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ANALYSIS OF RAIL ROUGHNESS ON TRAMWAY TRACK

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Abstract

Rail corrugation is an irregularity that often occurs on a railhead running surface and can cause an increase in the noise and vibration levels as well as faster track deterioration. The possibilities of direct and indirect rail corrugation measurements are described in this paper as well as direct rail corrugation measurement that was carried out on a tramway track network in the city of Zagreb. Railhead corrugation was measured on several locations on the tramway track and the values were analysed with respect to the exploitation period of the tramway sections and the type of horizontal alignment. Analysis has shown that rail corrugation occurs more often in the curves than in the straight track and that the wavelength and amplitude of rail corrugation are higher on tramway track that has longer exploitation period. The conclusions of this paper are as expected, but as a next step towards automating the rail corrugation data analysis, the indirect measurements model is tested with the purpose of application on the whole tram track network using tramway vehicle monitoring.

Keywords: tramway vehicle; track; rail corrugation; measurement; rail irregularities

1. Introduction

Rail running surface subjected to dynamic traffic loading can develop unevenness or corrugation of the running surface. It can cause elevated vibration levels in vehicles, railway track and its's surroundings as well as speed up the degradation of the track components and railway vehicles [1]. Such phenomenon can also be described as rail surface acoustic roughness if it contributes to elevated noise levels of rail vehicles in operation. Detection of these irregularities is very hard using only visual inspection of the track, especially in the early phase of corrugation development, and additionally requires sophisticated measurement methods and rail track occupation. Furthermore, grinding as a method for corrugation removal does not prevent the rail corrugation to reappear after it has been exploited for some time [2]. For that reason, monitor of rail corrugation development is proposed in controlled environment and to define the parameters that have an impact on its increase [3]. Rail corrugation can be measured directly (using manual measurement devices, directly on the track) or indirectly (using a railway vehicle equipped with an inertial measurement system) [4]. In [5], the authors describe the development of a measurement trolley for continuous measurement of the railhead surface roughness (direct measurement) with which data connected to the appearance of corrugation mechanisms was collected. As a result of the analysis, with the help of the rail corrugation measurements that were conducted using a corrugation measurement trolley (CAT) in a combination with a portable device for corrugation monitoring (that was installed on a railway vehicle), an efficient grinding management method was developed to optimise and reduce the costs of maintenance.

The use of railway vehicles with inertial measurement system (accelerometers) opens several possibilities for irregularities and damage detection on the rail track, such as rail breakage, poorly executed welds, isolated joints, and rail corrugation and acoustic roughness [6]. A mathematical model that was built as part of the study [1], predicts an increase of the corrugation and optimization of the rail grinding schedule, thereby increasing the efficiency of the method and as a result, represents a significant reduction of the rail track maintenance costs. The study confirmed that functions of the behaviour curves (growth) of corrugation over time can be modelled using the rail roughness measurements over a longer measurement period. Vibrations and dynamic forces generated by wheel – rail contact contains the most important information used to assess the rail track condition and predict the behavior of damage and irregularities on the track, to ensure a high degree of efficiency for such methods.

Considering the research of wheel – rail contact, two different indirect measurements of vibration on the track can be used: mounting the sensors on a railway vehicle bogie to monitor the rail or/and installing the sensors on a rail for wagon monitoring. As a part of the MaVico project [7], a system prototype for rail corrugation monitoring was developed to prevent the consequences that corrugation can have on the rail track and wagon equipment. Algorithms were made based on acceleration measurements on the bogie used to determine the state of rail corrugations, which showed satisfactory results of rail roughness measurements using the indirect method, compared to the classic, direct measurement method (using corrugation measurement trolley). The described system for indirect measurement of rail roughness can measure more than 100 kilometres of railway track in one day, while measurements on the same railway section using the direct method would last for several weeks [8].

This paper aims to present the data of railhead surface corrugation measurements using the direct method with the purpose of measured corrugation data analysis automatization in future research using the indirect method of rail roughness measurements and the possibility of applying the method on the whole tramway track network using monitoring on tramway vehicles.

2. Rail corrugation measurements on tramway tracks in the city of Zagreb

The first part of the research contains direct (manual) railhead corrugation measurements on the Zagreb tram track network. Railhead corrugation was measured according to HRN EN 15610 “Railway applications – Acoustics – Rail and wheel roughness measurements related to noise generation” standard [9], using the device for railhead corrugation measurement (Fig. 1d) which enables measurement of waveforms with wavelength between 1 and 40 centimetres. After the measurement, analysis of the results was made according to the mentioned standard because it gives a more detailed insight in the railhead corrugation wavelengths than the standard HRN EN 13121-3 “Railway applications - Track - Acceptance of works - Part 3: Acceptance of rail grinding, milling and planning work in track “ [10]. Measurement of railhead corrugation was carried out on Zagreb tramway network at locations: Horvaćanski zavoj (location L1, Fig. 1a), Horvaćanska street – Hrgovići street (location L2, Fig. 1b.), and at the intersection Horvaćanska street – Hrvatskog sokola street (location L3, Fig. 1c.), on both tramway tracks with a total of 54 measuring points (Table 1).

