Roughness measurements — Have the necessities changed?

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Abstract

Roughness of the running surfaces is the predominant source of noise of tracked transport systems in the major speed range applicable today.

It is therefore crucial to be capable of reliable measurements of the roughness of rails and wheels. In the past the incentive was the understanding of corrugation growth and the understanding of rolling noise generation. Initiated by Deutsche Bahn the RM1200E rail roughness measurement device was available in the early nineties of the last century and has since then gained a good reputation in the scientific community.

Recently the standards for measuring sound levels inside rail vehicles and pass-by levels of rail vehicles have been published on an European level. They require that the level of roughness of the test track is known. Furthermore Trans European rail networks have been defined, requiring technical specifications for interoperable, border-crossing vehicles, running in several countries. These specifications include noise limits, referring to the methods defined in the new standards. To allow for unambiguous results the knowledge of the roughness of the rolling surfaces is crucial.

Based on these developments in standards and specifications, the paper wants to address the requirements for roughness measurements and for the data evaluation involved. It will focus on the scientific and practical experience of the past as well as on the present necessities, specifically those derived from regulations on a European scale. Based on these requirements, practical consequences for roughness measuring devices will be derived.

1. Introduction

It is well accepted, that rolling noise is the predominant source of noise of operating tracked transport systems in the major speed range from approximately 60 km/h to 250 km/h. In the lower speed range machinery noise is dominant and for the high speed trains at high speeds aerodynamic noise becomes prevalent. The excitation mechanisms have been studied and simulation models have been developed [1][2] and are accepted tools in scientific and engineering work.

An important contribution to this research and development work was the development of a device to measure the roughness of the running surfaces of wheels and rails in the magnitude and wave length range necessary for acoustical questions in the late 1980ties [3]. In addition to the necessities of the noise research the need for the advanced study of corrugation growth had been an incentive for German Federal Railways (DB AG) to support the development of the measurement device RM1200E, which was based on the structure of a mechanical corrugation measurement recorder.
2. State of the art

The RM1200E, which is widely used in the railroad acoustics community, allows the measurement of the roughness of a length of 1200 mm of rail surface on one line at a time with a discretization of 0.5 mm. The measurement principle is a straight edge with a relative displacement transducer. The resolution of the original transducer is better than 1 µm resulting in a resolution in the wave length one-third octave spectra of approximately –20 dB re 1 µm. Figure 1 shows the influence of the measurement range of the transducer system on the noise floor measured on the calibration stone. For practical reasons it is desirable to use the setting with a higher displacement (similar to line A in the graph) as otherwise a signal overload may occur frequently due to vertical misalignment of the instrument.

![Figure 1. Influence of measurement range on noise level: A ± 2.5 mm, B ± 0.1 mm, measured with the RM1200E.](image)

The basic evaluation algorithm comprises a correction using the calibration data derived from a measurement on a calibration stone, a Fourier transform including windowing and a summation to one-third octave band spectra. The resulting one-third octave spectrum includes values for wave lengths up to 10 cm due to the requirement that a minimum of three lines in the FFT spectrum should be available for summing up the band value. Theoretically a value for the wave length of 120 cm is available in the FFT spectrum, however the statistical uncertainty for such a value is rather high compared to the values based on averages as for the shorter wave lengths.

Measurement experience showed that frequently raw data did contain spikes or pits caused e.g. by surface irregularities too small for a wheel to “see” on the rail or by dust build-up on the point of the sensor. These spikes or pits result in a broad banded spectrum hiding the desired results. To improve the situation the measurement data has to be corrected to remove these effects. The concept was first published in [4]. Figure 2 shows example spectra for two cases with and without pits and spikes correction.
Meanwhile several “pits and spikes removal” algorithms are in use in the research community developed by different users of the instrument (DB AG/Müller-BBM, SNCF, AEA-TR). A comparative benchmark has been carried out in the AEIF/EC project NOEMIE, which showed that a reasonable comparability is achieved for low roughness rails, but not for those with high roughness. As the low roughness rails are the important ones this was considered satisfactory. The underlying concepts vary greatly, from the practical approach of defining limits for certain geometric and derivative properties, including user intervention and manipulation, to the automatic model calculation based on an imaginary wheel checking the surface geometry and thus defining a filter for the suppression of the pits and spikes.

