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EVALUATION OF RAIL IRREGULARITIES BY PROCESSING TRAMWAY VEHICLE BOGIE ACCELERATION DATA

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Abstract

Acceleration data on in-service tramway vehicles provides helpful information related to the track condition. It represents advantages in terms of measurement frequency, the elimination of the requirement for additional track occupancy for measurements, and the safety of operations on the track. However, the collected acceleration data must be further processed to provide more precise information on rail surface irregularities and defects. Detecting and evaluating irregularities from bogie frame acceleration requires extensive signal processing along with determining track, vehicle, and operational parameters. For more precise results and a better approach, the vibro-acoustic characteristics of the track, vehicle, and wheels should be investigated in more detail to create transfer functions, along with evaluating the condition of the rail and wheel roughness. This paper aims to investigate the current state of the art, as well as to present some preliminary measurements and analyses connected to this topic.

Keywords: *tramway track, bogie acceleration, transfer functions, signal processing, rail irregularities*

1 Introduction

Traffic noise and vibration are two variables that can have a significant impact on urban standards of living. It is therefore essential to find techniques that can successfully define sources of noise and vibration, determine their magnitude, and assess the possibility of reducing them [1]. The use of in-service vehicles to optimize vehicle and track maintenance has become a common procedure in many urban railway networks, and it has recently been implemented on the Zagreb tram network [2]. The purpose of this monitoring is to investigate the effects of tram-induced vibrations on nearby historic and earthquake-damaged buildings, as well as to identify rail irregularities and defects at the wheel-rail interface, which are one of the primary causes of noise and vibration on railway and tramway tracks [2, 3]. Rail corrugation and rail roughness can be measured directly on the rail running surface (direct measurements) [4, 5] or indirectly by deriving an acceleration (vibration) signal obtained from a rail-bound vehicle (vehicle-based indirect measurements) [6]. Direct measurements enable the separation of rail and wheel contributions and provide an absolute estimate of the roughness of the railhead running surface [7]. Meanwhile, indirect measurements focus on characteristics produced by the wheel-rail interaction, such as bogie area noise or vibrations of the wheelset [8, 9], using on-board sensors.

To evaluate rail irregularities and defects based on vehicle-based indirect measurements, several procedures must be carried out, including an assessment of vibration transfer from the wheel-rail contact point to accelerometers mounted on the wheel frame, as well as the robust wheel's characteristics [10]. The methodology of deriving rail roughness from indirect measurements implies using signal processing and various transfer functions dependent on vehicle, track, and operational parameters [11, 12]. In [7], a hybrid model for deriving rail roughness from noise and vibration signals was presented, with a basic idea of separating direct and indirect measurement methods as well as space and frequency domains.

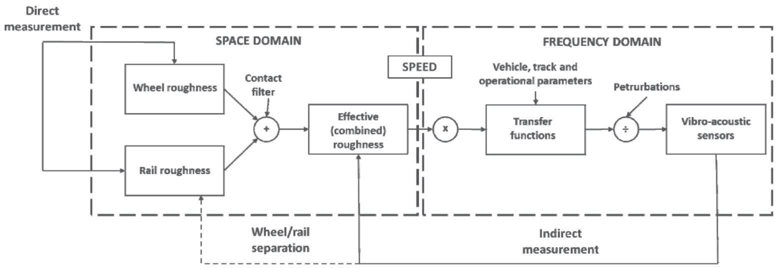


Figure 1 Simplified model of railway noise and vibration generation [6]

This paper provides an introduction to the topic, an overview of preliminary measurements made on the Zagreb tramway network with a final objective of deriving rail roughness data from vehicle-based indirect measurements, and some recommendations for future research.

2 Measurements

Following the methodology from the literature [8, 10, 11], various measurements were carried out on the tramway track network in the city of Zagreb, with the final goal of deriving rail roughness from the tramway vehicle bogie acceleration data. In the preliminary measurements, rail corrugation was more thoroughly inspected than other rail running surface irregularities.

2.1 Acoustic rail roughness

To assess the condition of the rail running surface, an acoustic rail roughness measurement campaign was carried out at several locations on the Zagreb tramway track network using a handheld device RAILPROF 1000 [4]. The main focus of measurements was to evaluate rail corrugation according to various exploitation periods and the horizontal alignment of the track (straight line or a curve).
In Figure 2., rail roughness for three different locations with various exploitation periods is shown, with obvious deviations in the data for the shortest exploitation period (5 years, marked with blue) and for the longest exploitation period (22 years, marked with purple).
Observing the relationship between rail corrugation and the exploitation period, it was concluded that the number of dominating wavelengths on the rail running surface will keep rising as the exploitation period increases. Directly measured rail roughness was further used in a future study to compare the data with indirectly measured combined roughness.