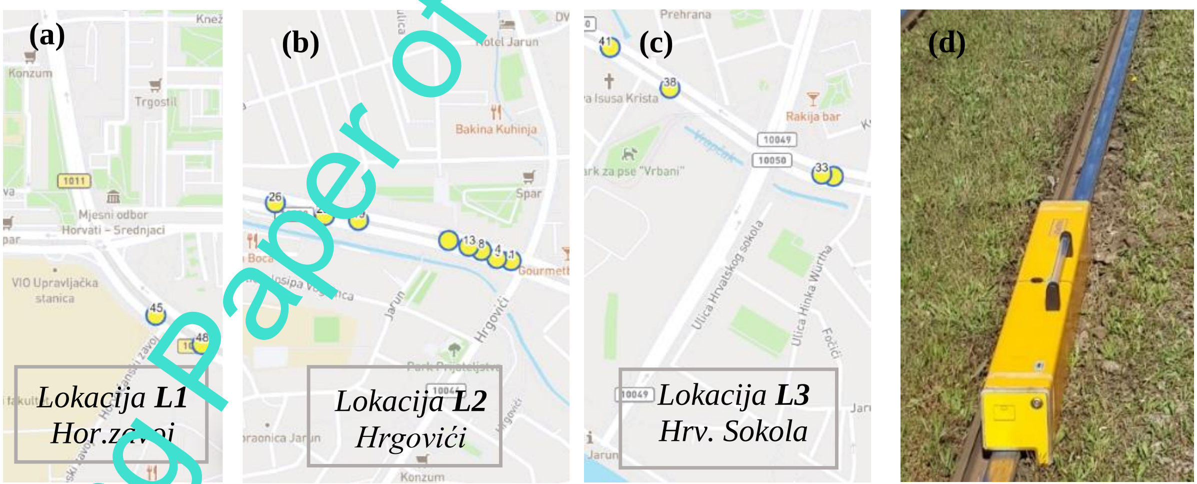

Fig. 1. Locations of railhead corrugation measurement (a, b, c) and manual device for rail roughness measurement (d)

The locations were chosen based on the visual inspection of the track, during which corrugation was noticed. Following the visual inspection, increased levels of vibration and noise were detected near the tram track. Additional criteria selection of the locations was various exploitation time of the rails on the observed locations, various fastening systems, and geometrical elements of the track (straight line and curve) to cover as many track and rail parameters as possible that could be analysed. At each of the locations (L1, L2, and L3), measuring points were located both in a straight line and in a curve which should additionally contribute to the analysis related to the geometrical elements of the track. After the measurements, result analysis was made with the aim of a qualitative evaluation of the railhead corrugation and a comparison regarding different parameters of the track.

Location	Year of reconstruction (exploitation)	Fastening system	Measuring point	Radius	Rail
L1	2017 (4)	PPE	**MP 1**	straight line	-
			MP 4	348 m	outer
			MP 7	348 m	inner
L2	2004 (17)	DEPP	**MP 2**	straight line	-
			MP 5	1025 m	outer
			MP 6	straight line	-
			MP 8	1025 m	inner
L3	2000 (21)	DEPP	**MP 3**	straight line	-

Table 1. Overview of measurement locations, measuring points, and their characteristics

3. Results analysis

Measured values of the railhead corrugation were analysed, and their amplitudes (dB re 1µm) and wavelengths (cm) were processed using Fourier transformations and presented in third-octave frequency bands with wavelengths between 1.25 and 40.0 centimetres, following the standard [9]. The occurrence and properties of the rail corrugation were analysed depending on the parameters that have an influence on the corrugation. Those parameters include the horizontal position of the track (straight line or curve), the size of the radius of the curve, and the position of the rail to the central axis (outer or inner rail). In the graphs below, along with the analysed railhead corrugation, a limit curve according to the HRN ISO 3095 "Acoustics – Railway applications – Measurement of noise emitted by rail bound vehicles" [11] standard is presented. According to the standard, values of railhead corrugation that are below the defined limit will not have an impact on the overall noise level of a passing rail vehicle, while the values above the limit will have an impact on noise levels. Rail corrugation wavelengths (in centimetres) are shown on the horizontal axis of the graph, while the amplitude values (in decibels, with the referent value of 1µm) are shown on the vertical axis. The basic comparison of the railhead corrugation is made for three different sections (L1, L2, and L3), analysing the exploitation period of the track.

