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A combined approach for correcting tyre hardness and temperature influence on tyre/road noise

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ABSTRACT

For the determination of the road surface influences on tyre/road noise, the standard ISO 11819-2 (International Organization for Standardization, 2017), also called "CPX-method" is used. There, tyre/road noise is measured with a dedicated measurement trailer and tyre. As various parameters, such as temperature, trailer design, shore hardness of the tyre, etc. have significant influences on the CPX levels, correction procedures to address these are described in the standard. Where currently the air temperature and the shore A hardness, measured under laboratory conditions, are used, a different approach is presented in this paper. Here, the tyre temperature is measured during the measurement run, and subsequently calculated to the in-situ shore A hardness. As this is assumed to be the dominating influence on tyre/road noise emission, a direct correlation between the in situ shore A hardness and the CPX levels is performed. Extensive measurements are presented, and the different correction procedures are analysed with regard to their repeatability. It will be shown that, within the limitations of the measurement setup, the combined correction of temperature and shore A hardness is feasible and may support the further development of the CPX method.

1. Introduction

In order to investigate the acoustic properties of road surfaces, the measurement method specified in ISO 11819-2 (Close-ProXimity method CPX) [1,2] is currently under development. Here, the main focus is laid on the identification of the texture influences on noise emission. As partly small variations, e.g. with regard to the ageing of road surfaces, are sought, low uncertainties, viz. high repeatability and reproducibility of the measurements are demanded [3]. Generally speaking, the most important uncertainty factors on tyre/road noise measurements are temperature influences during the measurement as well as the shore A hardness of the test tyre, as described e.g. in [4]. At present, these influence factors are corrected via an air temperature correction with a reference air temperature of 20 °C as well as a tyre hardness correction, whereat the rubber hardness of the tyre is measured under laboratory conditions (reference shore A hardness of 66).

Anfosso [5] described the temperature influence on tyre/road noise for vehicle pass-bys on seven different road surfaces and reported an air temperature influence factor of approx. -0.1 dB(A)/°C. In her study, a linear relationship between air, road surface and tyre temperature was determined. Although a high coefficient of determination was found, the temperature data published showed deviations of approx. up to 5 °C from the regression. Buehlmann [6] performed CPX as well as temperature measurements on different road surfaces. There, also high coefficients of determination were found for the interdependencies of air, road surface and tyre temperature. All measurements were conducted during full solar radiation. In addition, a reference measurement series is described during a cloudy day, resulting in deviating regression slopes. A detailed analysis of the reasons for the variations of temperature effects can be found in [7], where the measurement tyre as well as measurement speed and void content of the surface were identified as main influencing factors on the temperature corrections. In [8], a linear relationship between CPX levels and road surface temperature was found. Main influences of the pavement type were detected in the medium and high frequency range, whereby changes in the stiffness of the asphaltic road surface due to the increasing road temperature were suspected. Mioduszewski [9] performed CPX measurements with different tyres to investigate the air and road temperature influences on tyre/road noise. In his paper, good correlations between the different temperatures were found for comparable weather conditions, whereas effects of precipitation and subsequent evaporation were observed.

Lately, also a speed dependence of the temperature correction factor is discussed [10]. There, a decrease of the temperature effect with increasing measurement speed was found.

Regarding the tyre hardness corrections, the ageing of the

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measurement tyres was examined in [4]. Hardening effects of up to 3 shore A units were observed within one measurement season for the ASTM SRTT tyre [11]. In [12], an increase of up to 0.6 shore A/month is reported, whereas the influence of storage conditions of the measurement tyres is discussed in [13]. In the study of Sandberg et. al. [14], the most recent approach to correcting temperature and shore A hardness is described. The work described there is also expected to be adopted in [1,2].

Concerning the most suitable temperature correction, questions about the correct temperature to be used (air, road surface or tyre temperature) need to be debated. Where air temperature can be assumed to be mostly constant during the time of the single measurement runs, road surface temperature may change significantly within different road segments due to differences in solar radiation, road surface emissivity (albedo), etc. The correct description of tyre temperature may even be more intricate, as the tyre temperature is assumed to be different on various tyre positions (tyre tread pattern and tyre shoulder). Various factors influence the tyre temperature while driven, e.g. air and road surface temperature, solar radiation for open CPX trailers, friction and rolling resistance of the road surface, inflation pressure, and tyre flexing, some of which may even be speed-dependent. Also, when sudden changes in road surface temperature occur (e.g. when entering a shadowy region), heat transfer into the rubber may be relevant as well time-dependent.

Regarding the rubber hardness of the tyre, measurements of the shore A hardness may be e.g. performed on the tyre tread pattern or on the tyre shoulder. In addition, as will be shown in this paper, the rubber hardness is strongly influenced by the rubber temperature resulting in a coupled problem for temperature and rubber hardness correction terms.

