Revision of EN 15610 - Wheel roughness measurements

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Summary
EN 15610 (Railway applications - Noise emission - Rail roughness measurement related to rolling noise generation) was published in 2009 to support the European legislation for train noise limits. The standard has been revised over the last two years. As the rail roughness measurements have proved to be reliable and are well understood in practice, the main revision has been the inclusion of wheel roughness measurements. The wheel roughness is an important input quantity for rolling noise generation, however no standardized procedure exists for this task.
To gather information about the procedure and comparability of results, an exercise was undertaken with different available wheel roughness devices measuring the same wheelsets of one bogie. The results of this measurement exercise are presented in a separate paper [5].
The key provisions for wheel roughness measurements are the measuring system requirements, the data acquisition, the data processing, the presentation of the data and the reporting. The standard also provides a calibration framework (issues, concepts) and a method of estimating the measurement uncertainty.
The concepts behind these topics are explained here with background information helpful to apply the revised standard.

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1. Introduction

EN 15610 [1] (Railway applications – Noise emission – Rail roughness measurement related to rolling noise generation) was first published in 2009 to support the European legislation requiring the measurement of the train noise against limit values. The standard covers the measurement procedure, the data analysis and the presentation of acoustic rail roughness. The 'acoustic roughness' here describes the variation in the height of the rail running surface associated with rolling noise excitation in the form expressed as a one-third octave band wavelength spectrum of level $L_r = 20\log(r/r_0)$ where r is the r.m.s. amplitude of the rail surface height and the dB reference r_0 is 1 micron. The acoustic roughness typically has amplitudes of a few microns at wavelengths around 0.25 m, corresponding to the lower frequencies of rolling noise, down to less than a micron at wavelengths of a few millimetres corresponding to the higher frequencies around 6 kHz. Wavelengths shorter than a few millimetres do not excite rolling noise because their effect in causing a dynamic relative displacement between the wheel and the rail is averaged out over the length of the wheel-rail contact patch (typically 10 mm).

A 'road test' of the standard for measuring rail roughness at two different sites and the application in practice over the last 10 years showed that the standard leads to reliable measurement results and has been well understood in practice [13].

In the last two years, EN 15610 has been revised [2] with the aim to extend it to include the measurement of wheel roughness.

Measurements of wheel roughness have not previously been standardized because the test of the noise generated by different vehicles only requires the control of the test track. The need for reliable reproducible wheel roughness measurements has, however, increased in the past few years for the following purposes.

- To assess the acoustic wheel tread quality within vehicle type tests.
- To assess the combined wheel and rail roughness for rolling noise calculations.
- For the acoustic acceptance of brake blocks since these determine the typical sound pressure levels of tread-braked wheels.
- To enable the division of responsibility of noise generation between vehicle and track.
- To diagnose wheel-rail noise issues for specific wheel types.
- To enable acceptance testing of the running surface condition of the wheels where the acoustic roughness may be made an acceptance criterion.

A drafting group ('subgroup G') was formed within CEN TC256/WG3 to draft the text adding the measurement of wheel roughness to EN 15610. The group also added more detailed requirements for measurement devices and produced guidance on the assessment of measurement uncertainty.

The provisions of the standard for wheel roughness measurement are described below. The main topics are:

1. the preparation of the vehicle,
2. the selection of wheels,
3. the selection of measuring traces,
4. the data acquisition procedure,
5. the data analysis procedure,
6. requirements of the measuring devices.

2. 'Road test'

At the very beginning of the revision, a common measurement exercise was performed [5] using a bogie taken from a locomotive.

Figure 1. Test setup of the road test.

This provided a comparison of the results of different measurement devices and of the procedures applied by different measurement teams. The key was to stimulate an exchange of knowledge. A comparison of the results from two circumferential lines on the tread of a single wheel is presented in Figure 2. For this comparison all data were processed with the same software.