3.1 Railhead corrugation and exploitation period

The time-dependent form and development of railhead corrugation are being inspected with the analysis. It is important to emphasize that all the locations are situated on the same tram track section, so the traffic volume is proportional to the exploitation period. Railhead corrugation of the track in a straight line on locations L1 (MP1), L2 (MP2), and L3 (MM3) are displayed in Fig. 2. On the section which has the longest exploitation time (L3, MP3), a higher number of expressed corrugation patterns at wavelengths λ = 2cm, λ = 4 cm and λ = 8 cm appeared.

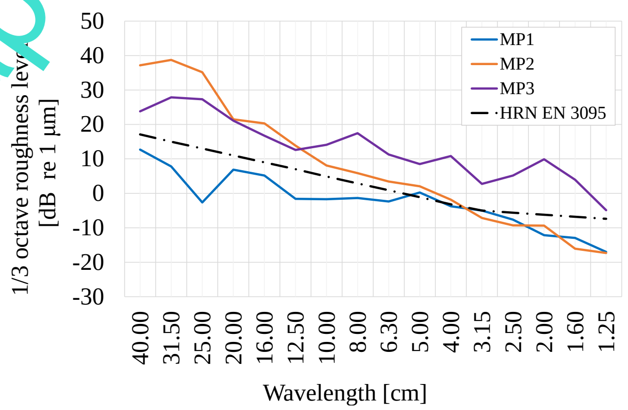

Fig. 2. Railhead corrugation comparison considering the exploitation period

On location L2 (MP2), dominant corrugation wavelengths were from 25 to 40 centimetres (with the highest amplitudes a = 38.7 dB for λ = 31.5 cm. Considering the short exploitation period on location 1 (L1, MP1), there was no railhead folds with dominant wavelengths spotted.

3.2 *Railhead corrugation and horizontal track alignment*

Outer rail railhead corrugation was analysed for different curve radii R = 348m (L1, MP4) and R = 1025m (L2, MP5) (Fig. 3.) in comparison to railhead corrugation for track in a straight line at the same measurement locations (L1, MP1 and L2, MP6). With this kind of analysis, it is noticeable that a significant corrugation difference is present with the smaller radius curves as opposed to the corrugation on tracks in a straight line. On the outer rail track with the smaller radius (MM4, R = 348m), a few dominant corrugation wavelengths were detected (λ = 25 cm, λ = 16 cm, λ = 4 cm), while on tracks with bigger radius (MM5, R = 1025m) only corrugation wavelengths around 25 cm with amplitudes a = 33.2 dB occur on the tracks. Looking at the rail track in the straight line, almost none of the corrugation wavelengths were dominant in location L1 (MM1), but at location 2 (MM6) there was a visible corrugation development, like the one in the curve with a big radius (MM5), with an additionally emphasized wavelength of 5 centimetres.

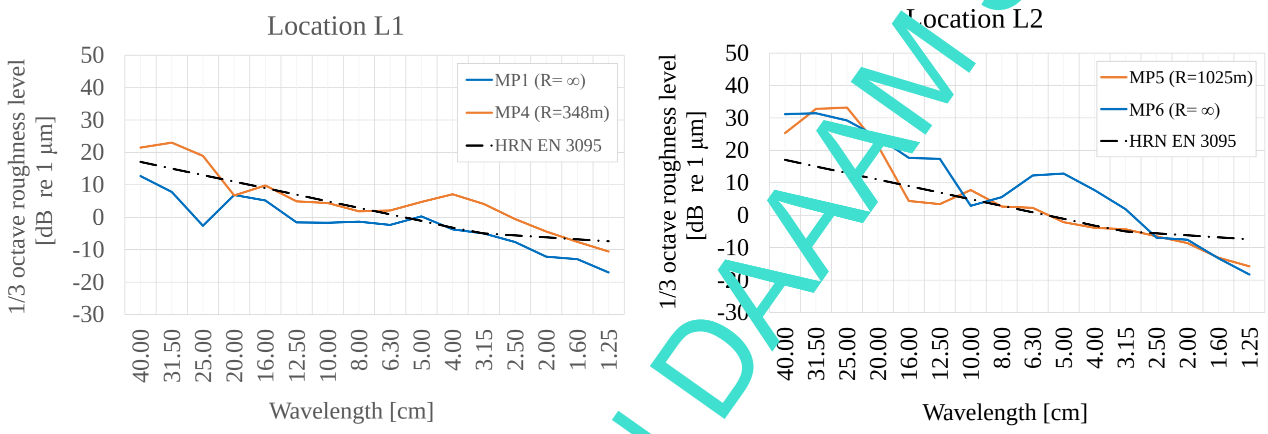

Fig. 3. Railhead corrugation comparison of outer rail in a curve and straight line on location L1 (a) and L2 (b)

