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Effect of rail corrugation on metro interior noise and its control

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ABSTRACT

Rail corrugation is very common in metro systems, and serious noise problems produced by rail corrugation, especially short-wavelength corrugations (25–50 mm), are a common cause of passenger complaints. For metro trains, the wheel-rail interface is the main source of noise, and the wheel-rail roughness, especially in the presence of rail corrugation, is the main excitation source. Rail grinding is a fast, economical, and effective control measure for reducing vibration and noise. However, the existing grinding cycle is not sufficient to meet the requirements of interior noise. There is no rail grinding standard based on interior noise limits for metro trains running on slab tracks in tunnels, which covers the vast majority of situations in China. Therefore, there is an urgent need to understand the effects of rail corrugation on interior noise for metro trains running on slab tracks in tunnels. At the same time, a rail grinding standard based on interior noise limits for such metro trains is very important. In this paper, the characteristics of the serious noise problems caused by rail corrugation are identified and suitable rail grinding controls based on noise limits are presented.

1. Introduction

The operation speed of metro trains is in the range 30–80 km/h. At such speeds, wheel-rail noise becomes a problem [1], and wheel-rail roughness, especially in the case of rail corrugation, is the main excitation source [2]. When obvious rail corrugation occurs, passengers are subjected to serious interior noise. Rail corrugation is difficult to study because of its mechanism, initiation, evolution, and classification. Different types of track generate corrugation with different wavelengths and amplitudes. A series of dynamic, vibration, and noise problems are caused by rail corrugation. Many scholars have attempted to understand and research rail corrugation. In the 20th century, Grassie set up field tests and developed measuring equipment to understand short-pitch rail corrugation [3]. From 1995 to 2005, considerable progress was made in the understanding, measurement, and treatment of corrugation. Measuring equipment for corrugation of a few microns that could be used at walking speed made it possible to propose objective standards for rail reprofiling to remove corrugation [4]. Sato reviewed studies from around the world on rail corrugation before 2002, with a focus on Japan [5]. Short-pitch rail corrugation studies from many countries were reviewed and placed in historical perspective. Through this review, situations such as a smooth rail surface, stiffer supported rail, or continuously supported rail were found to offer a significant delay in the formation of corrugation [6]. Jin developed a numerical model to study the initiation and evolution of rail corrugation [7–9]. Eadie studied top-of-rail friction control for corrugation rate reduction. The corrugation rate test was carried out over several years at Metro Bilbao in Spain. The results firmly demonstrate the very significant reduction in corrugation growth rates that can be achieved with friction modifiers under well-controlled conditions [10]. Li carried out an investigation into the mechanism of metro rail corrugation in China using experimental and theoretical methods [11]. Nielsen developed a dynamic train-track interaction model to study the influence of short-pitch wheel-rail corrugation on rolling contact fatigue in railway wheels [12], whereas Ling studied the effect of rail corrugation on the behaviour of rail fastenings through experimental and numerical methods [13]. Wheel-rail noise caused by corrugation was introduced [14], and Grassie examined the characteristics, causes, and treatments of corrugation [15]. Thompson studied the relationship between wheel-rail roughness and rolling noise, presenting experimental evidence from several sources to confirm the linear relation between the two. The validity of the assumption that the wheel and rail roughness spectra make an equal contribution to the total roughness spectrum was also investigated [2]. Reducing the growth of corrugation will clearly result in a significant reduction in noise, and thus to a reduction in the need for grinding. In the case of smooth wheels, it has been

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estimated that badly corrugated track can increase the noise by up to 20 dB [16]. Chiacchiari estimated noise and vibration levels from tram operations based on the measured rail roughness [17], and discussed the measurement methods for rail corrugation with particular regard to the analysis tools for evaluating the thresholds of acceptability in relation to the tramway Italian transport system [18]. Although the mechanism, initiation, and evolution of rail corrugation, the effect of rail corrugation on dynamics and fatigue strength, and the effect of corrugation on wheel-rail noise has been studied, the effect of rail corrugation on the interior noise inside metro trains has seldom been considered. The influence of the amplitude, frequency band, and transfer mechanism of rail corrugation on interior noise is not clearly understood.

There are many measures for reducing wheel-rail noise and interior noise, such as damping the wheels, damping the rails, reprofiling the wheel, and grinding the rails. Of these measures, rail grinding is a fast, economical, and effective control measure for vibration and noise reduction [19]. For metro systems in China, the rail corrugation phenomenon with serious noise problems is very common, especially in the presence of short-wavelength corrugations (25–50 mm). The existing grinding cycle is not sufficient to meet the requirements of interior noise. There is no rail grinding standard based on interior noise limits for metro trains running on slab tracks in tunnels, which covers the vast majority of systems in China. Although ISO 3095 [20] specifies rail grinding standards based on noise, it is not suitable for interior noise control within metro trains running on slab tracks in tunnels, because it is based on ballast tracks and does not consider tunnels. According to field investigations, ISO 3095 may be too strict, which will increase economic costs. Therefore, there is an urgent need to understand the effects of rail corrugation on interior noise within metro trains running on slab tracks in tunnels. At the same time, a rail grinding standard based on interior noise limits for metro trains running on slab tracks in tunnels is very important. In this paper, the characteristics of serious noise problems in metro systems caused by rail corrugation are identified and suitable rail grinding control based on noise limits are presented.

