analysed in this section.

All the 9 tyres investigated (Fluence Z.E. and ZOE) belong to the same tyre subclass C1b featured with a nominal section width of 185 to 215 mm and a limit value of 71 dB(A). From table 1 it may be easily checked that all tyres comply with this rolling noise limit value.

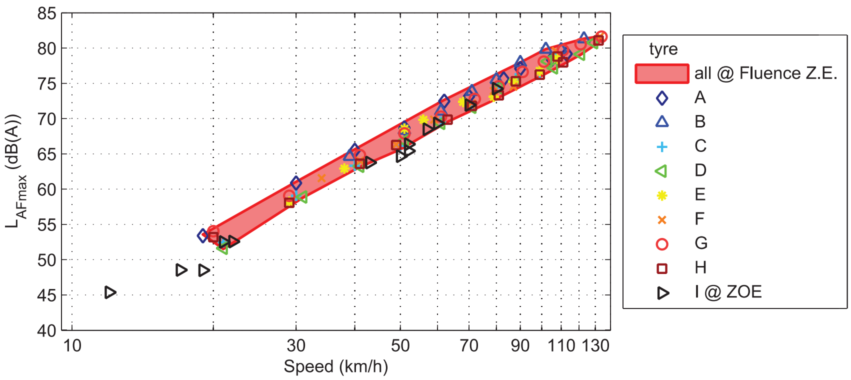

Fig. 5. Maximum pass-by level measured for 8 tyres fitted on the Fluence Z.E. and 1 tyre fitted on the ZOE – the red surface includes all dots related to the Fluence Z.E. tyres.

If the low-noise tyre definition would be "at least 1 dB below the noise limit value", i.e. an exterior noise label not greater than 70 dB(A), then no tyre should be removed from the tyre set since they all meet this definition. The mean noise level at 80 km/h, computed from the regression equations, is 74.0 dB(A).

If the low-noise tyre definition would be "at least 2 dB below the noise limit value", i.e. an exterior noise label not greater than 69 dB(A), then five tyres should be disregarded since only four tyres (A, B, C, F) fulfil this definition. Two of the remaining tyres are among the loudest tyres measured; another is in the middle range while the fourth is one of the quietest tyres of the collection. Then, if these were the only tyres fitted to passing-by vehicles with an even distribution, the emitted noise would be slightly increased (the rolling noise average at 80 km/h increases by 0.6 dB(A)).

Finally, if the low-noise tyre definition would be "at least 3 dB below the noise limit value", i.e. an exterior noise label not greater than 68 dB(A), then yet another tyre would be removed from the collection. Only three tyres (A, B, C) are still selected, as depicted in figure 6: the two noisiest over the most speed range and one of the quietest tyres measured with the Fluence Z.E. on an AC11 road surface. Thus, the resulting average noise level at 80 km/h eventually increases by 0.7 dB(A) when compared to the whole tyre collection.

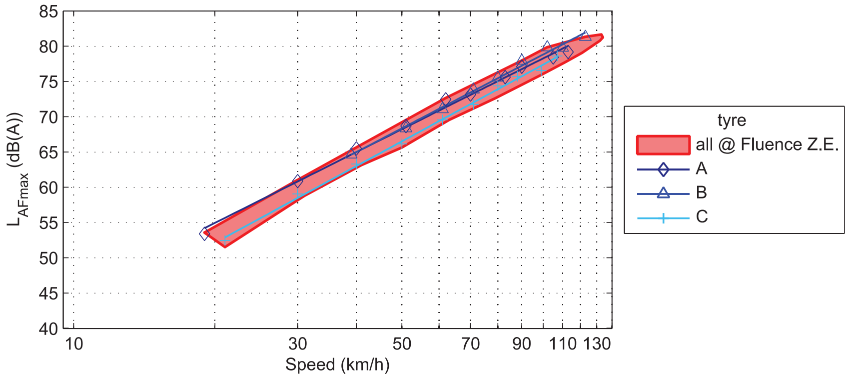

Fig. 6. Maximum pass-by level measured for 3 tyres meeting the low-noise definition "3 dB below the limit value" - the red surface includes all dots related to the Fluence Z.E. tyres.

4. Modelling of tyre-road noise from electric vehicles in CNOSSOS-EU

CNOSSOS-EU is the European method proposed for environmental noise prediction. The prediction of traffic noise relies on a vehicle noise emission model, composed of a propulsion noise component and a rolling noise component, specified by vehicle category in octave bands from 63 Hz to 8 kHz, whereas the method is indicated as being valid from 125 Hz from 4 kHz. Within the FOREVER project, a proposal for describing the propulsion noise component and the rolling noise component, to predict noise emission from EVs, has been made. A detailed explanation of the CNOSSOS-EU model can be found in the official Joint Research Centre Reference Report (Kephalopoulos (2012)), which is freely available on the internet.

While the development of a model to describe the propulsion noise of EVs was part of work package 2 of FOREVER (Pallas (2015)), this section will summarize the investigations for potential correction terms of the rolling noise of EVs. For this reason, the measurement results from section 2 as well as additional measurement data from 5 light EVs (obtained within work package 2 of FOREVER) have been used to validate CNOSSOS respectively to assess, whether the description of the rolling noise component of internal combustion engine vehicles (ICEV) needs additional correction terms to predict the rolling noise of EVs. Since CNOSSOS-EU is an average model intended to represent an average vehicle on an average road surface, whereas the sample dispersion may be significant, the model will be considered as satisfactory if the total noise is within the surface which is spanned by the measurement data (see figure 7), over most of the speed range.

