ABOUT THE REPRODUCIBILITY OF TEXTURE PROFILES AND THE PROBLEM OF SPIKES

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ABSTRACT

The ISO working group ISO/TC43/SC1/WG39 has recently been worrying about the quality of texture profiles, measured with laser profilometers. It appears that the quality has not improved in recent years, rather on the contrary: in spite of the technological progress it appears to decrease!

The WG is especially concerned of the presence of invalid positive spikes in some profiles which might dramatically affect the Mean Profile Depths (MPD) [1] and to some extent the texture spectra calculated with those spectra, if one does not properly deal with these erroneous measurement points prior to calculating the MPD or spectrum.

In this paper the results of an international round robin test with static laser profilometer devices on two epoxy moulds of dense asphalt concrete road surfaces are shown, indicating the reproducibility of this kind of devices for the wavelength range from 2,5 mm up to 125 mm.

A new procedure to deal with the spike problem is presented. The aim is to remove the spikes without affecting significantly the valid part of the spectra. The effect on MPD and spectra will be shown for some typical cases. The method, based on the detection of steep jumps in the profile, appears to work.

1. INTRODUCTION

Pavement texture plays a crucial role for important surface characteristics of a road: noisiness, skid resistance and rolling resistance. Measuring texture with a laser profilometer is an attractive way of assessing the surface characteristics: it is fast and cheap. The calibration of a laser profilometer is in principle simple, as it is just a distance measurement. Laser profilometry is moreover a *non contact* method: no part of the measuring device (like a measurement tyre) is in contact with the pavement, there's nothing that will wear quickly, increase the maintenance cost and reduce the reliability of the device.

There are three basic conditions for the assessment of a surface characteristic by means of a texture measurement device:

- The texture profile that serves as input for the model, e.g. for calculating MPD values, must be precise and free of erroneous parts, like spikes.
- The post processing of the texture profiles, like the application of filters (like the low pass filtering for the MPD calculation), the slope suppression, the drop out correction, the MPD and the spectrum calculation must be done uniformly and correctly.
- There must be a reliable model linking the surface characteristic to the texture. The risk on aquaplaning at higher speeds and - according to recent research [2] - also

the rolling resistance correlate very well with the Mean Profile Depth. The rolling resistance correlates also with the broad band megatexture level LMe:

$$LMe = 10 \log \sum_i 10^{Li/10}$$

with L_i the level of the i-th one-third-octave band in the megatexture range of the texture scale.
The rolling resistance of a newly laid road surface can hence be checked with a texture measurement, e.g. as a part of the acceptance procedure.

This paper focuses on the reliability/reproducibility of the texture profiles and on the presence and detection of spikes which were not recognized as invalid readings by the measurement device.

2. AN INTERNATIONAL ROUND ROBIN TEST FOR LASER PROFILOMETERS

2.1. Introduction

The ISO working group ISO/TC43/SC1/WG42TT, working on a revision of the standard ISO 10844 describing the test track for the acoustic testing of vehicles and tyres, considered to introduce a performance based requirement for the test track, using the French model “Estimated Noise Difference due to texture” (ENDt). This model predicts the difference of noisiness of a given pavement with respect to a reference pavement, based on the texture of both pavements and the known noise emission on the reference pavement. As this model requires as input the “enveloped” texture spectra, it is crucial that the texture data are reliable and that it is possible to measure it in a reproducible way all over the world.

2.2. Moulds

For practical and budget reasons it was decided to make epoxy moulds of two existing road pavements and send these to the participants, rather than to gather the profilometers to one place. A mould was made of a rather rough surface and one of a smooth pavement (both dense asphalt concrete).

The making of the moulds is shown in Figure 1, Figure 2 and Figure 3: first a flexible, negative mould is made of silicone and then a hard, positive mould is made in epoxy. On each of these samples, three one meter lines are defined (AB, PQ and XY) which were marked with needles (Figure 4).

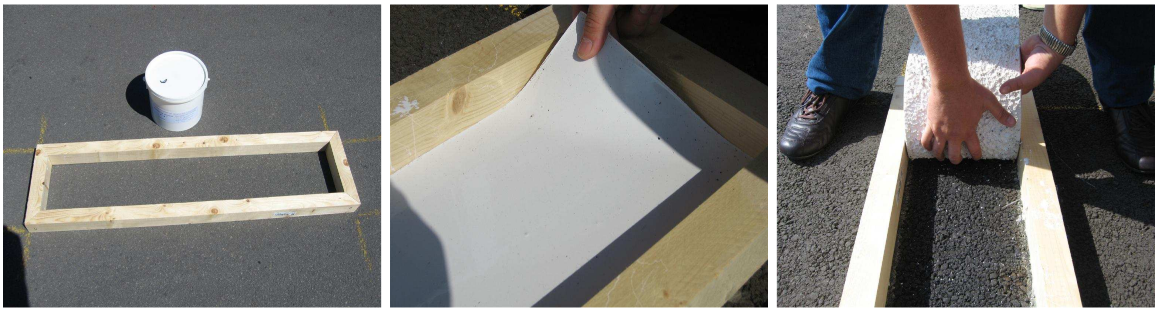

Figure 1 – Making of a negative print in silicone of a road surface using a wooden frame

Figure 2 – Making of a positive print in epoxy using the same wooden frame

Figure 3 – Removing the mould (left) and the results: a sample with a coarse texture (sample 1, middle) and a sample with a smoother texture (sample 2, right)

