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Road and Rail Infrastructure II

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RAIL ROUGHNESS MEASUREMENT AND ANALYSIS IN FRAME OF RAIL VEHICLE PASS-BY NOISE MEASUREMENTS

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Abstract

Railway rolling noise emerges from combination of wheel and rail surfaces roughness. Previous researches evaluated roughness of running surface as the main cause of railway vehicles noise from 60 km/h up to 250 km/h running speed. As an example, rail welds or local irregularities on rail running surface may cause an increase of noise up to 4 dB(A) for the same running speed. Railhead roughness therefore became important parameter in order to conduct typical vehicle passing-by noise measurements. Within European Union's strategy for harmonization of internationally running train services where developed new standards, as EN ISO 3095 or TSI-Noise, to set limits on the noise emitted by individual rail vehicles. Their requirement is "roughness level test" performed on a 'reference track' to confirm its influence on external passing-by vehicle noise.
This paper describes standard rail roughness measurement procedure on 'test sections' selected in order to determine passing-by noise of a new low floor EMV train constructed by Končar – Electric Vehicle for Bosnia and Herzegovina Federal Railways. It is mainly concentrated on measured data analysis according to European standards. Rail roughness with a broad spectrum of wavelengths is always present on the running surfaces of the rails and it has been shown that there is a high dependence between the amplitude and the wavelength of the roughness. Therefore, according to the standards above, measurements have been preformed with device that measures wavelengths from 0.1 up to 0.63 m. The track quality had to satisfy a rail roughness limit set by EN ISO 3095 based on one-third octave bands. Collected data needed to be filtered and grouped for further evaluation. The result of that spectral analysis is presented as a spectrogram which determined tested section as valid for further typical pass-by noise measurements.

Keywords: rail roughness, measurement, spectral analysis, rail vehicles

1 Introduction

In 1996 an estimated 20 % of population of Western Europe lived in the area with ambient noise levels over 65 dB, and over 60 % in the area with noise levels over 55 dB. These facts led to several reactions, by public as well as experts throughout Europe, which resulted in joined effort of member countries in forming unified policy on noise in the environment.
Environmental Noise Directive (END – directive 2002/49/EC) [1] issued in July 2002. Directive has a clear approach to environmental noise issue and requests prevention, avoidance and mitigation of harmful environmental noise effects. Basic requirements of the directive are synchronizing the procedure of noise mapping and noise maps themselves, determining total number of residents exposed to excessive noise levels and informing the public and European

Commission on the current state and financing of noise management measures. For railway authorities and infrastructure management systems, noise mapping and action plans imply having to evaluate the means of reducing the railway traffic noise to acceptable levels. Since unified method has not yet been established, European commission has adopted interim guidelines [2] for railway noise map generation based on Dutch RMR, until a unique method is developed under projects Harmonoise and Imagine.
Regardless of the method for determining the exposure of surrounding population to elevated noise levels, efficient and quality solutions for noise mitigation have to be based on detailed analysis of all the elements that produce the noise. Railway borne noise can be decomposed to several main sources such as engine noise, wheel rail interaction, and aerodynamics. Therefore it is possible to influence two critical emission elements: vehicles and infrastructure. Special problem arises when trying to determine the share of each noise emission element while conducting pass-by noise measurements. This is particularly obvious when testing newly constructed rail vehicles, which according to action plans on noise mitigation have to comply with the eligible standards. In the effort to precisely determine noise emission levels, when testing railway vehicles it is essential to determine the contribution of each noise emission source to the overall noise levels. This procedure, beside standard pass-by noise measurements, requires additional measurements such as rail surface roughness measurements which are covered by this paper.

2 Rolling noise

Rolling noise is noise originated at the wheel-rail interface. From the definition itself, it is clearly visible that the mentioned noise is cause by irregularities that appear both on a wheel and rail running surface. It is therefore almost impossible to examine this issue from the aspect of just one component, but with today's knowledge it is possible to determent the contribution of each component in the overall rolling noise with high accuracy. Regardless of the component that contains irregularities, they significantly increase vibrations of the moving vehicle, and can often cause elevated noise levels in the environment. Previous researches evaluated roughness of running surface as the main cause of railway vehicles noise from 60 km/h up to 250 km/h running speed, [3]. Rail roughness with a broad spectrum of wavelengths is always present on the running surfaces of the rails and it has been shown that there is a high dependence between the amplitude and the wavelength of the roughness, [4]. Researches indicate that the variance in rail roughness can influence the railway vehicle pass-by noise level up to 20 dB(A). Railhead roughness therefore became important parameter in order to conduct typical vehicle passing-by noise measurements according to EU standards and directives. [4, 5]

