

Evaluation of the acoustic potential of grinding textures

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ABSTRACT

To reduce tyre/road noise, in recent years concrete road surfaces in Germany and Austria are refurbished as diamond grinding surfaces. There, fine linear grooves with a typical lateral wavelength of 4-6 mm and a depth of approx. 1 mm are cut into the concrete road surface. In this way, a smooth tyre/road contact with low excitation of tyre vibrations, as well as a reasonable amount of air-pumping reducing cavities in the contact zone is manufactured.

In this paper, the modes of action of grinding textures are discussed. Measurements according to ISO 11819-2 (CPX-method) as well as of the road surface texture will be shown. Due to the anisotropic road surface, the texture measurements were performed synchronously with a continuous high-resolution 3D texture sensor. Relevant explanatory surface parameters will be identified by means of statistical modelling. Their variation along the grinding texture will be discussed and their influence on the CPX levels will be analysed.

Keywords: Tyre/Road Noise, Diamond Grinding, Surface Texture

I-INCE Classification of Subject Number: 13

(see <http://i-ince.org/files/data/classification.pdf>)

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1. INTRODUCTION

With increasing road traffic and therewith raising demands on the durability of the road surface, concrete road are a widely used surface type in high-level road networks. Along with requirements on the stability, skid resistance and ride comfort, environmental protection such as low noise emissions are needed. In recent years, next to the further development of exposed aggregate cement concrete road surfaces, the acoustic potential of diamond grinding road surfaces is evaluated. Here, longitudinal grooves are cut into the concrete road surface with the aim of producing a smooth road surface texture (see Figure 1). Therewith, low tyre vibrations as well as a reasonable amount of void content in the tyre/road contact zone are sought. Although primarily used as a pavement preservation technique, where the topmost layer of the original concrete road surface is removed, the application of diamond grinding on new concrete road surfaces is contemplated due to its good noise-reducing properties [1].

Measurements analysing the noise reduction of diamond grinding surfaces were presented in e.g. [2]. The potential of diamond grinding as well as other new concrete road surface types is described in [3]. Information not only regarding the noise emission, but also skid resistance, longitudinal and transverse evenness and longevity of the construction can be found in [4–7]. Research on the optimisation of the including noise emission simulations and as well as laboratory and in-situ measurements is presented in [8]. First results of the work described in this paper were published in [9].

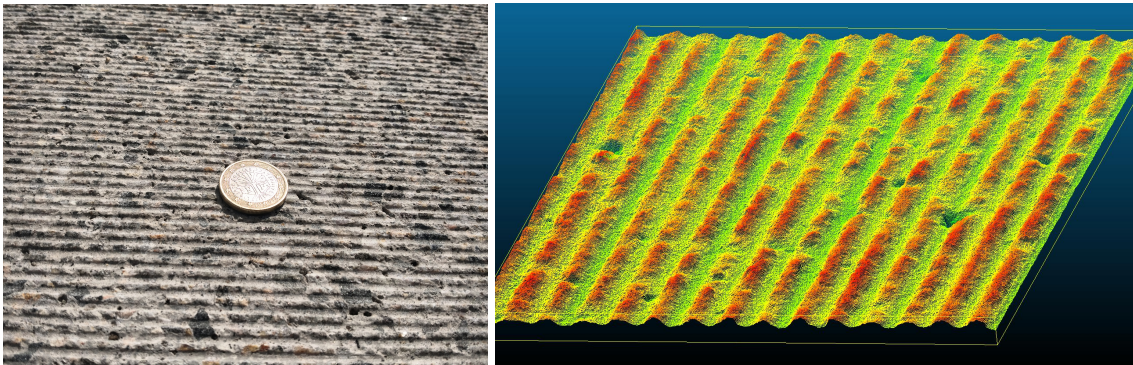


Figure 1: Photo and 3D texture patch of a grinding surface

During the years 2017 and 2018, tests of the applicability of diamond grinding road surfaces were performed in Austria and Germany. There, the skid and rolling resistance, the evenness as well as the acoustic properties of diamond-grinding refurbished as well as newly constructed concrete road sections were tested. Different lateral wavelengths, viz. lane width and groove widths were built and examined on different test sections. The lateral wavelengths varied between 4.2 mm and 5.4 mm. The acquired dataset consists of 9 different measurement sections with in part varying grinding texture wavelength, whereat different traffic lanes are considered as independent measurement sections.