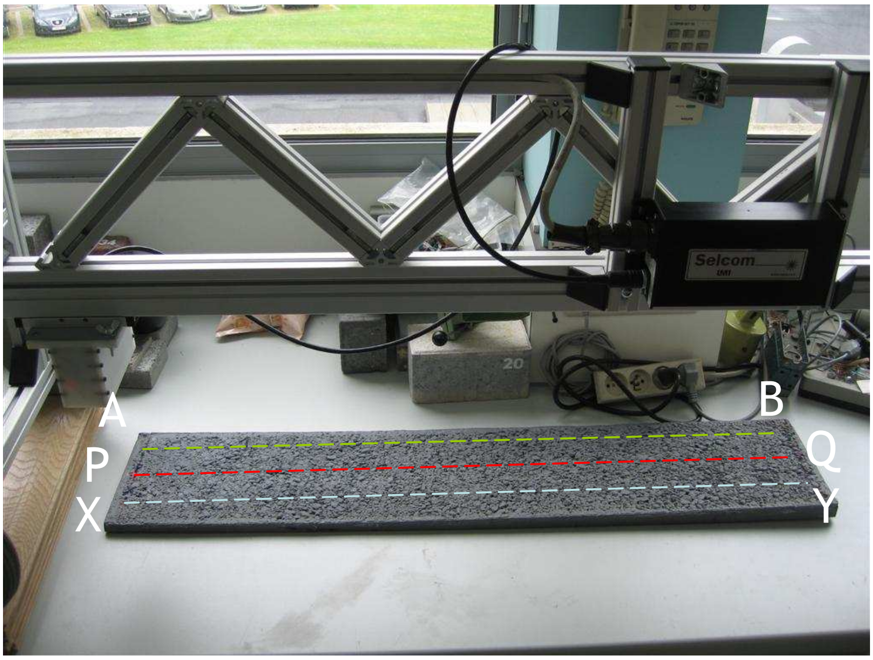

Figure 4 – Three straight lines (AB, PQ and XY) of 1 m length each are defined on each sample

2.3. Measurements

Participants to the round robin test were asked to measure as precisely as possible the texture along these lines between the two needles. Measurements were carried out by participants in Japan, Belgium, the Netherlands and Sweden. The participants were assigned randomly a code for the sake of confidentiality: A, B, C and D.

2.3.1. Repeatability

A repeatability check was carried out with the Belgian device and the spectra of eight consecutively measured profiles along the PQ line on sample 1 are shown in Figure 5. The step size is 0.2 mm. The sample was taken away and repositioned after each measurement.

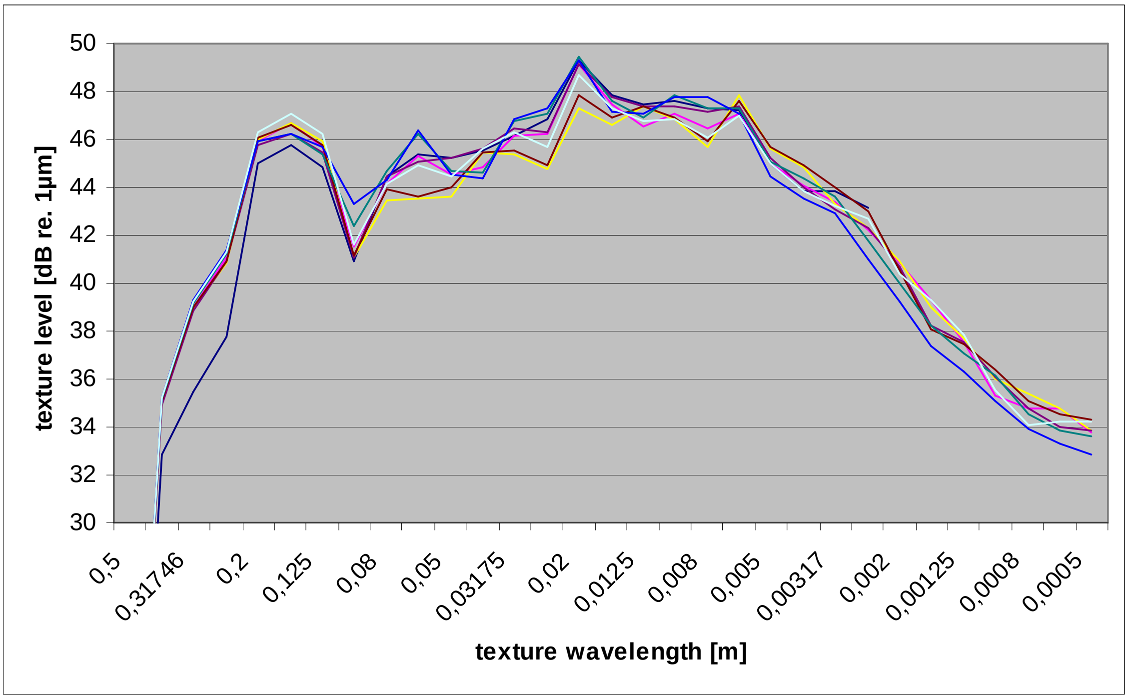

Figure 5 – Repeatability of texture spectra measured along line PQ on the sample with the rough texture (sample 1)

The repeatability of the texture spectrum is good to excellent for texture wavelengths down to 5 mm: standard deviation is below 1 dB for each one third of octave band. The spread on the one-third octave texture levels may be partly due to small misalignments of the measurement trajectories.

2.3.2. Reproducibility

The reproducibility of the four devices is considered in terms of the Mean Profile Depth (MPD) and the one third octave texture spectrum. Both the MPD values and the spectra are calculated from the texture profiles measured by the participants, by means of the software of BRRC in order to exclude differences due to calculation errors.

Per line on each sample the average of the MPD values was calculated, as well as the average of all the MPD values measured on one sample. The uncertainty (66% confidence interval) is indicated. The results for sample 1 are presented in Figure 6 and for sample 2 in Figure 7.