3 Rail roughness measurements

Generally, methods for measuring rail running surface roughness can be divided into direct and indirect. Indirect methods are based on measuring vibrations induced by wheel-rail interaction. Shortcoming of this method lays in the fact that it is quite difficult to distinguish vibrations induced by wheel irregularities and rail running surface roughness. Additional shortcoming of indirect roughness measurements is the need of installing expensive equipment on the existing measuring vehicle or acquiring a new measuring vehicle. This measuring method, usually preformed using accelerometers fitted to vehicle axel, can acquire data on irregularities of higher wavelength opposed to direct measurement method which gather data on irregularities of shorter wavelengths. Therefore they are suitable for measurements on high-speed railway tracks. Data gathered by indirect roughness measurements can vary up to 3 dB(A) in spectral analysis, as a consequence of rough differentiation between vibration caused by wheel or rail imperfections.

In common engineering practice there are four possible reasons for conducting rail roughness measurements:
· test track measurements with the purpose of conducting pass-by noise tests,
· determining the need for rail grinding,
· determining the state of rail surface as an input for noise map calculation,
· roughness growth monitoring.

Direct roughness measuring method is conducted using mobile transducer based measuring instruments. Due to slow pace of the measuring procedure (measurements are usually taken repeatedly on ~1 m long stretch of track) it is not suitable for evaluation of large railway network segments, but for shorter test sections. Due to greater accuracy (estimated maximal error of 1 dB(A)) direct method is appropriate determining the influence of rail roughness on overall noise levels when conducting pass-by noise measurements. This method will further be elaborated in the scope of this paper. Namely, within the European Union's strategy for harmonization of internationally running train services new standards and specifications such as EN ISO 3095 and TSI-Noise [4, 5] have been developed, in order to set limits on the noise emitted by individual rail vehicles. They elaborate test section measurement procedures, requirements for measuring instruments and data processing.

3.1 Measurement procedure

Type noise measurements of railway vehicles have to be conducted on a referent test track in order to eliminate the influence of different irregularities that could affect noise measurement outcome. However, if such test track is not available, it is possible to perform the measurements on a railway track in exploitation if it meets the required condition of geometrical configuration, surrounding environment, rail roughness etc. described in [5].

A 100 m long test section has been indentified along the Vrpolje – Ivankovo railway line. This section has been chosen by its geometry features that would enable typical pass-by noise measurements of a new EMV ŽFBH 4412 made by Končar Electric Vehicles [7] at speeds of up to 160km/h. Standard track geometry measurements according to [8] have been conducted on the test section resulting with valid track geometry (average track gauge of 1433.11 mm and cant of 1.09 mm).

According to [5] the test section complies with the described conditions: measurements shall be made with ballast bed and wooden or reinforced concrete sleepers, the track shall be dry and not frozen, the tests shall be done on a rail section and sleeper design in common use on the particular railway network, the level gradient at the track shall be 3:1 000 at the most and the radius of curvature r shall be › 5000m (v › 120 km/h), Figure 1.

Figure 1 Test section on Vrpolje – Ivankovo railway line with tested EMV

The track at the measuring section also had to be laid without rail joints (welded rail) and free of visible surface defects such as rail burns or pits and spikes caused by the compression of external material between wheel and rail: no audible impact noise due to welds or loose sleepers should be present. It had to be clear of any reflecting surfaces such as buildings or fences in the near vicinity. Direct roughness has been measured along the whole section of 100 m to gather as much data for further analysis and comparison. Instrument used for measurements was RAILPROF 1000 (Figure 2). The instrument logs the data on 1 m long sections so it took total of 400 measurements to cover the 100 m long section of a double-track railway line.

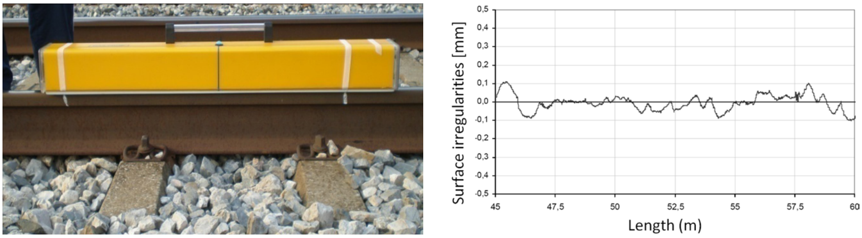

Figure 2 Measuring instrument RAILPROF 1000 and raw data output

Further data analysis has been performed on data extracted at these measuring locations suggested by [5] in respect to the position of pass-by noise measuring instrument. In total 24 measurements (12 per track) have been extracted for further analysis.