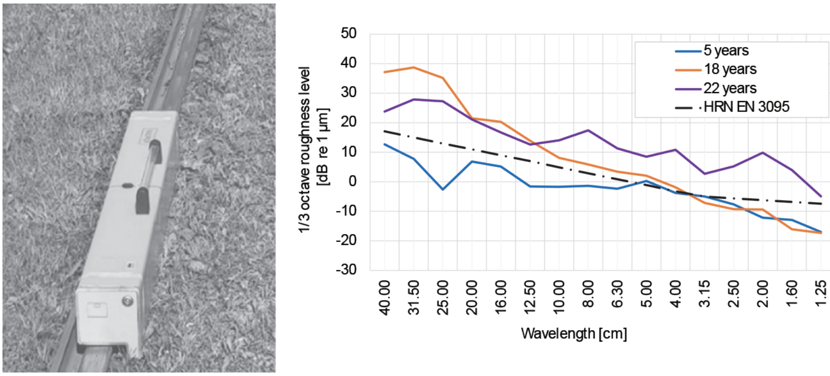


Figure 2 RAILPROF 1000 handheld device (on the left) and rail roughness graphs for locations with different exploitation periods (on the right) in the wavelength domain [4]

2.2 Tramway vehicle bogie acceleration – combined roughness

To compare combined roughness acquired by bogie frame acceleration data with rail roughness, an additional measurement campaign was done on a few locations with increased vibration levels and high amplitudes of rail corrugation on the rail running surface. Several analyses were performed to investigate the impact of different operating speeds on indirectly measured effective (combined) roughness, and how it corresponds with direct rail roughness data.

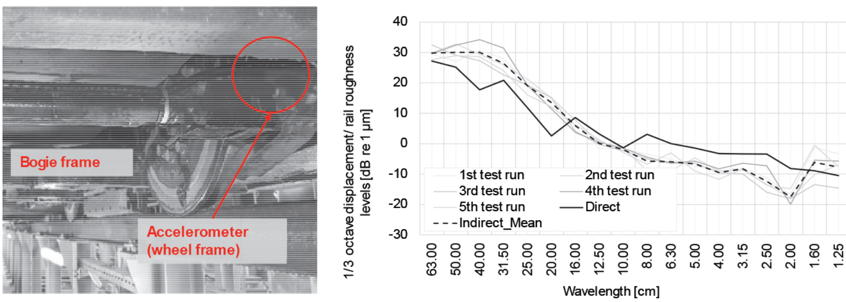
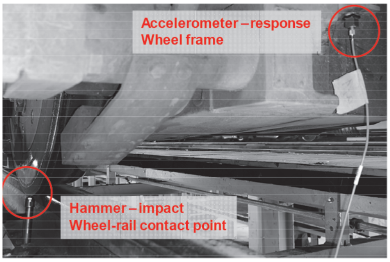


Figure 3 Position of the accelerometers (left) and comparison of rail roughness and displacement (combined roughness) amplitudes for different tramway passages in the wavelength domain (right)

Bogie frame acceleration data was double integrated to get the displacement data and compared with the results acquired by direct rail roughness measurements [4] (with a handheld device RAILPROF 1000) in third-octave wavelength bands. The mean indirect effective (combined) roughness data averaged from five different test runs with operating speeds ranging from 32 to 40 km/h agreed well with the trendline of directly measured rail roughness data (Figure 3). However, obtained bogie frame acceleration data should be processed by implementing several transfer functions (wheel receptance, wheel-rail transfer function, and wheel roughness determination) to get more accurate results.

2.3 Vibroacoustic measurements

To inspect the vibroacoustic characteristics of the vehicle and the wheels, an impulse response test was performed on the wheel and bogie frame of a tramway vehicle, in the premises of the Zagreb tramway network operator. Measurements were performed on a standstill vehicle, using an impact hammer (force impulse) and an accelerometer to record the impulse response, varying the positions of the hammer and the accelerometer, both on the wheel and on the bogie frame (wheel frame). The measurements were conducted to determine the transfer function H1 (frequency response function (FRF) magnitude), between the wheel-rail contact point and the wheel frame, on which the accelerometers are mounted during the in-service tramway vehicle vibrations monitoring that is currently ongoing on the Zagreb tramway network.



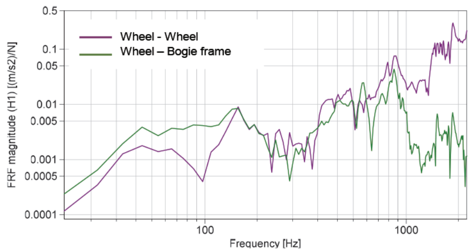


Figure 4 Measurement setup (left) and transfer function (FRF magnitude) between contact point and wheel frame (right) in the frequency domain

The analysis provided valuable insight into the wheel-to-bogie frame transfer function (Figure 4, marked green), compared to the wheel-wheel transfer function (Figure 4, marked purple), where significant deviations can be observed in the frequency range up to 150 Hz and above 600 Hz. This gives valuable data for further evaluation of indirect rail roughness evaluation. In the upcoming research, the resulting transfer functions for both the wheel and bogie frame will be utilized in the existing combined roughness data to extract rail roughness data from bogie frame acceleration. Furthermore, this data will be evaluated and compared to directly measured rail roughness data.

3 Conclusion

The presented research investigates the possibility of using tramway vehicle bogie acceleration data in detecting and evaluating rail irregularities. Additionally, it emphasizes the importance of such data for track maintenance optimization and noise and vibration reduction in urban environments.
Preliminary research in Zagreb revealed promising results for correlating combined roughness to directly measured rail roughness. However, to derive rail roughness data more efficiently from bogie frame acceleration, the suggested methodology requires additional signal processing, and the creation of transfer functions based on the vehicle's vibro-acoustic characteristics. Future research will focus on incorporating transfer functions into bogie frame acceleration data and verifying the method's effectiveness in detecting and analysing various rail irregularities using vehicle-based indirect vibration measurements.

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