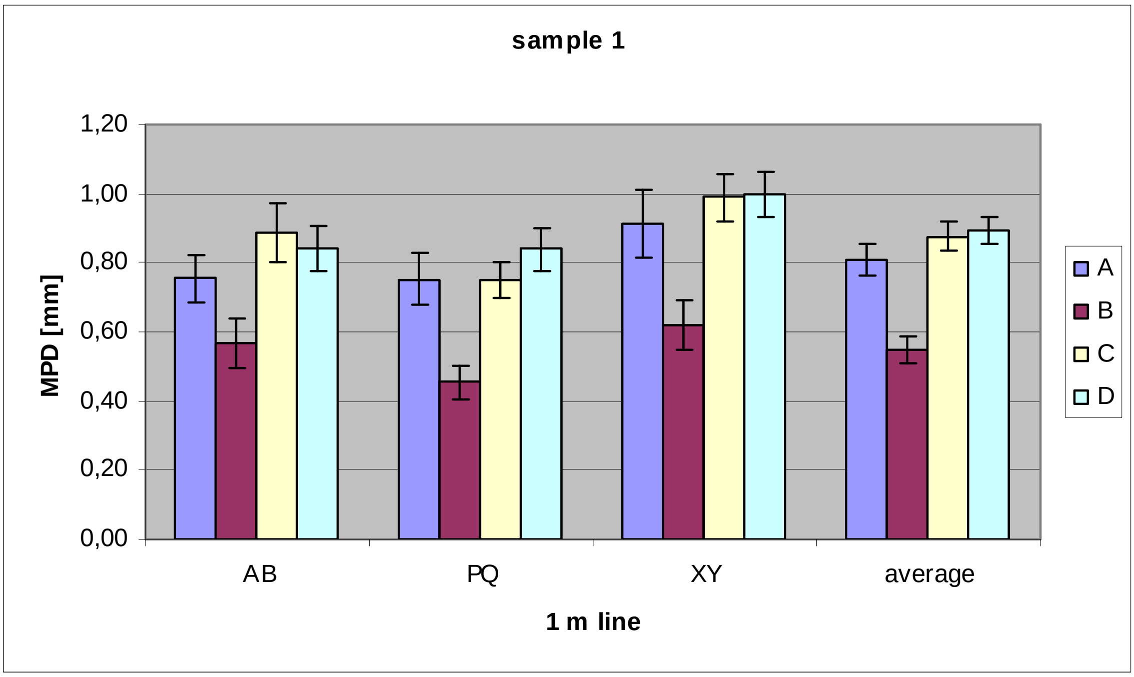

Figure 6 – Average MPD values for the three 1 m lines and for the whole sample (sample 1) measured by all participants (A, B, C, D)

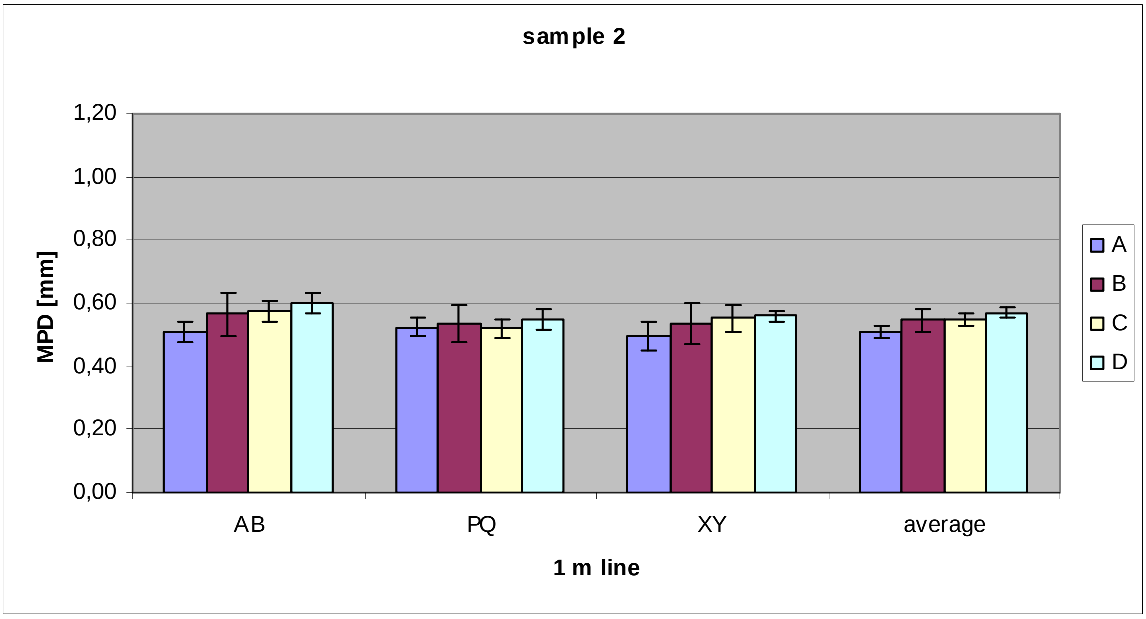

Figure 7 – Average MPD values for the three 1 m lines and for the whole sample (sample 2) measured by all participants (A, B, C, D)

One can see that for the smoothly textured sample 2 the MPD values obtained with the profiles of different participants lie very close to each other: maximum 0,04 mm standard deviation for the average on a line (10 MPD values) and 0,02 mm for the average over the whole sample (30 MPD values). In percentages this accounts for 9 % and 4 % at maximum.