Therefore, the question arises if a separate treatment for the correction of temperature and tyre hardness influences on tyre/road noise is plausible, or a combined approach may be feasible. In this paper, the temperature influence on the tyre rubber hardness is investigated. Tyre temperature behaviour during CPX measurements is presented, finally a multivariate regression analysis on tyre hardness, temperature(s) and tyre/road noise is performed.

2. Temperature influence on tyre shore-A hardness

Shore A hardness of 5 ASTM SRTT tyres of different age (1 to 9 years old, date of production 2014 to 2006) was measured in dependence of temperature. The tyres were placed in a climatic chamber and the ambient temperature changed from 5 °C to 40 °C. Before every hardness measurement, the temperature was held constant for approx. 1 h to ensure the tyres to have reached equilibrium temperature. The hardness was measured on 15 different random measurement positions on the tread pattern (see [2]) as well as on the tyre sidewall for each tyre. Results of the measurements on the tread pattern are shown in Fig. 1. A linear regression analysis was performed for each tyre separately, the outcomes are presented in Table 1. The coefficient of determination is high for all regressions, the slopes of the regressions are comparable for all tyres. This leads to the conclusion that the relationship between tyre hardness and temperature may be captured by means of a linear model as according to

$$H(T_{tyre}) = H_{ref} + \alpha\cdot(T-T_{ref}) \tag{1}$$

with

$H(T)$ = shore A hardness at temperature T
H_{ref} = tyre hardness at reference temperature (20°C)
α = slope of the linear regression line
T = tyre temperature [°C]
T_{ref} = reference temperature ($T_{ref} = 20$°C)

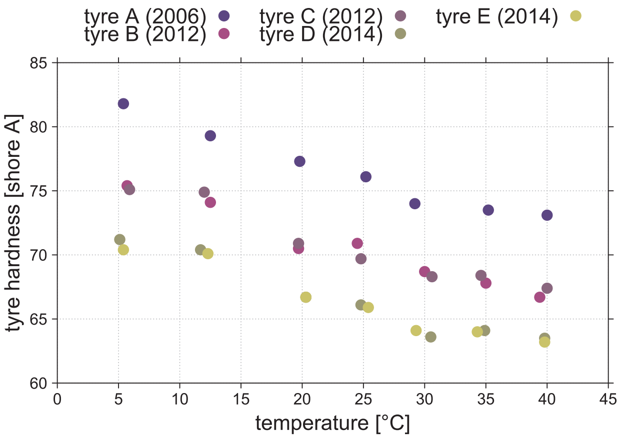

Fig. 1. Shore A hardness of tyre tread pattern versus temperature.

Table 1
Results of the linear regression analysis of tyre hardness versus rubber temperature.

Tyre index	Age [years]	α [shore A/°C]	R^2
A	9	−0.26	0.96
B	3	−0.26	0.96
C	3	−0.25	0.93
D	1	−0.23	0.95
E	1	−0.25	0.93

The slopes of the 5 linear regressions show high repeatability for the correlation of tyre hardness and temperature also for tyres of very different age. Also, the coefficient of determination is above 0.90 for all measurement series. This fortifies the use of a linear relationship to calculate shore A hardnesses at different temperatures. Generally, a slope of −0.25 shore A/°C can be suggested for tyre hardness corrections for different temperatures.

3. Tyre temperature of a rolling tyre

When driven, the temperature and thus the effective shore A hardness of a tyre may change. The tyre temperature thereby is dependent on the ambient air temperature, road surface temperature, airflows around the tyre, sunlight radiation for open trailers, friction, rolling resistance and tyre flexing, etc. as well as the temperature history of the tyre. Therefore, when determining the tyre temperature, the time response of the rubber has to be taken into account.

3.1. Air and road surface temperature

In the field of meteorology, a lot of research was performed to predict surface temperatures due to air temperature and solar radiation. In recent years, the results have been e.g. applied to road surface temperatures for the prediction of possible icing on streets to optimize the use of de-icing salt [15]. Also, efforts were made to reduce urban heat islands by finding low-temperature road surfaces and thus reducing the stored heat in urban environments [16]. The variation in albedo with regard to the ageing of road surfaces is discussed e.g. in [17]. One common basic model for predicting the surface temperature is described in [15] viz. [18]. It is based on the law of conservation of energy by considering the net radiation R_N, the heat transfer due to evaporation of humidity LE, the heat flux to air H and the heat flux to the soil S:

$$R_N + LE + H + S = 0 \tag{2}$$

The input variables for this model, relating to the problems addressed in this paper, are mostly the air temperature, which may vary in central Europe during the year in a range of −10 °C to 35 °C (with [1] limiting CPX measurements to conditions between 10 and 35 °C), the