Based on the experience with the RM1200E a wheel roughness device RMR1435 was built, which uses the axle bearing as a reference point for turning the wheel round. Due to this fact the precision of the results is lower than for the rail instrument, as the roughness measured includes the unroundness of the bearing and axle construction. The data evaluation algorithm is similar to that for rail roughness; in addition to the one-third octave spectra the so-called wheel harmonics are extracted from the FFT spectra, attributing a value to the unroundness (first FFT line) and the following n-th order polygonisation of the wheels.

British Rail Research and its successors have been using an acceleration measurement based trolley system for rail roughness measurements which was further advanced, used and offered by Grassie as CAT. The advantage of the system is the ability to measure unlimited length sections, the draw back is the need for double integration from acceleration to displacement to arrive at the desired quantity needed to calculate the one-third octave roughness spectra. Another so called TRM system is offered by ODS. The system is based on a 1200 mm straight edge principle similar to the RM1200E.

3. Necessities

Fifteen years ago the need for roughness measurements on rails was of pure scientific nature. Today the importance of the knowledge of the source quantity “roughness of the running surfaces” is widely accepted. The roughness of rail and wheel running surfaces used to be acknowledged as influential on the sound creation, but had nevertheless only been verbally described with attributes.
like “very smooth”, “not corrugated”, “heavily corrugated”, etc. after subjective visual inspection by the responsible measurement team.

With growth of experience about roughness excitation the necessity to establish values for the qualitative characterization of rail and wheel running surfaces, especially in the context of e.g. type testing, was acknowledged. Therefore the two draft ISO standards 3095 [5] and 3381 [6] included the measurement of rail roughness and a limit spectrum not to be exceeded for type testing (see Figure 4). The measurement method described in the standards is based on the available 1200 mm straight edge devices and asks for the measurement of one to three traces depending on the width of the running band at six positions defined by the distance of the microphone from the track as shown in Figure 3.

![Diagram showing measurement method according to ISO 3095](image)

Fig. 3. Position of traces according to ISO 3095 [5]

The idea behind the limit spectrum is to insure that the contribution of the track to the sound creation on interior and pass-by sound is small compared to the vehicle contribution. This approach insures that the vehicle manufacturers have the noise creation under their control and the responsibility in case of exceeding of limit values described in technical specifications for the order of the vehicle are clearly defined. Furthermore it facilitates the reduction of legal limits, as the trackside noise has to be treated separately with the networks.

Within the scope of the development of the European high-speed network the technical specifications regarding interoperability of systems were defined (TSI-HS [7]). For conventional traffic a proposal of the AEIF Noise Expert Group is currently prepared (TSI-CR [8]). Concerning the roughness measuring method TSI-HS and TSI-CR refer to ISO 3095. In the TSI-HS the curve labelled TSI in Figure 4 is asked for, whereas in the TSI-CR the curve labelled ATSI was proposed. The definitions for the TSI-HS and CR limit curves are still under discussion and the latest proposal is a compromise of TSI and ATSI called TSI⁺ as shown in Figure 4.

The definition of the limit curves poses demands on the measurement technology concerning the precision necessary and the wavelength range to be measured. The noise floor of the instrument should be 3 dB or more below the limit curve to be compared with. A comparison with Figure 1 shows that this is achievable with available instrumentation.

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Fig. 4. Limit roughness spectra according the ISO standards 3095 (and 3381) and according to the European technical specifications for interoperability TSI-HS and TSI-CR.

The wavelength range necessary depends on the frequency range to be considered and the speed of the vehicles. Table 1 shows the evaluation of the formula $f = v / \lambda$ for relevant speeds $v$, wavelengths $\lambda$ and corresponding frequencies $f$.

Tab. 1. Relation of frequency $f$ for selected wave length $\lambda$ and train speed $v$

<table>
<thead>
<tr>
<th>$\lambda$, cm</th>
<th>80 km/h</th>
<th>160 km/h</th>
<th>240 km/h</th>
<th>320 km/h</th>
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<td>11</td>
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<td>25</td>
<td>89</td>
<td>178</td>
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<td>356</td>
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<td>178</td>
<td>356</td>
<td>533</td>
<td>711</td>
</tr>
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<td>705</td>
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<td>2123</td>
<td>2831</td>
</tr>
<tr>
<td>1.6</td>
<td>1389</td>
<td>2778</td>
<td>4167</td>
<td>5556</td>
</tr>
</tbody>
</table>