The results obtained on the more roughly textured sample 1 however, look quite different: the MPD values of participant B are systematically and significantly lower than those of the other participants. The MPD values obtained with the results of participant B lie about 0,3 mm lower than the average of the other three. The reproducibility of the other three is less than 0,07 mm per line (average of 10 MPD values) and 0,05 mm for the average of all MPD values on the sample 1. In percentages: 11 % and 6 % at maximum.

Figure 8 and Figure 9 show the one third octave band spectra for sample 1 and sample 2 respectively.

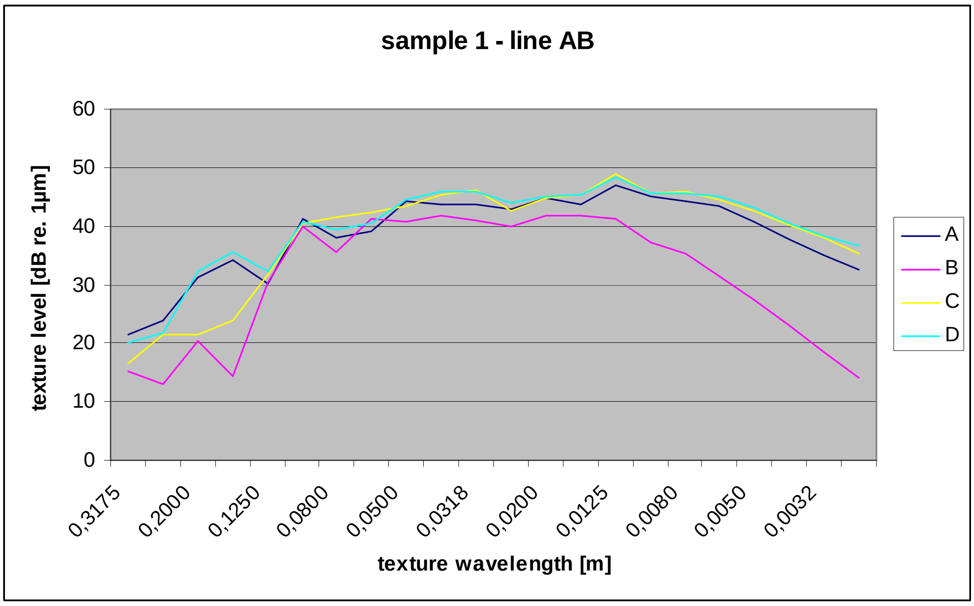

Figure 8 – One third octave band spectra for line AB on the rougher textured sample 1 measured by all participants (A, B, C, D)

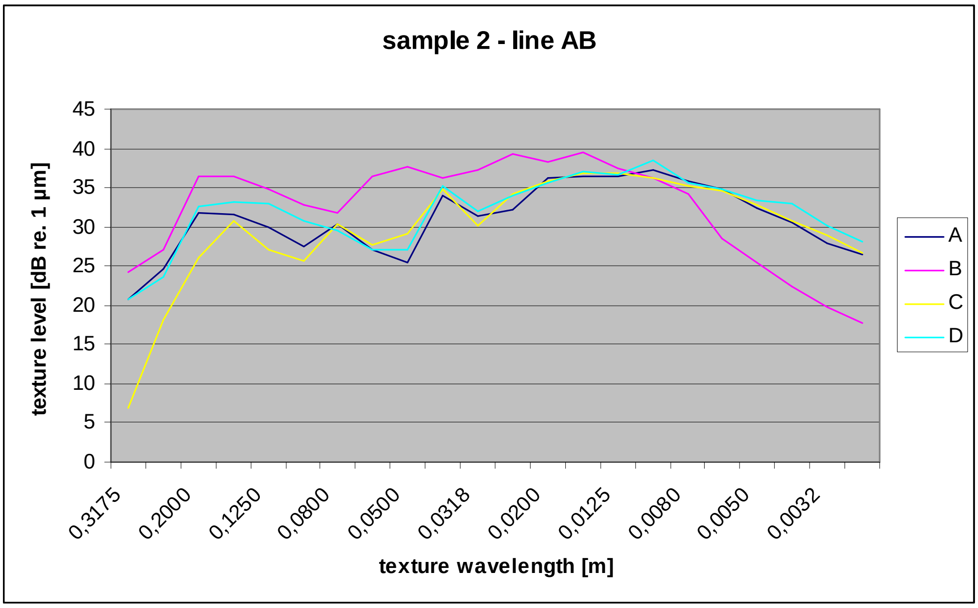

Figure 9 – One third octave band spectra for line AB on the smoother sample 2 measured by all participants (A, B, C, D)

Figure 8 en Figure 9 show that on both samples the profiles of participants A, C and D are quite close to each other, especially for the texture wavelengths below 0,125 m (length of the profile divided by eight). The profiles of participant B are significantly deviating from the others. The reproducibility in terms of standard deviation is better than 1,5 dB.

3. SPIKES IN A TEXTURE PROFILE AND HOW TO HANDLE THEM

The ISO working group suspects spikes to be one of the mayor causes of texture profile inaccuracies. Although a laser sensor is normally equipped with a system that detects invalid readings (“drop outs”) by the measuring of light intensity of the laser spot and flagging when this is below a certain threshold, an invalid reading might pass undetected (e.g. by specular reflection). Spikes emerging from a texture profile with a considerable amplitude may change the calculated MPD and texture spectrum dramatically and must therefore absolutely be identified and discarded prior to the calculation of these parameters.

3.1. A simple spike identification procedure

Consider a profile with amplitude z_i, belonging to horizontal position index i and step size Δx. The criterion for assigning a posteriori the status of invalid reading to the i-th data point is:

$$|z_i - z_{i-1}| \geq \alpha \, \Delta x \qquad \text{(Equation 1)}$$

with “α” a constant factor. The value of α can be varied to make the procedure more or less severe (the higher α, the less severe). The question which value to assign to α is discussed in the next paragraph.