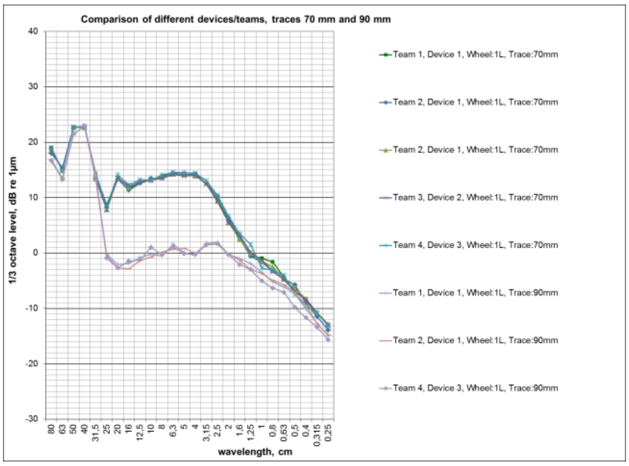

Figure 2. Wheel roughness measurement, result of different teams, devices on two different traces of one wheel.

The results gave confidence that wheel roughness measurements may be performed accurately, reliably and repeatably.
Figure 2 also illustrates that the wheel roughness changes considerably with the lateral position of the trace on the wheel tread.
When comparing different software codes, it was found that the software of one device produced a shift in the one-third octave band wavelength. It was thus decided to require a validation of the software for both, the wheel and rail roughness measuring devices.

3. Preparation of the vehicle

The railway vehicle must be prepared prior to the measurements. The car body is lifted and the wheels are jacked clear of the rail by a distance just sufficient to allow free rotation.
Since any movement of the wheels during the measurement would distort the result, the wheel must be fixed so that the lateral and vertical movements of the wheel are minimized. Two different methods are proposed to fix the axles.

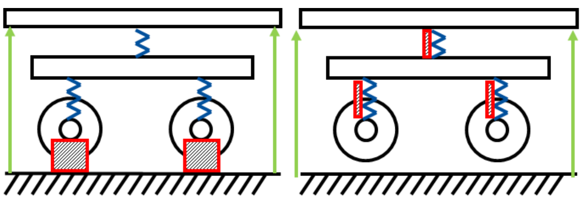

Figure 3. Methods to minimise lateral and vertical movements of wheels jacked clear off the rail, (left) support of the wheel bearing housing and (right) bypassing the primary and secondary suspension [10].

Supporting the wheelset at its bearings with a rigid support (*e.g.* metal blocks or lockable hydraulic supports) is the preferred method as it provides the best restraint of the axles.
In the same context, vibrations from people inside the vehicle or from running traction, braking and signal equipment must be avoided.
The ability of the measurement setup to ensure a correct result has to be proven by the repeatability test (Section 7).
All contamination of the wheel tread would influence the measurement result so the wheel tread must be cleaned before measuring. An inevitable remaining small contamination after the cleaning, by dust *etc*., may be removed during the data analysis from the measurement record within a 'spike removal' process (Section 8).

4. Selection of wheels

Tests have been conducted to determine an appropriate sample of wheels of a train to be measured so that

- the results remain representative of the train or train type but also so that
- the tests do not become uneconomic, especially for long trains with a lot of axles.

Accuracy in this context means that the measurement uncertainty is not significantly increased by measuring the roughness of a reduced number of wheels.
The proposed method is derived from measurements conducted at different railway cars (EMU, wagon, metro, light rail vehicle). Within these tests all wheels have been measured and analysed. Then the average acoustic roughness of all wheels was compared to the average roughness of a sample of wheels. Different procedures to select wheels have been tested and assessed.
Figure 4 shows the acoustic roughness level over the wavelength λ of all wheels of the metro train (wheel diameter: 850 mm, mileage since reprofiling about 4000 km).