2. Characteristics of metro interior noise and wheel-rail roughness

In this section, the measurement of serious interior noise and interior sound source identification is characterised. The frequency spectrum of serious interior noise, wheel-rail noise, car body vibrations, bogie and axle box vibrations, and wheel-rail roughness are measured under the same test considerations, and the relationships among them are analysed. The effect of wheel-rail roughness on interior noise is then investigated.

2.1. Characteristics of serious interior noise and sound source identification

Fig. 1 shows the measurement points of interior noise and sound source identification. The measurement point of interior noise is at a height of 1.6 m above the floor of the bogie. The sound source identification device (including 50 microphones and 12 cameras) is arranged near the measurement point of interior noise. Fig. 2 shows the sound pressure level (SPL) of interior noise and the speed versus mileage. It can be seen that the interior noise generally increases with an increase in speed. When the speed is stable at about 75 km/h, the interior noise level varies because of different rail conditions at different points along the track. The highest SPL of interior noise reaches 98 dB(A) at cross-section 1. This is very noisy, as the interior noise limit is only 83 dB(A) [21] inside tunnels.

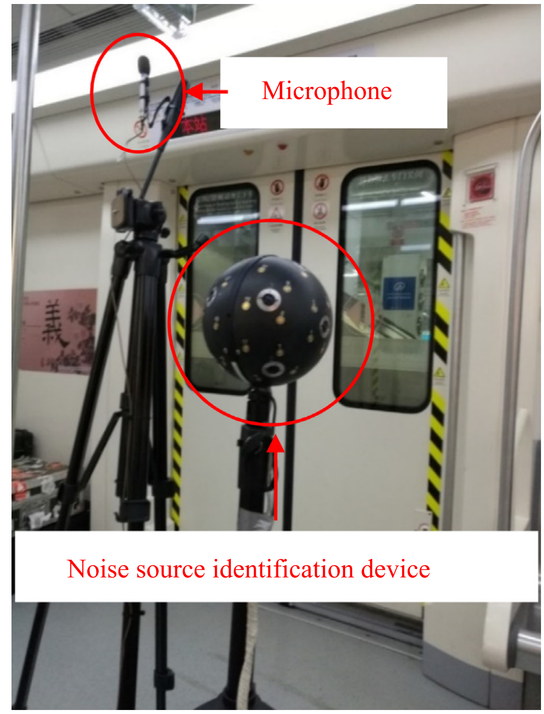

Fig. 1. Measurement points of interior noise and sound source identification.

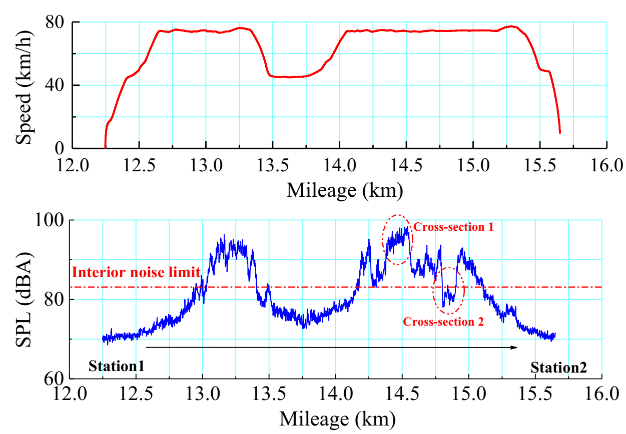

Fig. 2. Interior noise and speed vs. mileage.

In Fig. 2, we also observe some cross-sections with low interior noise levels, such as cross-section 2. Fig. 3 shows the one-third octave band spectrum of interior noise at cross-sections 1 and 2. It can be seen that the frequency band of the most significant peak is 500–630 Hz. In this frequency band, the difference in interior noise between the two cross-sections is obvious. This demonstrates the effect of rail corrugation on interior noise. As the same train was operating over two different sections at the same speed, the main reason for this difference in interior noise is likely to be the rail roughness. Thus, an investigation into the serious interior noise should be carried out systematically, and should focus on the rail roughness.

Fig. 4 shows the overall sound source identification across a range of 3 dB. It can be seen that the main noise source is the floor (structure-borne and air-borne sound) above the bogie. Noise also comes from some other locations. As the floor above the bogie is the main source of interior noise, the mechanism of vibration and sound transfer from the wheel-rail to the interior needs to be understood.