The criterion $|z_i - z_{i-1}| \geq \alpha \, \Delta x$ (Equation 1) is checked for all the data points i of the profiles.

Subsequently, the “normal” drop out treatment procedure is applied.

3.2. Which value to assign to α?

The choice of α is crucial and must be a good compromise: low enough to detect the spikes and high enough not to “smoothen” the profile by too many erroneous detections of spikes.

In order to determine an appropriate value for α, the following “experiment” was conducted: 1 m texture profiles, measured on the two aforementioned road samples were measured and visually inspected in order to make sure that they do not show any spikes (see Figure 10).

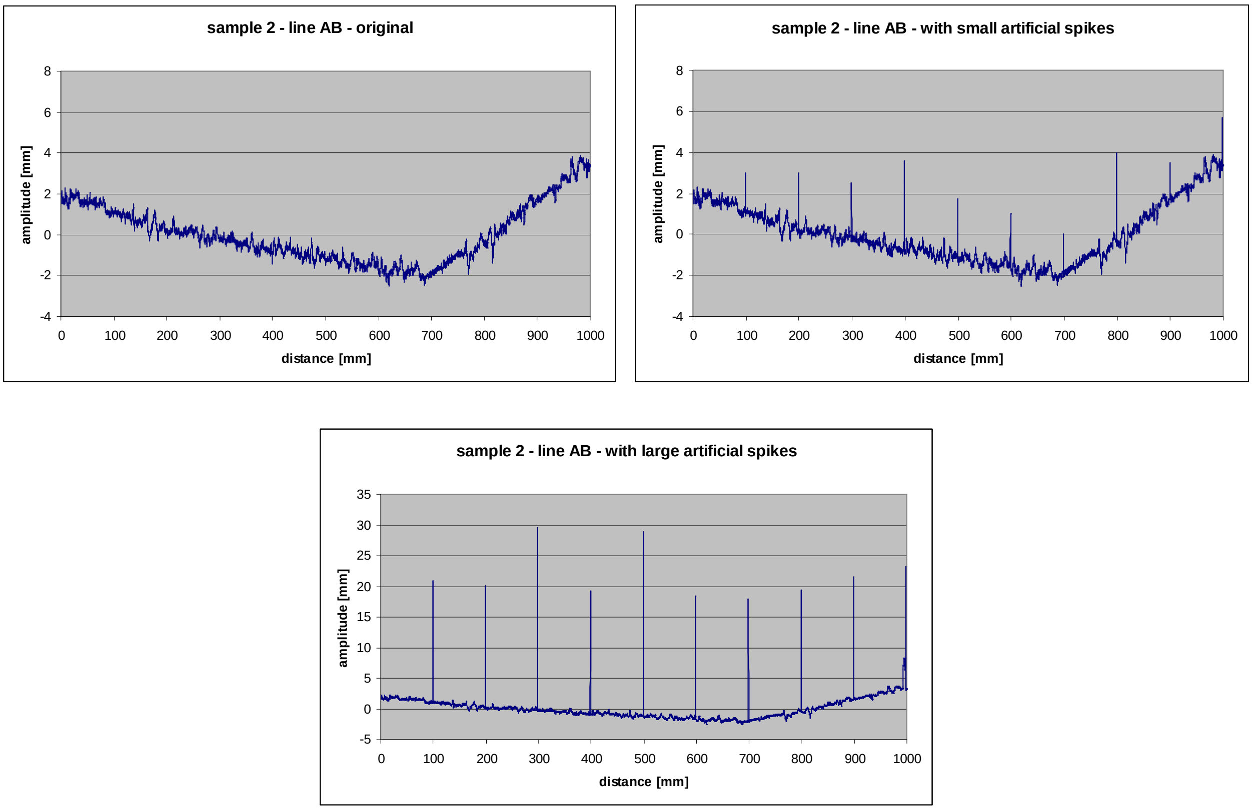

Figure 10 – The original 1 m texture profile measured on the smooth sample 2 and the same profile with small artificial spike of 2-3 mm (upper right hand side) and large artificial spikes of 20 – 30 mm (lower side)

On these two samples, ten artificial spikes are added. Two cases are considered: the case with “small” spikes (emerging 2 to 3 mm from the profile) and the case with “large” spikes (emerging 20 to 30 mm).

The MPD values and the texture spectra are calculated from the original profile, from the profile with the spikes and from profiles on which the described spike removal procedure is applied for several values of α: 10; 5; 2; 1; 0,5 and 0,2. This allows observing for which values of α the original, “true” MPD values and texture spectra are reproduced.

Figure 11 shows that when the spikes are removed with the above described procedure taking for α the value 5, the MPD value approximates very well the original MPD value.

The figure also indicates that α equalling a value between 10 down to 2 would also be an acceptable choice.

