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Correlation between rolling noise generation and rail roughness of tangent tracks and curves in time and frequency domains

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ABSTRACT

Despite considerable advantages of the railway track over other means of transportation, noise pollution is the main adverse consequence of railway transportation. The basic cause of railway noise is rail corrugation. Although characteristics of railway noise have been considerably studied in the literature, rail corrugation effects on rolling noise generation in tangent tracks and the curves have not been sufficiently investigated. This research addresses the limitations of the current understanding of the rolling noise generation by investigating rail corrugation effects on rolling noise in tangent tracks and curves. This research was made based on the results obtained form a thorough field investigation carried out in a railway line which includes tangents tracks and sharp curves. A track geometry recording car was used to measure rail corrugations. For this purpose, an indirect method was developed in this research to obtain rail corrugation patterns from the data recorded by the track recording car. The effectiveness of the new method was shown. The induced noises were recorded using two particular types of microphones and implementing the method suggested by the ISO 3095 Standard. The rolling noise signal was distinguished from the total noise, using Butterworth Band-Pass Filtering. The role of rail corrugations in the rolling noise was discussed. Correlations were made between various types of corrugations and the induced noises. The results were presented and discussed in the spatial and frequency scales. Results obtained have led to new findings in rail corrugation effects on rolling noise generation. This research paves a way toward a better understanding of rolling noise sources and the parameters influencing the noise.

1. Introduction

With the advent of the new generation of high-speed trains, there is no doubt that railway is preferred over other means of transportation mainly due to its speed as well as its environmental factors such as less energy consumption and less pollution. Nevertheless, the railway has negative impacts on the environment, which mostly concern noise. Furthermore, in terms of physiological parameters related to sleep, contrary to expectations, the impact of railway noise is much greater than the road and air traffic [1]. Intermittent sounds and vibrations endanger people's mental health in the long term and lead to depression and fatigue. Therefore, maintaining the railway noise within the allowable limits is essential, particularly for the new generation of high-speed trains [2]. There are various sources of railway noise. The dominant source of noise differs, as the track conditions vary. However, the most important type of railway noise is rolling noise [2]. Rolling noise is generated by the vertical vibration of the wheel and the rail. This vibration is induced by the relative displacements between the rail and the wheel because of the roughness on their surfaces. Rail corrugation is an important type of surface roughness, which constitutes an undesirable periodic wear pattern on the contact surface of the rails [2]. Short-pitch corrugation is a less understood type of corrugation. This type of corrugation has wavelengths in the range of 25–80 mm. An investigation of this form of corrugation is of interest when considering acoustic roughness development. Although a great deal of work has been published on the subject of corrugation, there is not much literature available on the development of acoustic roughness [1]. An accurate knowledge of rail and wheel roughness and its effect on the noise is an essential factor in noise control policies. That is, a more maintenance attention should be paid on the high roughness levels. The maintenance includes re-profiling the wheels and grinding the rails. The process of rail grinding to reduce roughness and corrugation is time-consuming and expensive. In order to optimize the minimization method of rail roughness, one should be aware of

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the rail wear and roughness development mechanisms and hence the costs of noise control and its maintenance. One of the main topics in railway acoustics is the role of the infrastructure and rolling stock in the total noise radiated into the environment [1]. In this regard, the most controversial questions is related to the noise source. The controversy primarily focused on whether the wheel or the rail is the main source. The physics of noise generation by means of the roughness on the running surfaces of the wheels and rails is very complex [3–5]. Consequently, to fully understand the main controlling factor of wheel/rail noise generation, researchers have relied on the results obtained from analytical models. Although the theoretical modelling approach can determine the wavelength of some corrugations types, they have limitations in explanation of all corrugation formations [6]. This remains corrugation as an area which needs further researches. Despite the extensive studies of rail corrugations including short-pitch corrugation and rolling contact corrugation developments in the last 30 years, there is no clear sense on the effect of these two important and conventional types of corrugation on the railway rolling noise generation. This research is a response to this need.