λ [cm]	Wheel roughness level averaged over axle [dB]																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
79,4	9,4	8,9	7,0	9,3	13,1	1,0	9,0	4,1	8,3	12,1	5,6	12,0	2,1	11,8	6,9	12,4	6,0	9,1	5,4	9,0	5,6	11,1	4,7	3,2
63,1	7,2	6,8	5,3	9,8	11,0	0,9	3,6	-1,5	8,3	7,8	1,9	10,1	0,2	8,5	4,7	12,8	6,1	6,6	-2,1	4,6	1,1	12,2	4,0	0,5
50,1	8,0	6,4	4,4	6,0	9,5	0,2	2,8	1,9	8,0	8,0	1,4	8,6	-1,2	5,2	-0,3	12,6	4,3	5,1	-2,3	4,7	3,7	11,1	1,0	1,8
39,8	9,6	10,2	3,7	10,8	7,8	6,2	3,8	8,2	12,5	8,6	5,8	6,0	4,8	4,4	2,7	10,8	4,0	7,8	2,5	11,6	8,5	13,5	7,0	4,8
31,6	4,9	5,9	4,3	7,6	6,3	4,6	4,5	6,5	8,9	4,5	2,4	1,4	3,6	1,8	-0,8	8,5	2,1	3,9	-0,8	5,7	2,7	11,3	1,5	4,1
25,1	6,8	3,6	3,4	4,2	5,1	1,4	1,9	2,7	5,5	1,8	-2,4	2,6	-3,6	0,9	0,2	11,8	0,5	1,3	-3,8	7,7	-2,0	5,8	-3,3	3,5
20,0	5,1	3,8	1,9	2,0	5,6	4,4	2,0	2,0	2,0	3,1	-3,6	3,5	-4,8	6,1	-2,6	12,7	1,8	8,8	0,4	9,7	-1,7	9,0	0,4	6,8
15,8	4,5	9,5	2,7	3,2	3,1	6,9	1,1	4,7	0,7	1,5	-3,8	8,1	-1,6	12,6	-2,6	14,4	4,3	8,1	-1,0	12,0	-0,3	17,2	-0,4	9,1
12,6	4,3	5,6	0,7	2,0	2,6	9,5	2,0	5,1	3,8	1,7	-4,2	11,0	-1,9	11,9	-2,9	14,9	3,5	13,9	-0,2	17,1	-0,8	15,6	-4,1	12,8
10,0	4,2	6,3	0,1	1,6	3,1	9,9	1,0	3,1	4,6	1,6	-1,7	4,9	-5,3	9,4	-2,8	11,8	8,1	12,1	0,1	11,1	-1,4	17,7	-2,1	9,8
7,9	7,0	0,4	-0,9	1,9	3,5	6,0	-0,5	0,6	4,6	0,5	-2,7	0,0	-3,8	4,1	-1,3	8,1	4,4	5,5	-2,2	7,9	-1,1	14,5	-4,2	5,7
6,3	5,1	0,1	-0,7	2,7	-0,2	2,6	-2,6	-1,6	4,3	5,4	-3,6	-3,2	-4,7	2,4	-4,0	3,3	4,1	2,8	0,1	6,0	-3,7	10,8	-3,8	2,9
5,0	0,7	-1,4	-2,8	2,0	-0,5	-0,3	-3,0	-2,1	4,5	0,3	-8,2	-3,0	-5,7	1,1	-2,5	-0,1	-1,7	0,4	-1,4	3,3	-6,4	0,9	-4,9	-1,8
4,0	-1,9	-3,6	-4,3	1,1	-1,9	-3,0	-2,0	-4,2	0,9	0,5	-8,8	-4,0	-5,3	-1,3	-4,1	0,0	-5,6	-1,4	-2,9	3,4	-6,7	-0,7	-5,2	-4,6