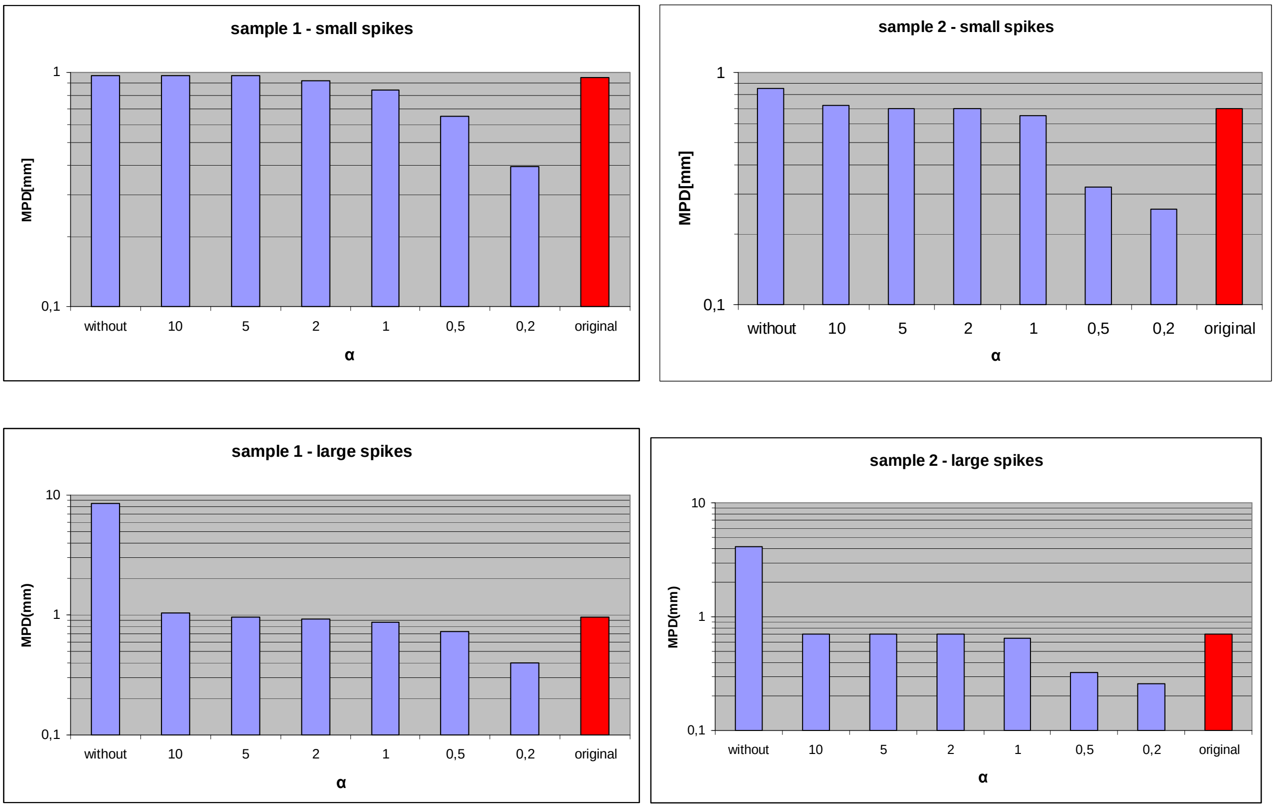

Figure 11 – MPD values calculated from texture profiles on sample 1 (rough) and sample 2 (smooth) with small and large artificial spikes. The bar "without" indicates the value without spike removal procedure and the MPD value calculated on the original profile is indicated in red.

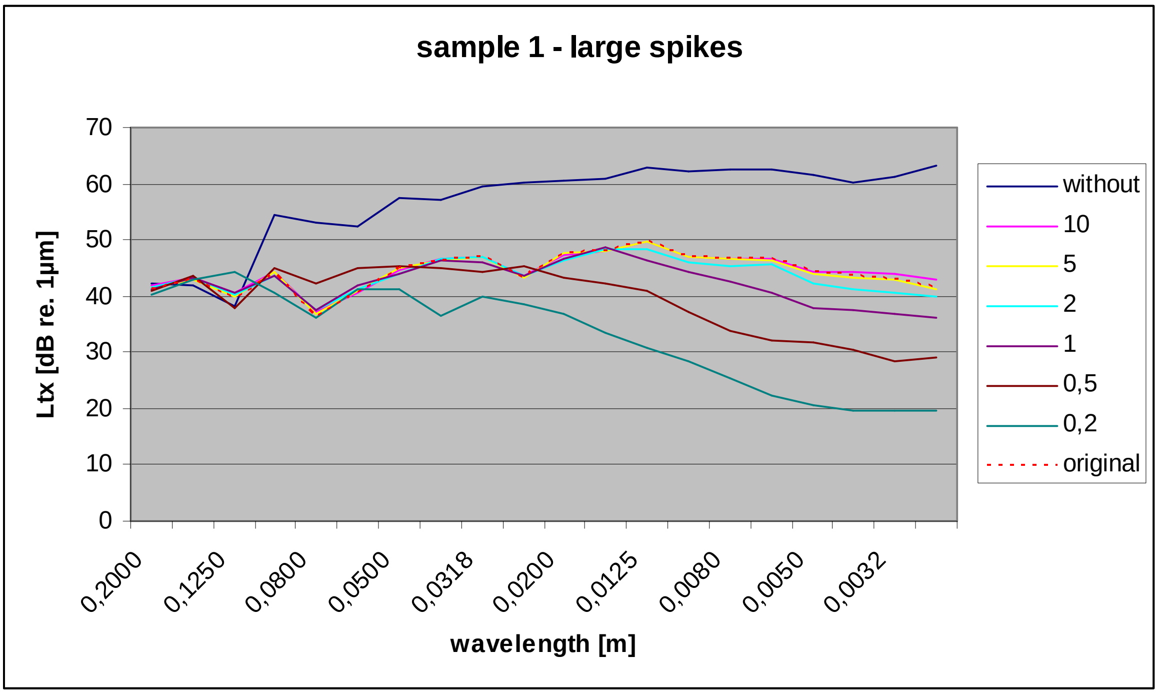

Figure 12 – Texture spectra calculated from texture profiles from sample 1 (rough) with large artificial spikes. The figures in the legend are the values of α