2. Review of literature

Railway noise has been studied extensively since the late 1970s [1–3]. Remington [3,4] in 1976 developed the first theoretical model of rolling noise. In 1993, Thompson [1,5,6] extended Remington's theory and developed the model as a computer program called TWINS. During the last decade, the sources of rolling noise and the importance of surface roughness in railway noise has been well studied using TWINS. Results indicate that the roughness of the running surface of the rail and the wheel is the predominant source of railway noise. In 2006, Kitagawa and Thompson [7] investigated the impact of wheel/rail noise radiation on Japanese railways using the TWINS model and microphone array measurements. Hardy and his colleagues [8] carried out a statistically based study into the effects of railhead roughness on the rolling noise prediction. Their works were further developed by Nielsen et al. [9–11], Gullers et al. [12] and Jiang et al. [13]. Although, theoretical models for prediction of noise such as TWINS [14–22] provide a clear understanding of railway noise sources, they just import the roughness levels into the model and do not take into account the role of the track system in the development of roughness or corrugation over the time. Moreover, although the type of rail corrugation in the case of short wavelength corrugation can have a large influence on the rolling noise, it has not been considered in the noise prediction models. Most of the previous studies have used the experimental results of measured noise during train pass-by and compared them with those predicted by the TWINS program. The experimental works reported in the available literature are very limited and just used for the validation of TWINS.

A review of the literature [23–30] indicates that surface roughness and wheel–rail contact, as important factors in railway rolling noise, have not been adequately investigated. That is, there is a need for further investigations (in particular field investigation) into the effect of rail irregularities such as rail corrugation on rolling noise. In response to this need, these authors have made a limited investigation into the effects of corrugations on rolling noise in the time domain [2]. Their research was developed further in this paper in both time and frequency domains using an improved filtering approach. That is, this research is a comprehensive experimental study on noise and rail corrugation in railway track system, leading to develop correlations between corrugation and rolling noise. In this paper, an indirect method for rail corrugation measurement was developed. Using this method, rail corrugation (with various amplitudes and wavelengths) was precisely obtained from a track recording car. Due to the speed and availability of track recording cars, this method is cost effective compared with the conventional ones. This research has focused on the effects of particular rail corrugation types (i.e., short-pitch rail corrugation and rolling contact corrugation) on only one type of railway noise (i.e. rolling noise) as this has not been attempted in the available literature. For this purpose, railway noise was measured from the passage of a railway vehicle using microphones in a railway field. Using the vertical longitudinal profile of the railhead recorded by the EM50 track recording car, rail corrugation in the tangent track and the curve was derived [2]. The short-pitch rail corrugation signal and rolling contact fatigue signal were extracted from the corrugation signals by means of an improved Band-Pass Filtering. Utilizing a new procedure, a rolling noise signal was extracted from the original recorded noise signal for the tangent track and the curve. Through analyses of rail corrugation and rolling noise in various track conditions, correlations between the rail roughness effect and rolling noise generation were derived and compared in the frequency and time domains.

3. Rail corrugation and noise in time and frequency domains

The conditions required to achieve reliable and repeatable measurements of the noise emitted by railway system have been defined in standard ISO 3095 [14]. This standard also provides us with the descriptions of processing techniques for rail roughness measurements. This research was made according to ISO 3095. For the field tests, noise prone areas were identified, such that the noise generated by the passage of a railway vehicle could be recorded using measurement equipment. As a result, Tehran metro was identified as the most appropriate location for the field tests [2]. Field noise measurements and the corrugation measurements in a tangent track and a sharp curve were carried out initially in 2013, and their results were presented in [2]. Improved, extended and completed field measurements were conducted in this research (2014–15). The lines tested were exposed to severe corrugation growth. The metro line under investigation including location of the field tests (the tangent track and the curve) is presented in Fig. 1. Since one of the aims of this research was to find the main reason of high level of noise near residential areas, the test site is located near a region of high residential density, with limited but significant traffic. The track segment in this investigation includes an approximately 50 m length tangent track and a curve with an approximately 300 m radius and 25 m in length. The track is ballasted with CWR-UIC 60 rail, rail cant of 1:20 rested on B70 concrete sleepers and a Vossloh fastening system [2]. According to ISO 3095, direct roughness measurements are taken over the reference section, whose length is proportional to the microphone distance r from the track and varies from $-2r$ to $+2r$ (i.e.; $4r$) ($r = 7.5$ m) relative to the center of the reference section where the noise measurement microphone is positioned. In addition, the track at the measuring section shall 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 presented [14]. According to ISO 3095, for Indirect roughness measurement as used in this paper, this distance can be considered more depending on track conditions such as welded rail and being free of visible surface defects such as rail burns or pits and spikes caused by the compression of external material between wheel and rail [14]. So in this paper the measurement distance in the test was considered about 50 m for the tangent track and 25 m for the curve length which is in accordance with ISO 3095.

As indicated above, the track instrumentation for noise measurements were performed in accordance with the ISO 3095