4 Rail roughness data analysis

Data acquired by direct roughness measurements represents the running surface of the railway track measured at the distance of 0.5 cm from each other (200 measuring points per 1 m). Since measurements of rail roughness have been conducted with 1 m long measuring device, wavelengths up to 0,1 m have been taken into account according to [5]. In order to determine roughness levels the data processing has been accomplished using MATLAB programming environment. The analysis process itself is composed out of two steps: (1) removing the peaks from the raw measured data and (2) spectral analysis of the data.
High peaks which do not influence the actual wheel-rail interaction had to be removed prior to spectral analysis because they can influence the spectrum and lead to conclusion on inappropriate running surface. Several techniques have been suggested for non linear filtering which basically differ in the shortest spectrum wavelength, [9], [10]. Used technique consisted of local smoothing with weighted linear least squares and first degree polynomial. It is important to note that peak removal techniques are still not standardized and represent the area of intensive research.
The goal of the spectrum analysis is representing measured data in a form similar to noise measurement results. General idea is to decompose the signal to frequency bands interesting for the analysis. Commonly used method for data representation is one-third octave power density spectrum. The spectrum analysis can be performed by applying Fourier transform or band filtering representing the data in one-third octave ranges according to standard [11]. Butterworth filters, continued according to the standard, have been used with central frequencies determined according to [12], Figure 3.

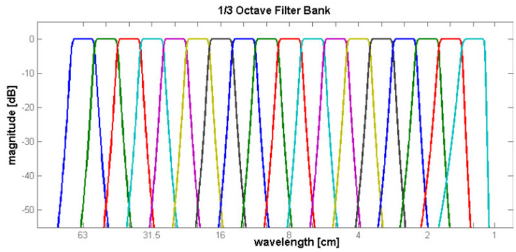

Figure 3 Spectral characteristics of the filter bank

Designed filter bank has been used for decomposition of original roughness signal to frequency ranges of certain width. Equivalent mean values of the output signal of each filter represent the absolute level of roughness for each one-third octave with central wavelength of l, expressed as:

$$r(\lambda) = \sqrt{\frac{1}{n}\sum\nolimits_{k=1}^{n} r_k(\lambda)},$$

where n is the number of samples and rk (l) the sample at the filter output that corresponds to wavelength l. To compare the data to limits set by [5], logarithmic values have been calculated for each wavelength Lr (l) in dB according to expression:

$$L_r(\lambda) = 10\log\left(\frac{r(\lambda)}{r_0}\right)^2,$$

where ro = 1 μm of reference roughness.
Final results of spectral analysis are shown in the following figure for each railway track. In respect to the standard limits the southern railway track can be evaluated as valid for further typical pass-by noise measurements, Figure 4.

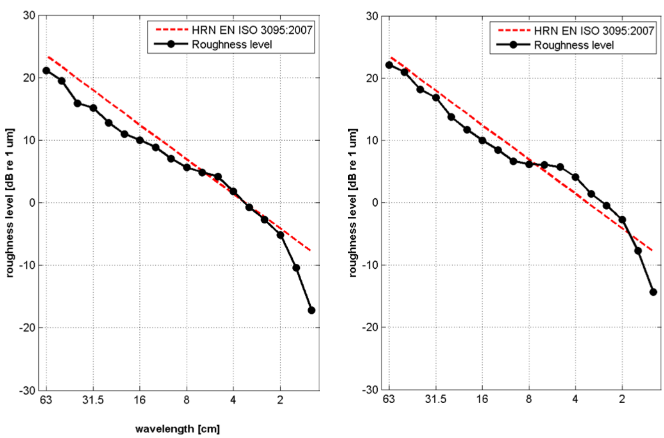

Figure 4 Results of spectral analysis of both railway tracks at the test section (southern on the left and northern on the right)

5 Conclusion

Dominant component of railway born noise is the noise produced by wheel-rail interaction at the operation speed of 50 to 250 km/h, [3]. Track maintenance is a crucial component of safe and reliable railway network operation. By measuring and evaluating rail surface roughness it is possible to perform on time rail grinding achieving cost saving and smooth operation of the railway network.

For the purpose of typical noise measurements of EMV ŽFBH the reference track on Vrpolje – Ivankovo railway line has been analysed. From the aspect of track geometry, both northern and southern tracks have been evaluated as suitable for typical pass-by noise measurements. However, from the aspect of rail roughness, only the southern railway track has been declared suitable for the mentioned noise measurements.

This kind of roughness measurements and analysis procedures are required for all the railway sections selected for typical noise measurements, whether they are being used for testing new or existing railway vehicles and equipment.

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