2. DATA ACQUISITION

For the analysis of the noise reduction potential of diamond grinding, CPX measurements [10] were performed with speeds of 80 and 100 km/h. As measurement tyre, the P1 tyre [11, 12] was used.

In order to better understand the noise-reducing modes of action, and taking into account the strong anisotropic road surface geometry, continuous 3D texture measurements were performed alongside the CPX measurements. For this purpose, a stereoscopic surface texture sensor with a recording width of 7.5 cm and a resolution of approx. 75 μm was mounted in the wheel track inside the CPX trailer. With this, along the whole measurement section, the surface texture was surveyed. As the currently maximum allowed measurement speed of the 3D texture system is 60 km/h, the correlations between texture and CPX levels discussed in the following sections were performed consecutively.

During the project duration, overall 29 measurements of the texture and CPX levels were performed. All of these measurements are considered as independent measurements, as at least 3 months elapsed in between the measurements. It should be kept in mind that all diamond grinding sections were tested with a maximum grinding age of 18 months. Therefore the results presented here should be interpreted as representative of diamond grinding surfaces in relatively new condition.

2.2.1. Tyre/road noise results

To give an initial idea of the acoustic properties of diamond grinding textures, the overall CPX levels at 80 and 100 km/h are shown in Figure 2. Where the median L_{CPX} value is quite low compared to other dense road surfaces, the span of the CPX levels is surprisingly high, considering the exact definition of the surface texture. This can be partly explained by an ageing effect, which suggests a degradation of the CPX levels of approx. 1 dB within the project duration. Secondly, for the initial measurements after applying the diamond grinding, the L_{CPX} also vary in the same order of magnitude. Here, the newly built and instantaneously grinded concrete road surfaces outperform the refurbished road surfaces. As a reason for this, the diamond grinding construction is suspected. For the refurbished test sections, due to the longitudinal unevenness of the original concrete road surfaces, the grinding of the grooves could not be performed as exact as for the newly built test section.

One-third octave band values are given in Figure 3. When comparing the frequency distribution to an average spectrum of exposed aggregate cement concrete (grey dashed line), benefits can be observed over the whole frequency range with improvements of up to 5 dB in the one-third octave bands from 1000 Hz upwards. The one-third octave bands

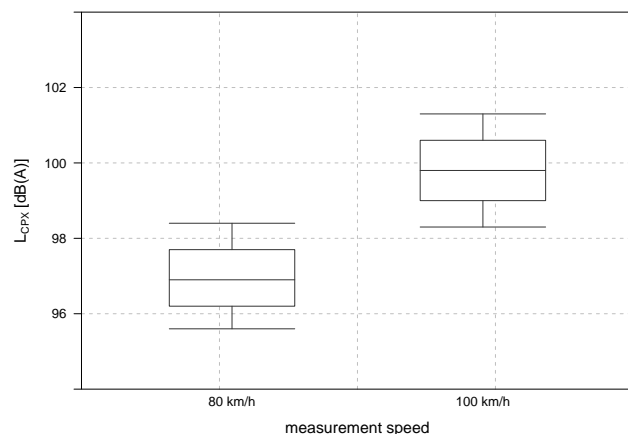


Figure 2: CPX level variation of the grinding sections

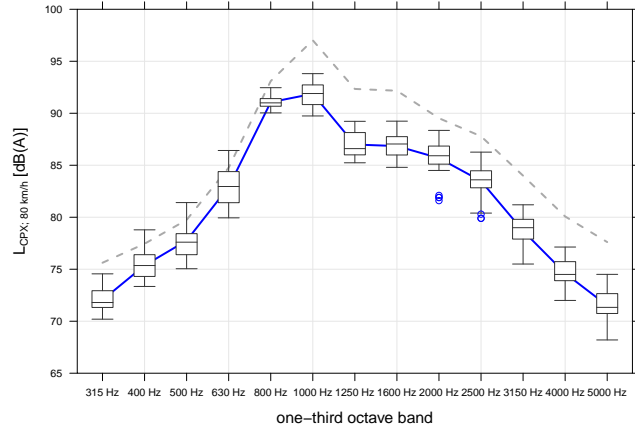


Figure 3: CPX one-third octave band level variation of the grinding sections at 80 km/h meas. speed; the grey dashed line gives an average L_{CPX} level for EACC.

show correlating behaviour, the pearson correlation for the 80 km/h dataset (Figure 4) shows two main components (up to 800 Hz and 1 kHz and above).