3,2	-4,2	-3,8	-6,5	-1,1	-4,2	-5,9	-3,0	-6,4	-1,2	-2,3	-8,9	-6,0	-7,4	-4,5	-5,3	-1,1	-6,4	-4,1	-3,3	1,5	-6,5	-3,6	-4,1	-4,9
2,5	-4,3	-2,3	-7,7	-3,7	-4,8	-5,1	-2,8	-7,3	-7,0	-6,3	-9,2	-7,7	-7,4	-7,5	-6,4	-4,6	-6,1	-5,6	-2,7	-2,3	-8,0	-7,6	-4,0	-6,3
2,0	-5,0	-4,5	-9,2	-6,3	-5,8	-5,7	-4,0	-7,9	-6,6	-8,8	-9,8	-8,3	-9,8	-9,2	-8,0	-7,4	-8,0	-5,1	-4,2	-5,3	-7,0	-9,1	-5,7	-6,3
1,6	-6,4	-6,1	-8,9	-8,1	-7,4	-7,4	-7,0	-8,7	-9,1	-7,4	-10,7	-8,6	-9,5	-9,6	-9,0	-8,8	-9,3	-6,2	-6,2	-6,4	-8,5	-9,1	-6,2	-7,9
1,3	-7,3	-7,1	-9,3	-8,4	-9,6	-8,7	-9,2	-9,4	-9,1	-8,0	-10,3	-7,7	-10,3	-8,9	-9,6	-9,7	-10,0	-8,1	-8,5	-7,3	-8,2	-9,8	-8,3	-8,0
1,0	-8,9	-8,5	-10,3	-9,4	-11,9	-10,1	-10,1	-10,1	-11,6	-9,1	-11,2	-9,7	-10,7	-9,6	-10,6	-10,9	-10,6	-8,8	-9,4	-7,1	-7,4	-9,1	-8,5	-7,6
0,8	-9,8	-9,7	-11,4	-10,0	-11,9	-10,3	-10,6	-11,8	-12,5	-9,7	-11,5	-9,7	-10,9	-9,9	-11,4	-11,7	-11,2	-9,0	-10,5	-8,8	-8,7	-10,0	-9,0	-8,6
0,6	-11,0	-11,0	-12,0	-10,9	-13,3	-11,7	-11,6	-11,9	-12,4	-10,6	-12,6	-10,9	-11,5	-11,1	-11,5	-12,8	-12,0	-10,0	-11,2	-11,1	-10,4	-11,1	-9,3	-9,4
0,5	-12,1	-12,3	-12,8	-11,8	-14,0	-12,2	-12,8	-12,8	-13,6	-11,4	-12,5	-12,0	-12,1	-12,0	-12,8	-13,3	-12,9	-11,1	-12,4	-11,4	-10,9	-11,7	-10,4	-10,2
0,4	-13,3	-13,3	-13,8	-13,2	-15,0	-13,5	-13,8	-13,6	-14,6	-12,9	-13,6	-12,8	-13,2	-13,0	-13,4	-14,0	-13,4	-12,2	-13,0	-12,6	-11,9	-12,4	-11,4	-11,5
0,3	-14,5	-14,8	-14,7	-14,4	-15,9	-14,6	-15,0	-14,5	-15,2	-14,0	-14,6	-14,0	-14,4	-14,3	-14,4	-15,0	-14,7	-13,7	-14,1	-14,0	-13,2	-13,9	-12,9	-13,0
0,3	-15,6	-15,8	-15,6	-15,5	-16,5	-15,6	-15,7	-15,5	-15,8	-15,1	-15,2	-15,1	-15,1	-14,9	-15,3	-15,5	-15,2	-15,0	-15,1	-15,0	-14,1	-14,6	-14,1	-14,0
traction	d	d	d	d	nd	nd	nd	nd	d	d	d	d	d	d	d	d	nd	nd	nd	nd	d	d	d	d