It is also interesting to observe the corrugation difference between the inner and outer rail on measuring points in a curve because of the different effects of vehicle load coming from the impact of centrifugal force that is present during the circular motion. In Fig. 4., the railhead corrugation of the inner and outer rail for tracks with different curves radii (R = 348m, R = 1025m) is shown. Independent of radius size, bigger corrugation wavelengths were dominant in the 31.5 (a = 23 dB) and 25 centimetres (a = 33.2 dB) frequency bands on the outer rail (MP4, MP5). On the inner rail (MP7, MP8), shorter corrugation wavelengths from 5 to 10 centimetres with amplitudes a = 18.7 dB (for R = 1025m) and a = 12.7 dB (for R = 348m) were dominant. Bigger amplitudes occurred on the track in curves with bigger radii (which was not expected). The explanation for this could be the fact that the tram track at the location L2 (MP5, MP 8) has a longer exploitation period than the one at location L1 (MP4, MP 7) and the exploitation period parameter has more effect on the size of the amplitude than the radius size.

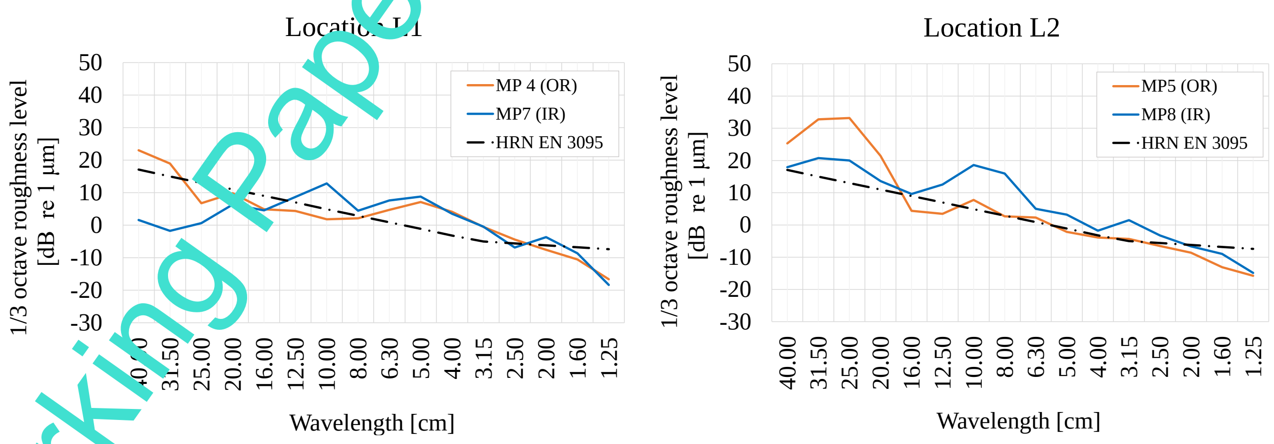

Fig. 4. Railhead corrugation of inner (IR) and outer (OR) rail in curves with different radii on locations L1 (a) and L2 (b)

3.3 Future research

The second part of the research implies the conversion of wavelengths (measured with direct railhead corrugation measurement method) into the frequency domain to make the values comparable to the vibration signal values recorded onboard an instrumented tramway vehicle (indirect measurement method). Finally, direct, and indirect measurement methods comparison would represent the basis for further research and making of the rail corrugation development assessment model (considering the amplitude and wavelength of the fold). That kind of model would serve for the development of optimal track maintenance (grinding) schedule and would be based on the indirect measurements using accelerometers installed on in-service tramway vehicle, which would represent not only a big step ahead and simplification of data acquisition (no need for manual (direct) measurement) but also additional financial relief for track maintenance and decrease of noise and vibration levels.

4. Conclusion

Observing the dependence of corrugation on the exploitation period, it is concluded that the number of dominant wavelengths will increase on the rail tracks with the increased exploitation period. In the case of curved tracks, it is noticeable that the radius size is inversely proportional to the corrugation development and that the corrugation development on the tracks with bigger radii is similar to the one recorded on the track in a straight line. Higher values of outer rail corrugation wavelengths are more dominant than those on the inner rail, and dominant wavelengths are not dependable on radii value. The results of direct measurements, which were carried out on 3 locations in the city of Zagreb according to the EN 15610 standard, will serve as the basis for corrugation detection using indirect measurement method and for further research on the correlation of indirect and direct rail corrugation measurement methods.

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