2.2.2. Description of the road surface texture

In order to describe the surface texture, various parameters were calculated from the 3D texture. Therefore, the continuous 3D texture band is split in rectangular patches of length and width of 7.5 cm, on which the texture parameters were determined and subsequently averaged over the measurement section. A description of the single texture parameters is given in Table 1. The aim of this compilation was not to find a single texture parameter to fully describe the specific properties of diamond grinding surfaces,

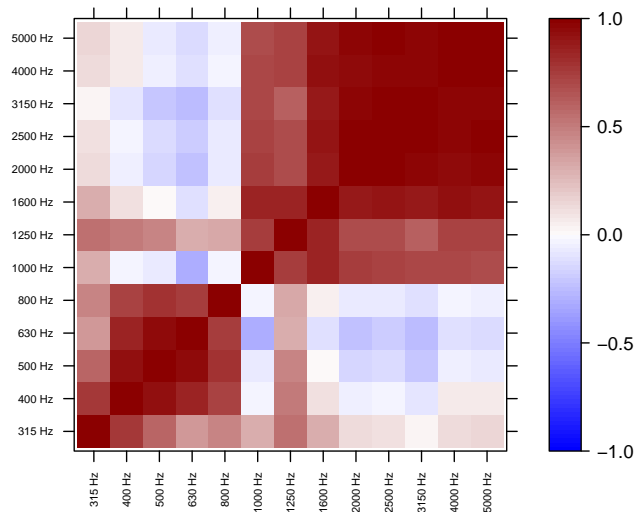


Figure 4: Pearson correlation of the one-third octave band L_{CPX} levels at 80 km/h meas. speed

Table 1: Description of the different surface texture parameters shown in Figure 5

parameter	description
nmax rel	number of local maxima respectively profile peaks, related to 1 m ²
nmax rel corr	number of local maxima respectively profile peaks, related to 1 m ² , and corrected for the lateral wavelengths of the grinding structure
hmax	mean height of the local maxima, related to the mean texture level
hmin	mean depth of the local minima, related to the mean texture level
dmax	min/max height range of the local maxima
dmin	min/max height range of the local minima
dheight	difference between the mean height of the local maxima and the mean depth of the local minima
Rq	root mean square of the roughness profile
MPD	mean profile depth
g	gestalt factor
L _{CPX} 80 km/h	measured CPX level at 80 km/h

but to give a overview of single descriptive parameters describing road surfaces. The distribution and correlations of these texture parameters as well as the CPX levels at 80 km/h are depicted in Figure 5. In the lower panels of the scatter plot matrix, the 2-dimensional correlations of the parameters as well as a loess fit are shown. In the upper panels, the coefficient of determination of the linear regression fit is given. Finally, in the diagonal of the scatter plot matrix, the kernel density estimate of the parameters can be seen in order to describe the distribution of the texture parameters.

Strong correlations can be found especially for the parameters describing the height distribution of the local maxima and minima. When examining the correlations of the CPX levels and the number of local maxima, one can clearly see that relating the number of maxima to the lateral wavelength and thereby interpreting it as the number of local maxima per land area of the grinding surface, improves the predictive potential of this parameter. Therefore, this parameter is primarily used in the subsequent modelling approach.