Figure 4. Acoustic roughness level Lr over the wavelength λ of all wheels of the metro train ('d' driven, 'nd' non driven).

The wheelsets of the second part of train have a significantly higher acoustic roughness than the wheelsets of the first part. Furthermore, the second wheelset of each bogie has a significantly higher acoustic roughness than first wheelset.

Conclusions from this test are that bogies should be selected regularly distributed along the train and each wheelset of a selected bogie should be measured.

Tests on other vehicles produced further criteria.

1. At least eight wheelsets or one quarter of the wheels should be measured. For units with fewer than eight wheelsets, all wheelsets should be measured.
2. Wheelsets of all the different types present in a vehicle should be included in the sample, at least to be approximately in numbers proportional to their occurrence in the unit. A 'different type' is implied by a difference in the following factors: powered/unpowered, brake type, presence of tread cleaning devices, or any aspect of bogie design that affects vehicle dynamics (wheel diameter, wheel spacing, steering mechanism).
3. The wheelsets of the end bogies should be measured as the wheel roughness might be higher due to the higher mechanical wear of these wheels in curves.
4. Both wheels on any wheelset should be measured.

5. Selection of measuring traces

It has been found in a study of a number of samples of data that the choice of the lateral position of the running surface is a factor in wheel roughness measurements that may lead to a significant degree of uncertainty in the result.

Figure 5 shows the acoustic roughness L_r over a wheel with a running band of about 45 mm width. The acoustic roughness has been measured over nine traces with a distance of 5 mm between them.

	Wheel roughness level Lr [dB re 1 um], traces [mm]								
	-20	-15	-10	-5	0	5	10	15	20
Wavelength [cm]	3	4	5	6	7	8	9	10	11
79,4	0,65	-5,5	-0,9	0,92	0,91	2,86	3,4	7,35	4,95
63,1	-1,3	-7,8	-4,2	-3,3	-6,2	-4,4	-2,6	-0,2	-2,2
50,1	-3,8	-4,3	-7,3	-8	-6,8	-5	-4	-6,6	-4
39,8	-3,3	-3,6	-4,7	-9,4	-7,9	-8,8	-6,2	-7,5	-4,6
31,6	-1,4	-3,5	-6,2	-11	-9,5	-12	-6,7	-7,3	-7,9
25,1	-4,2	-5	-13	-3	-8	-14	-12	-12	-10
20,0	-4,4	-2,9	-6,1	-4,4	-11	-11	-12	-11	-9,1
15,8	-2,2	-4,7	-6,5	-7,4	-6,2	-14	-13	-4,9	-3,9
12,6	-7	-4,9	-5	-7,2	-9,8	-10	-14	-4,9	-5,8
10,0	-4,5	-6,7	-9,6	-3,6	-5	-14	-10	-6,5	-7,5
7,9	-9,7	-5,2	-7,7	-5,5	-8,1	-11	-12	-10	-11
6,3	-5	-5,8	-7,4	-3,4	-9,2	-8,6	-11	-13	-12
5,0	-6,8	-7,7	-5,9	-7,9	-8,8	-11	-12	-11	-14
4,0	-9	-8,1	-7,7	-7,2	-7,8	-8,6	-12	-14	-15
3,2	9,01	8,15	6,74	5,99	9,53	10,9	6,38	-8,9	-11
2,5	-6,9	-10	-11	-9,4	-8,1	-7,1	-15	-13	-15
2,0	-5,9	-10	-11	-9,4	-7,1	-5,2	-13	-15	-16
1,6	-6,3	-8,8	-10	-10	-5,9	-6,4	-12	-14	-16
1,3	-8,1	-10	-12	-11	-6,2	-8,2	-14	-13	-18
1,0	-8,3	-9,9	-11	-10	-7,6	-8,1	-15	-13	-18
0,8	-5,6	-10	-12	-11	-7,5	-9,6	-13	-14	-18
0,6	-7,7	-13	-10	-9,2	-8,7	-12	-14	-14	-18
0,5	-8,8	-13	-11	-11	-9,6	-12	-15	-15	-20
0,4	-9,1	-13	-14	-14	-11	-14	-16	-18	-19
0,3	-12	-15	-15	-13	-14	-15	-17	-18	-19
0,3	-14	-15	-16	-15	-15	-16	-17	-18	-19

Figure 5. Acoustic roughness level L_r over the wavelength λ of all traces within the running band. The wheel has a high roughness level at wavelength of about 3 cm.

The results show that the acoustic roughness varies considerably with the lateral position on the wheel. On the other hand, it may be uneconomical to measure a lot of traces for every wheel. For this reason, different criteria for the selection of traces were tested.

Figure 6 shows the average roughness over the wheel and the average roughness of the measurement over five traces spaced at 5 mm distance and three traces spaced at 10 mm distance either side of the centre of the running band.