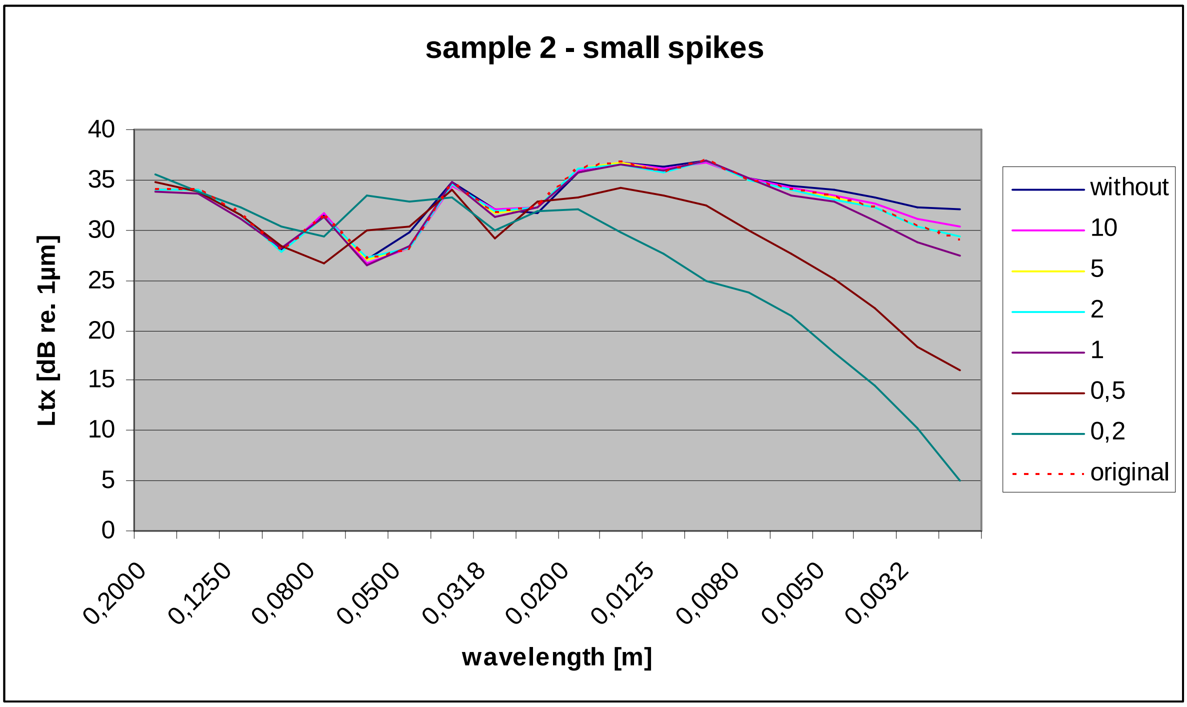

Figure 13 – Texture spectra calculated from texture profiles from sample 1 (rough) with large artificial spikes and sample 2 (smooth) with small spikes. The figures in the legend are the values of α

Figure 12 and Figure 13 shows that the spectra calculated with α = 5 coincide almost exactly with the original spectra and that α = 2 or α = 10 are acceptable as well, confirming what has been observed for MPD. A good choice for α is hence 5 and this value is not critical.

4. DID SPIKES CAUSE THE DIFFERENCES IN THE RESULTS OF THE INTERNATIONAL ROUND ROBIN TEST?

At first sight one would not think so, as the results of participants A, C and D in **Figure 6**, **Figure 7**, **Figure 8** and Figure 9 are close to each other, making it unlikely that they are influenced significantly by random spikes. The MPD values of participant B, which are deviating from the others, are on the other hand *lower* than those of the other participants. One would expect the opposite if they would be influenced/contaminated by spikes.

To make sure, the spike removal procedure was applied on the texture profiles measured by the participants of the round robin test. Typical results are shown in Figure 14 and Figure 15.