By using the measurement results presented in section 2 as input data for CNOSSOS, the following results have been observed:

- In the octave bands 125 Hz and 250 Hz, the rolling noise component has been underestimated by 2-3 dB(A), in particular at high speeds.
- The model is satisfactory in the octaves bands 500 Hz, 1000 Hz, 4000 Hz and 8000 Hz.
- The rolling noise component is clearly overestimated by 2-3 dB(A) in the octave band 2000 Hz, with a significant contribution to global levels.

By using the measurement results of 5 light EVs as input data, the model is quite satisfactory in all octaves bands from 250 Hz to 4 kHz, at 125 Hz CNOSSOS slightly overestimates the noise levels within speeds from 30 km/h and 70 km/h. However, the prediction of the overall noise levels is satisfying, as depicted in figure 7.

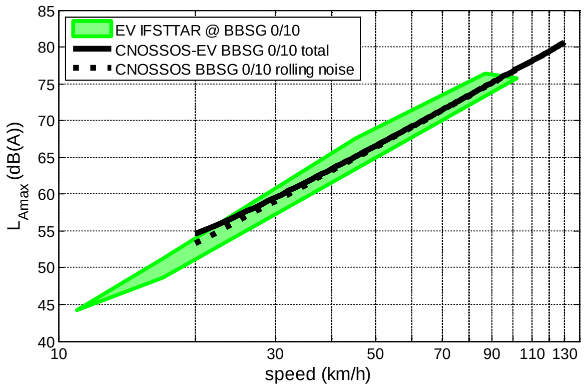

Fig. 7. Global noise levels at 7.5 m measured with the 5 vehicles in electric mode on DAC 0/10 (green surface) – dashed line: rolling noise model corrected for the road surface – solid line: total noise model for EVs.

Based on these results, it is proposed that no additional correction terms have to be applied to the rolling noise model of ICEVs to predict the rolling noise of light EVs in CNOSSOS-EU.

5. Summary and conclusions

This paper presented the main content of work package 3 of the European FOREVER project, the investigation of the influence of potential and dedicated tyres for electric cars on the tyre-road noise. Furthermore, the concept of “low-noise” tyres, connected to the EU exterior noise label, has been reviewed and discussed.

Based on the EU tyre label ratings for rolling resistance and wet grip, a selection of nine different sets of tyres, which aimed to represent the market of tyres for highway-suited electric cars by the end of 2013, has been investigated to determine the tyre influence on rolling noise from electric cars. By carrying out controlled pass-by measurements based on the standard ISO 11819-1, it turned out that the overall maximum pass-by noise level difference between two investigated tyres never exceeded 3.6 dB for lower speeds (20 – 50 km/h), and for speeds between 50 and 120 km/h the spread never exceeded 2.4 dB. The main contribution to the overall pass-by noise level came evidently from the tyre-road noise, even down speeds of 20 km/h.

Investigations conducted on noise measurements at pass-by of an electric vehicle successively fitted with nine different tyre sets did not bring to light any relation between the exterior noise EU-label and the noise on actual road surfaces, in particular regarding tyre ranking. This has impacts on the concept of low-noise tyres since a possible requirement on the limit value based on the EU-label would not lead to select the quietest tyres on actual dense road surfaces and would probably not modify the road traffic noise.

On the basis of current knowledge, it turns out that rolling noise from light electric vehicles does not differ from conventional vehicles. Thus, for predictions of traffic noise according to the European assessment method, the use of the rolling noise component given in CNOSSOS-EU remains available without amendment for light electric vehicles. Only the propulsion noise component requires correction terms, as proposed in the final report of work package 2 of the FOREVER project.

Acknowledgements

The work described in this paper was performed within the project FOREVER, funded by the Conference of European Directors of Roads (CEDR).

References

Altinsoy, E., 2013. The detectability of conventional, hybrid and electric vehicle sounds by sighted, visually impaired and blind pedestrians, Proceedings of the 42nd Inter-Noise, Innsbruck.

Berge, T., 2012. NordTyre – Tyre/road noise testing on various road surfaces - State-of-the-Art. SINTEF report.

Czuka, M., Conter, M., Wehr R., 2014. drivEkustik: Acoustic Detectability of Electric Vehicles, Proceedings of the 6th Congress of Alps-Adria Acoustics Association, Graz.

Gasparoni, S., Czuka, M., Wehr, R., Conter, M., Pallas, M.A., Berengier, M., 2015. Impact of low-noise tyres on electric vehicle noise emission, Final report of FOREVER WP3, CEDR.

ISO 11819-1, 2002. Acoustics -- Measurement of the influence of road surfaces on traffic noise -- Part 1: Statistical pass-by method.

Jabben, J., Verheijen, E., Potma, C., 2012. Noise reduction by electric vehicles in the Netherlands, Proceedings of the 41th Inter-Noise, New York.

Kephalopoulos, S., Paviott, M., Anfosso-Lédée, F., 2012. Common Noise Assessment Methods in Europe (CNOSSOS-EU). JRC report.

Kragh, J., Oddershede, J., 2013. NordTyre - Car tyre labelling and Nordic traffic noise, Proceedings of the 42nd Inter-Noise, Innsbruck.

Pallas, M.A., Kennedy, J., Walker, I., Berengier, M., Lelong, J., 2015. Noise emission of electric and hybrid-electric vehicles, Final report of FOREVER WP2, CEDR.

Statistics Norway, 2014. Registered motor vehicles, by type of transport and type of fuel in 2014.

Swieczko-Zurek, B., Ejsmont, J., Ronowski, G., 2014. How efficient is noise labeling of tires?, Proceedings of the 21st ICSV, Beijing.

UN (ECE) Regulation No. 117 Rev. 3, 2014. Uniform provisions concerning the approval of tyres with regard to rolling sound emissions and/or to adhesion on wet surfaces and/or to rolling resistance.