	Roughness level Lr, dB				
Wavelength [cm]	Average roughness of all traces	Average roughness of traces -10 mm, -5 mm, 0 mm , 5 mm, 10 mm	difference to all traces	Average roughness of traces -10 mm, 0mm , 10mm	difference to all traces
79,4	2,9	1,7	-1,2	1,5	-1,4
63,1	-3,0	-4,0	-0,9	-4,1	-1,1
50,1	-5,3	-5,9	-0,7	-5,7	-0,5
39,8	-5,7	-7,1	-1,4	-6,1	-0,4
31,6	-6,0	-8,4	-2,4	-7,2	-1,2
25,1	-7,3	-7,9	-0,6	-10,4	-3,1
20,0	-6,7	-7,8	-1,0	-8,9	-2,2
15,8	-5,7	-8,3	-2,5	-7,6	-1,9
12,6	-6,8	-8,2	-1,4	-8,1	-1,3
10,0	-6,6	-7,0	-0,4	-7,6	-1,0
7,9	-8,2	-8,2	0,1	-8,8	-0,6
6,3	-7,3	-7,1	0,2	-8,8	-1,6
5,0	-8,8	-8,6	0,2	-8,2	0,6
4,0	-9,2	-8,3	0,9	-8,7	0,5
3,2	7,4	8,4	1,0	7,8	0,4
2,5	-9,7	-9,4	0,3	-10,6	-0,8
2,0	-8,9	-8,3	0,6	-9,6	-0,7
1,6	-8,8	-8,3	0,6	-8,6	0,3
1,3	-10,0	-9,4	0,6	-9,3	0,7
1,0	-10,3	-9,8	0,5	-10,3	0,0
0,8	-9,9	-10,1	-0,2	-10,1	-0,2
0,6	-10,9	-10,4	0,5	-10,4	0,5
0,5	-11,9	-11,4	0,4	-11,3	0,6
0,4	-13,2	-13,5	-0,3	-13,4	-0,2
0,3	-14,9	-14,6	0,3	-15,0	-0,1
0,3	-15,8	-15,7	0,1	-16,0	-0,2

Figure 6. Acoustic roughness level *Lr* over the wavelength λ of all traces within the running band and with selections of traces.

The average roughness of three traces with a spacing of 10 mm and five traces with a spacing of 5 mm provides quite reliable results. The difference between the average roughness level of the selected traces and the average roughness level of all traces is quite small. In this example the maximum difference ΔL_r was 3.1 dB. This was tested and validated for further wheels.

Measuring the acoustic roughness over three traces spaced at 10 mm has proved to be a good compromise between the precision and the measurement effort.

The correct choice of the middle of the running band is of special importance. The running band, and especially its centre-line may, however, be difficult to determine (Figure 7).

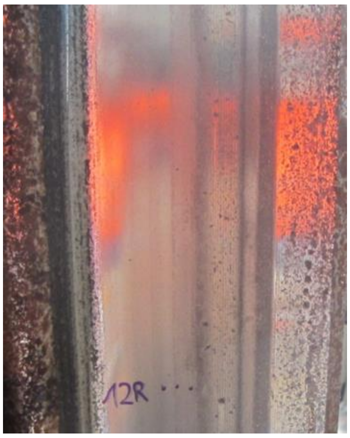

Figure 7. Surface of a wheel (flange on the left side).

Three methods with decreasing preference are therefore suggested for the identification of the running band and its centre.

a) The running surface on the wheel tread associated with running on the relevant track section is clearly identifiable either from inspection or from observation during running. The centre line shall be located at the centre of the running surface.

b) The central line is determined as the most common wheel-rail contact position that is predicted from the geometry of rail and wheel transverse profiles using simulation tools. (Note this depends on parameters of, or assumptions about, the track.)

c) If none of the above methods is applicable or appropriate, the central line of measurement can be taken as the nominal running position of the wheel.

All measuring positions are defined relative to the flange back of the wheel.

6. Measurement

For a spectral analysis a trace measured around the wheel circumference amounts to a periodic function. As local defects may occur and the acoustic roughness may vary over the circumference, at least one full circumference of each line on each wheel must be measured in a continuous record.

In the case of localized wheel features, such as wheel flats or shelling, no editing of the record is permitted. It however depends on the purpose of the measurement whether the data from damaged wheels are to be included in an average result or not.