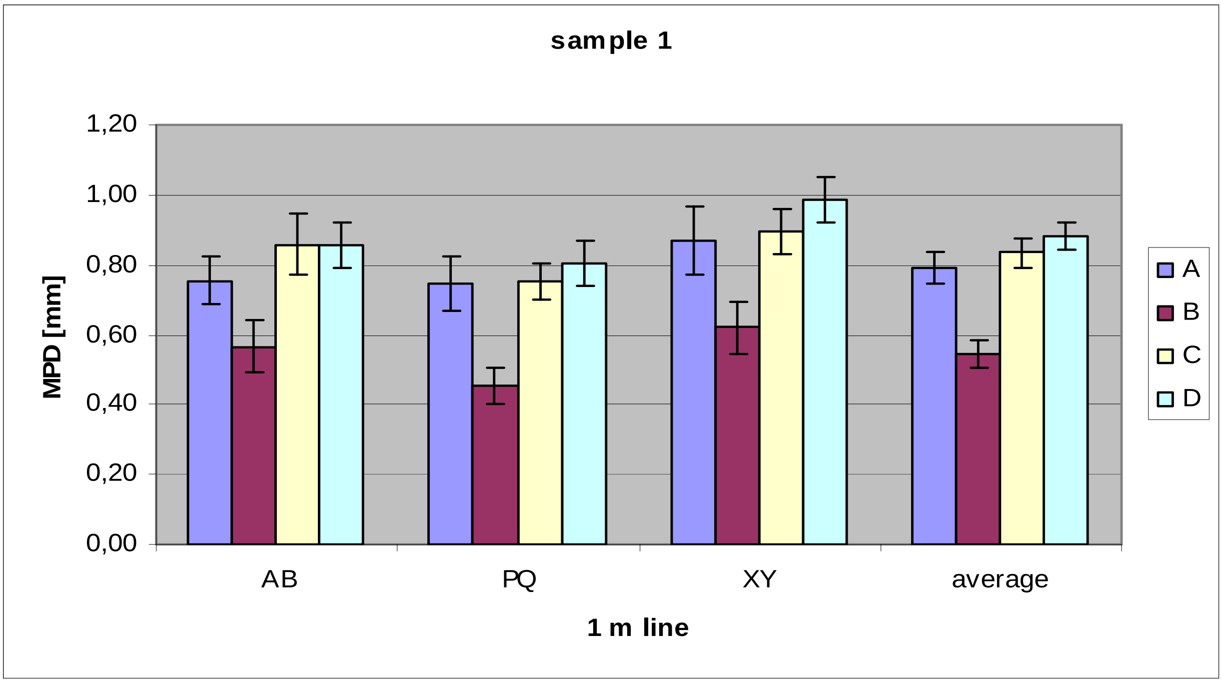

Figure 14 – MPD values calculated with texture profiles on which the spike removal procedure was applied. There is no significant difference with the results calculated without spike removal (Figure 6)

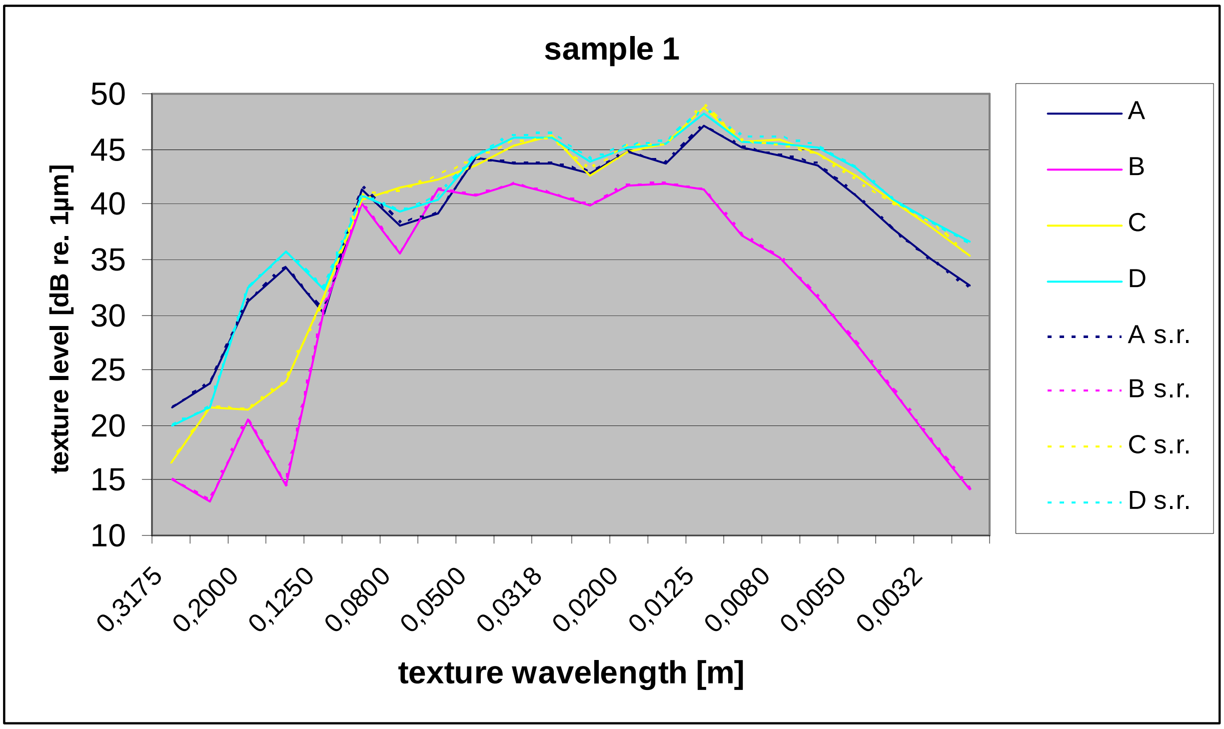

Figure 15 – Spectra calculated with texture profiles on which the spike removal (s.r.) procedure was applied (dashed lines) as well as the original spectra. Here as well no significant difference.

It appears that the spike removal has no influence on the MPD and the texture spectra measured at the round robin test, proving that – at least in this case – spikes are not playing any role. The reason why the results of participant B deviate has to be sought in the poor accuracy of the device. Confronted with the results of this round robin test, participant B has in the mean time replaced this device by a more accurate one.

5. CONCLUSIONS

An international round robin test has been conducted for laser profilometers and it appears that the reproducibility of the properly functioning devices is better than 0,07 mm (standard deviation of the average of 10 MPD values). The reproducibility of the one third octave band levels is better than 1,5 dB in the texture wavelength range from 2,5 mm up to 125 mm.

A spike removal procedure has been presented and validated. It is recommendable to assign the parameter α the value 5, but this is not critical, as in principle any value between 2 and 10 would do. This procedure is simple and requires very little computing time. Unlike some other countermeasures against spikes, like low pass filters, it does not alter spectra if there are no spikes present. It is recommendable to apply this procedure to texture profiles as a matter of precaution.

The deviations observed in the round robin test are not due to spikes, which is not so surprising, as typical conditions inducing spikes – like a glossy surface or deep holes – were not present.

REFERENCES

[1] ISO 13473-1

[2] Bergiers, A., Goubert, L., Anfosso-Lédée, F., Ejsmont, J.A., Sandberg, U., Zöller, M. (2011) Comparison of Rolling Resistance Measuring Equipment - Pilot Study. MIRIAM, SP1 Deliverable No. 3, downloadable from http://miriam-co2.net