As the measurement of longer wave lengths poses problems, at least with the straight edge instruments, thought should be given to the definition of the upper limit of the wave length range for which the roughness of the test track is defined and thus has to be measured. A simple straightforward approach is to use available sound measurements and test for the sensitivity of the A-weighted overall sound pressure level for the lower frequency limit using the following calculation:

$$\Delta(f) = \sum_{f=20kHz}^{20kHz} L_{pa}(f) - \sum_{f=f_j}^{20kHz} L_{pa}(f)$$

with the difference $\Delta(f)$ for frequency $f_j$ of the A-weighted one-third-octave band sound pressure levels $L_{pa}(f)$. For high speed trains it was found that frequencies under 500 Hz do typically only add less then 0.5 dB to the overall level.

Additional information can be gained from a calculation based on the following roughness sensitivity definition: Assume we do not control the roughness over a certain wave length, what will an increase of roughness (and consequently also sound) in a single one-third-octave band show for an effect in the A-weighted overall sum. For high speed trains it was found that a 6 dB roughness
error in one one-third octave band will typically give less than 0.5 dB change for frequencies below 500 Hz; for a 10 dB error the frequency range below 250 Hz shows changes of less than 0.5 dB. It can therefore be deduced that for high speed trains the knowledge of wave lengths up to 25 cm are desirable, whereas for conventional rail wave lengths up to 10 cm were adequate.

As already described above, the wave length range measured is limited to 10 cm due to the length of the measurement device and the evaluation algorithm for the 1200 mm straight edges. To allow for longer wave lengths the RM1200E includes an angle sensor measuring the inclination of the instrument’s longitudinal axis. For data traces measured overlapped by approx. 200 mm it is then possible to concatenate these traces using correlation techniques and estimate values for the longer wave lengths. Figure 5 shows such data from the RIM validation campaign [2] for 20 concatenated traces together with the data evaluated using the standard method for shorter wave lengths. A comparison of the data derived in that way with data measured in a track measurement car for wave lengths around 5 m and more shows a good correspondence.

![Figure 5](image)

Fig. 5. Roughness spectra measured on a smooth track (---) and on a corrugated track ( . . . ), for wave lengths above 12.5 cm evaluated using concatenation.

The above described procedure has also been used by AEA-TR and is included in an extended measurement procedure described in documents from the STAIRRS project by AEA-TR.

4. Standardisation

Concerning the topic of roughness measurements of rail and wheel running surfaces only ISO 3095 (and identically in 3381) are available. In these standards only the measuring positions relative to the microphone (see Figure 3) using the 1200 mm straight edge and a procedure to allow for some exceeding of the limits for single result spectra are mentioned. No description is given for the measurement method nor the evaluation method nor the calibration of the equipment.

Currently requirements for standards concerning these issues are under discussion, the respective development of such standards is to be expected in the near future by CEN and should be used to advance certain issues.
5. New development (Müller-BBM’s mbbmRM1200)

Based on the experience of more than 10 years of measurements with the RM1200E and the frequent need for more measurements a successor device to the RM1200E has been developed. Due to practical size and weight limitations the measurement length was kept at 1200 mm as well as the discretization of 0.5 mm. Additional features however have been added to facilitate the use of the new mbbmRM1200. The instrument is able to automatically measure a set of traces equidistantly spaced across the rail head in one clamping position. Due to the integration of a PC into the device it is possible to view the resulting data directly while measuring as displacement trace and as one-third octave spectra on completion of all traces on the radio connected PDI panel which is used as system pad to control all activities of the device. For ease of positioning in lateral direction a laser pointer has been added, as well as a tail wheel for longitudinal placing. Apart from the controlling PDI panel the device is self-contained including the power supply.

Fig. 6. New mbbmRM1200 rail roughness measurement device on a test track

5. Conclusions

The measurement of roughness of running surfaces has become more important in the last decade outside of the scientific field as the standards for interior and pass-by sound measurements as well as the new European TSIs call for knowledge of the surface roughness. It is therefore desirable to improve the device allowing easier handling for multi-trace measurements. The main wave length range needed for conventional speed can be covered by the 1200 mm straight edges in use, although there is a necessity for the extension above 10 cm using a concatenation procedure which should be defined and used for high speed tracks.

References


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