7. Quality check

The restraint of the wheelset and an appropriate means to turn the wheel with a constant force are important in avoiding movement of the wheel during the measurement. A movement may also result from a sinking hydraulic jack.
It is however often not possible to avoid some small movement of the axles and this may influence the result.
Quality checks have therefore been introduced

1. Any drift in any data record, *i.e.* a difference between the beginning and the end of the circumference record, shall not exceed 25 µm per revolution. (Tests have shown, that small drifts below 25 µm do not influence the result significantly.)
2. The measurement setup and the correct restraint of the wheels shall be proved by a repeatability test. This test is to be conducted at the beginning of the measurements. This involves three or more consecutive measurements on one measuring trace. Preferably, the force used to turn the wheels is modified within the repeatability test (turning of the wheels with a high or low force application, either applying a pure moment to the wheels a pulling force). The repeatability test is passed and the setup is verified if the maximum spread of the acoustic roughness level L_r in any one-third octave band of all repeated measurements does not exceed 3 dB. If the repeatability test is not passed, the measuring setup has to be improved.

8. Data analysis procedure

The data analysis procedure of the acoustic wheel roughness follows, in principle, the concept of the acoustic rail roughness data analysis. It is however adapted to the specific properties of the wheel. This is mainly that the wheel roughness forms a periodic excitation with the wheel circumference as period of motion. This is different from the rail roughness, which is considered to a sample of an infinite stochastic function. This necessitates a difference in the analysis procedure between wheel and rail roughness.
The data is processed in three stages before calculating the wavelength spectrum.

1) Remove narrow upward spikes that are regarded as being linked with the presence of small particles of foreign matter on the wheel surface. This is called the 'spike removal' process.
The spike removal process for the wheel roughness is identical to that of the rail roughness. A spike is identified as a sharp upward peak on the basis of the first dr/dx and the second derivative d^2r/dx^2 of the roughness function r.

This empirical criterion has been introduced in the rail roughness standard and has proved to be practical. Even if other criteria from signal analysis theory are available, this engineering orientated criterion is based on the physical background of the measurement and is easy to understand.

2) Processing the data to take account of the effect of the small radius of the sensor tip compared to that of the wheel ('curvature processing'). This differs from the equivalent rail roughness since it is considered that the wheel roughness follows the wheel curvature. This implies a different algorithm compared to the rail roughness.

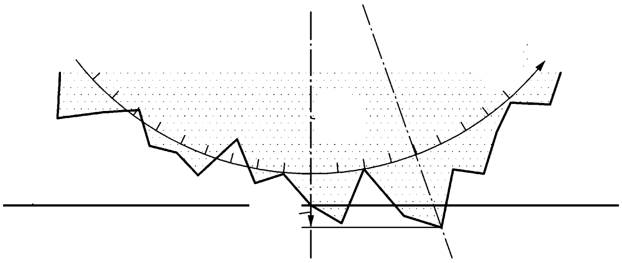

Figure 8. Curvature processing.

This processing takes into account some effects of the wheel-rail contact that cause a change in the spectrum content affecting the excitation mechanism of rolling noise. Other effects, such as that of the 'contact filter', are not within the scope of the standard.
The curvature processing cannot be done after the acoustic roughness spectrum has been produced.

3) The drifts in the data record (difference between the beginning and the end of the circumference record) are removed by a linear end-point detrending. Tests with acoustic wheel roughness data have shown that the influence of a nonlinear trend is negligible.

4) The one-third octave band spectrum is calculated by Fourier analysis. Due to the periodical characteristics of the wheel, no Hann or similar window is applied. (Continuity of the function relies on the end-point detrending and for approximate continuity of slope by the limit of the

drift in measurement from beginning to end of the circumference trace.)

5) The results of different records are r.m.s. averaged where averaging is required. This holds for different lines on one wheel as well as for the results of different wheels or bogies.

9. Measuring devices

The major purpose of the standard EN 15610 is to give guidance on rail and wheel roughness measurements. However, since different transducer technologies are used by different devices, there is no standard addressing the precision and calibration of roughness devices *per se*, the standard sets out some basic requirements.
This includes requirements on the components as well as requirements to the accuracy of the device and the software as a whole system. The requirements to the components are as follows.