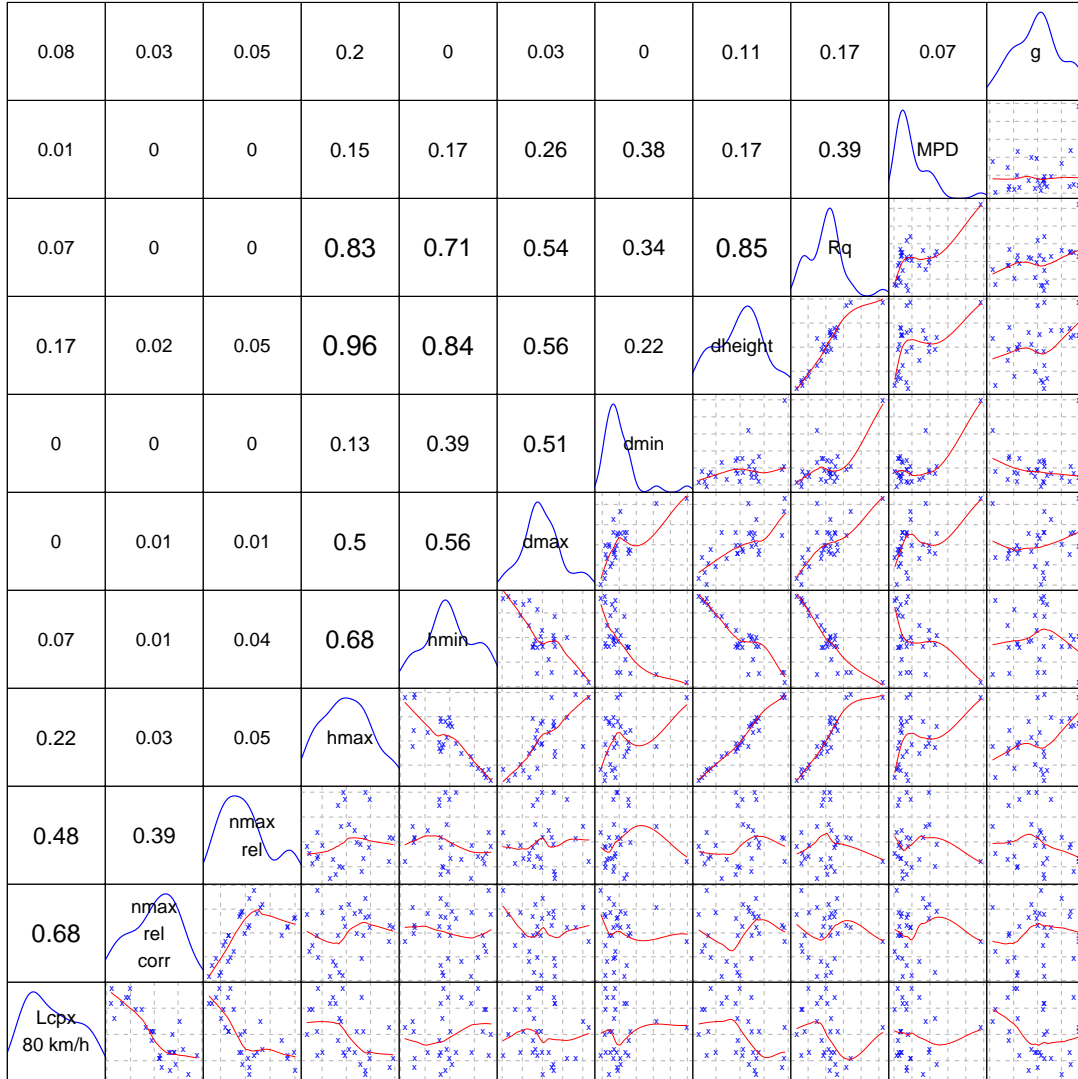


Figure 5: Scatter plot matrix of various 3D texture parameters; the number in the upper panels gives the coefficient of determination of the linear regression models, the diagonal depicts the gaussian kernel density estimate of the parameter; the lower panels show the scatter plot of the texture parameters as well a loess fit.

3. STATISTICAL MODELLING OF THE RELATION BETWEEN TEXTURE AND TYRE/ROAD NOISE

For the purpose of understanding the texture-related noise reduction parameters of diamond grinding surfaces, statistical modelling is performed on the 3D texture parameters and the CPX levels at 80 km/h. As the pearson-correlation of the one-third octave CPX levels shows a clear discrimination between 800 and 1000 Hz (see Figure 4), the presented statistical modelling approach was performed for the summed low-frequency area (315 - 800 Hz, assumed to be tyre-vibration dominated) and high-frequency area (assumed to be dominated by air pumping mechanisms) separately. In both cases, the dataset was divided into a training and a test dataset to estimate the validity of the models. In Figure 5, it could be seen that as relevant predictors, the number of local maxima as well as to a minor extent the mean height of the local maxima

Table 2: Parameters of the low-frequency statistical model

parameter	estimate	std. error	p-value
(intercept)	96.1	1.3	< 2e-16
nmax rel corr	-6.2e-05	1.4e-05	1,2e-04
hmax	2.3e+03	4.6e+02	3.4e-05

Table 3: Parameters of the high -frequency statistical model

parameter	estimate	std. error	p-value
(intercept)	107.1	1.4	< 2e-16
nmax rel corr	-1.0e-04	1.6e-05	9.0e-07
hmax	-3.9e+03	5.4e+02	1.5e-07

relative to the mean texture level are of interest. Additional in the modelling process incorporated texture parameters, as well as considering nonlinearities, only led to a minor improvement in the statistical model and were therefore rejected.