- The dimension of the sensor should be small. In case of a contact sensor, the sensor tip must be spherical and its radius must not exceed 7 mm. In the case of a non-contacting sensor, its effective width must be less than the sampling interval.
- As the roughness varies significantly with the lateral position, an accurate tracking of the sensor with a tolerance of ± 1 mm parallel to the coordinate reference is required.
- In order to provide reliable results in the required wavelength range down to the 3 mm band, the device shall record the data with a sampling interval maximum of 1 mm.
- The accuracy of the length measuring system must be no worse than 3%.

Besides this the precision of the whole device and the analysis software must be proven. This is achieved by the calibration procedure of the device. It is required that the measuring system performs valid measurements for the specific situation under test (expressed by the wavelength range and at the acoustic roughness levels being characterized). If it is required to show that the estimated acoustic roughness does not exceed a given upper limit, it is sufficient for the device to effect valid measurements for one-third octave band acoustic roughness levels equal to or greater than this limit curve.
The 'accuracy' of a device is assessed by the measurement accuracy. A measurement device is considered to make valid measurements if the standard uncertainty resulting from the measuring device, does not exceed 3 dB.
A calibration procedure appropriate to the device is required that verifies its accuracy and estimates its precision. Documentation of the calibration method must be available that justifies the method by which all aspects of the instrument's operation are checked, including the electronics and processing. The calibration must also be traceable to a national measurement standard or a primary standard.
The calibration is done by means of a reference roughness surface (*e.g.* 'a reference metre'). The surface geometry of the reference standard is to be measured by an accredited standards laboratory. For comparing the measurement values to a limit curve, the roughness of this reference roughness standard shall be of a measureable value and shall be no greater than 10 dB above the respective limit curve over the whole wavelength range of the limit curve.
A recalibration of the instrument is required every 24 months or if an instrument has been repaired or is suspected of fault, damage or wear.

10. Conclusion

This article explains the standardisation of acoustic wheel roughness measurements conducted by WG3/TC256 of CEN. The document is currently at the very end of the enquiry process and should be submitted to the formal vote in Q4 2018. A publication is expected by mid 2019.
With the adoption of the methods and procedures that have been described, acoustic wheel roughness measurements have proved to be reliable and accurate.

References

[1] EN 15610 Railway applications - Noise emission - Rail roughness measurement related to rolling noise generation; EN 15610:2009

[2] prEN 15610 Railway applications - Noise emission - Rail and wheel roughness measurement related to rolling noise generation; prEN 15610:2017

[3] ACOUTRAIN, Virtual certification of acoustic performance for freight and passenger trains, D2.4 Proposed analysis method for wheel roughness, 07/11/2012

[4] DINGS P.C; DITTRICH, M.G.: Roughness on Dutch railway wheels and rails, Journal of Sound and Vibration, (1996) 193(1), 103-112, November 1995

[5] EICHENLAUB, LUTZENBERGER, STEGEMANN, CZOLBE; A road test on acoustic wheel roughness measurement, Internoise 2017 Hamburg

[6] GALEITSIS. A.; BENDER, E.; Wheel/Rail Noise – Part V: Measurement of wheel and rail roughness. J. Sound Vibrat. 1976, 46 (3) pp. 473–451

[7] GUTMANN. C., LUTZENBERGER, S.; Practical aspects of acoustical wheel roughness measurements, AIA-DAGA. Meran, 2013

[8] GUTMANN. C., LUTZENBERGER, S; Aspekte der Datenverarbeitung bei Radrauheitsmessungen. DAGA, Oldenburg, 2014

[9] JONES. C.;FODIMAN, P.; LÉTOURNEAUX, F.; CROFT, B.; Testing the new acoustic rail roughness measurement standard, Notes on numerical fluid mechanics and multidisciplinary design. Springer Verlag, Vol. 99, 2008

[10] Manual wheel roughness measuring device m|wheel, Müller-BBM Rail Technologies

[11] SQUICCIARINI. G.; TOWARD, M. JONES, C.; THOMPSON, D.; Statistical description of wheel roughness. In: Noise and vibration mitigation for rail transportation systems. Springer Verlag, 2015

[12] VERHEIJEN E., A survey on roughness measurements, Journal of Sound and Vibration, 293 (2006) 784-794, 9 March 2006

[13] CEN/TR15874 Railway applications — Noise emission — Road test of draft standard for rail roughness measurement prEN 15610:2006