To validate the models, the low and high frequency datasets was divided 100 times into randomly chosen trainings- and test datasets. The therewith generated low-frequency models exhibit a mean coefficient of determination of 0.57 for the test dataset evaluation as well as a mean residual standard error of 0.46 dB. The modelling of the high frequency fraction, which includes the dominating one-third octave band of 1000 Hz, is showing higher test parameters: a mean coefficient of determination of the test-data of 0.82 and a residual standard error of 0.51 dB could be achieved. Although not excessively high, the test parameters substantiate the validity of the model, especially in the dominating high frequency range. Moreover, the residual standard errors exhibit values not especially larger than the measurement uncertainty of CPX measurements. The modelling parameters for the full models, built from the complete dataset, are given in Table 2 and 3. From the standard errors of the estimates as well as the p-values it can be seen that the chosen parameters exhibit relevant correlations with the CPX level. Thereby, a high (relative) amount of local maxima per land area influences both the low and high frequency range in a noise-reducing way. On the other hand, high local maxima result in increasing tyre vibrations, whereas decrease noise emissions in the high frequencies.

Finally, the two models are evaluated on the dataset, energetically added up and compared to the measured CPX levels. The so calculated re-evaluation of the training data leads to the linear correlation shown in Figure 6. A residual standard error of 0.40 dB, a coefficient of determination of 0.77 and a slope of 0.98 between prediction and measured data confirm the influence of the chosen texture parameters on the rolling noise emission on diamond grinding surfaces.

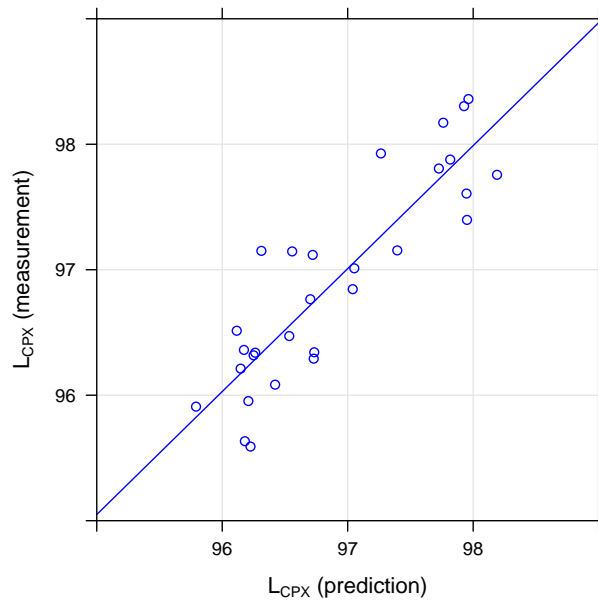


Figure 6: Re-evaluation of the model by comparing the predicted and measured L_{CPX} values

4. CONCLUSIONS

Summarising, diamond grinding exhibits a good noise reducing potential. Especially as a preservation technique, noise-sensitive areas can be protected. Moreover, it can be stated that the modelling of tyre/road noise from 3D texture parameters results in satisfactory results for the presented dataset. The both the low- and high-frequency area number of local maxima can be physically meaningful interpreted as high amounts of local maxima lead to a constant land area. The change in the algebraic sign of the mean maxima height from the low to high frequency area can below 800 Hz be interpreted as resulting in low variations in the tyre contact patch. From 1 kHz upwards, a high mean local maxima height leads to a higher amount of void content in the tyre/road contact zone.

Forthcoming, the long-term stability of the rolling noise needs to be further monitored. For investigating the acoustic ageing of diamond grinding surfaces, synchronous texture measurements can be valuable to describe the road surface alterations as well as further development the diamond grinding construction process.

5. ACKNOWLEDGEMENTS

The work presented was performed in the research projekt "INGGO - Innovative Grinding- und Grooving-Oberflächen". The authors would like to thank the German Federal Ministry of Transport and Digital Infrastructure and the Austrian Ministry for Transport, Innovation and Technology for funding the work presented in this paper.

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