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Acceptance criterion for rail roughness level spectrum based on assessment of rolling contact fatigue and rolling noise

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A B S T R A C T

The influences of train speed and rail roughness level on rolling noise and subsurface initiated rolling contact fatigue (RCF) impact are studied. In particular, the consequences of short-pitch rail corrugation on tangent track with wavelengths in the interval 3–8 cm are simulated using models of dynamic vehicle–track interaction. Based on the calculated results, a criterion in terms of a limit for maximum levels of rail roughness with respect to the current traffic conditions can be determined. Such a criterion may be useful for planning of rail grinding intervals if used together with a system for regular monitoring of rail roughness levels. It is concluded that the importance of controlling rail roughness increases with increasing train speed. Increasing axle loads on freight vehicles from 22.5 tonnes to 30 tonnes leads to a significant increase in RCF impact. In operational practice, this is usually compensated for by introducing more conformal wheel–rail profile combinations. Calculated vertical wheel–rail contact forces and rolling noise levels show good agreement with field measurements.

1. Introduction

Small amplitude undulations (irregularities, roughness, waviness) with wavelengths in the order of 1–10 cm on the running surfaces of wheels and rails induce high-frequency vertical wheel–rail contact forces. Consequences of such broad-band excitation are vibrations and rolling noise. In particular, contact forces with high magnitudes are generated in operations with out-of-round wheels and/or on track sections with rail corrugation. In severe cases, it may lead to further damage of wheels and rails in the forms of subsurface initiated rolling contact fatigue (RCF) [1,2] and broken rail fastenings. In general, vertical contact forces and rolling noise increase with increasing rail roughness levels and train speed. Thus, a future introduction of high-speed trains (in Sweden) requires that limits for roughness levels are set.

Vertical wheel–rail contact forces have been measured for an X2 passenger train operating at 200 km/h on the line Stockholm–Gothenburg. The contact forces were recorded using a trailer wheelset instrumented with strain gauges on the wheel discs [3]. Track sections, generating high force magnitudes with significant contributions in the frequency range 500–1350 Hz, were identified [4]. Based on subsequent measurements with the Corrugation Analysis Trolley (CAT) [5], it was confirmed that the rails at these sections were corrugated with roughness levels in the order of 20 dB (re 1 μm) at wavelengths in the interval 3–8 cm. This type of corrugation is referred to as short-pitch rail corrugation [6]. Tread braking with cast-iron brake blocks are known to generate wheel roughness with similar wavelengths and amplitudes [7].

The influences of train speed and rail roughness level on rolling noise and sub-surface initiated RCF impact will be investigated. Based on the calculated results, a criterion in terms of a limit for maximum levels of rail roughness with respect to the current traffic conditions can be outlined. The criterion may be useful for planning of rail grinding intervals if used together with a system for regular monitoring of roughness levels. The objective is to reduce the generation of RCF in wheels and rails and to limit rolling noise levels. The study is based on an integrated analysis using the cross-disciplinary computer models in DIFF [8] for simulation of dynamic vehicle–track interaction at high frequencies, FIERCE [9] to predict subsurface initiated RCF impact and TWINS [10] for calculation of rolling noise.

2. Field tests

2.1. Wheel and rail roughness

In connection with the X2 test campaign referred to in Section 1, see also Ref. [3], sites along the railway line generating high vertical wheel–rail contact forces were identified. To determine the magnitudes of the rail irregularities at these locations, the accelerometer-based system CAT with a sampling distance of

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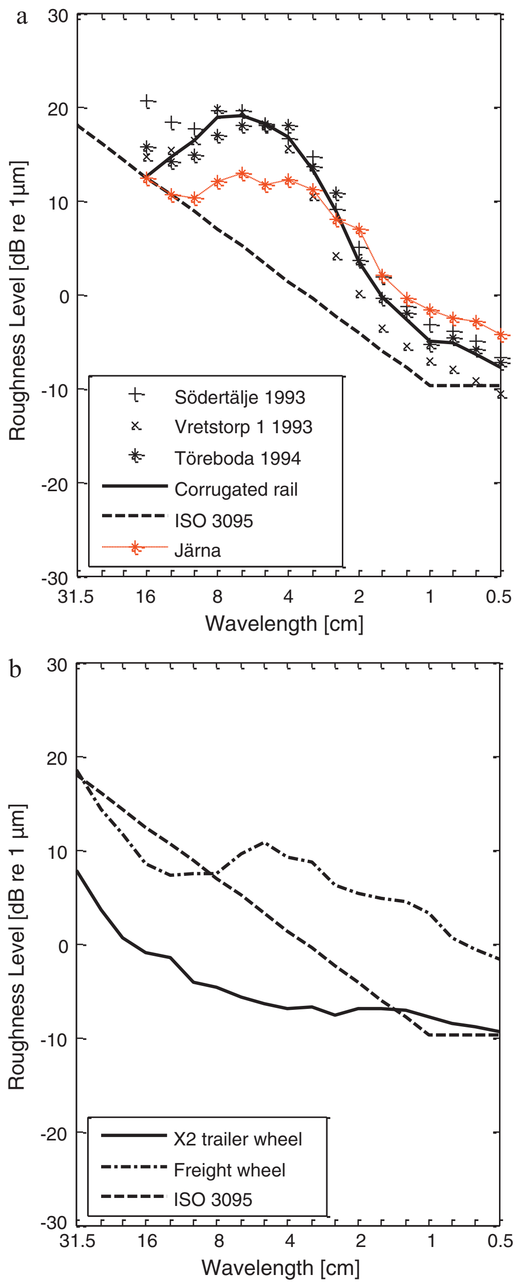

Fig. 1. (a) Rail roughness level spectra for selected sections of the line Stockholm–Gothenburg. Measurements were performed by Banverket in March 2003. The years when the rails, according to available database information, were installed or ground are reported in the legend. "Corrugated rail" is the energy mean of the three spectra from Södertälje, Vretstorp and Töreboda. (b) Wheel roughness level spectra [12].

1 mm was used. Roughness level L_r is defined by

$$L_r^k = 20\log_{10}\left(\frac{\tilde{r}_k}{r_{ref}}\right)\ [\text{dB re } 1\ \mu\text{m}], \quad (1)$$

where $r_{ref} = 1\ \mu m$ and $\tilde{r}_k$ [m] is the root-mean square value of the roughness profile $r(x)$ evaluated in one-third octave band k with centre wavelength λ_k.

Rail roughness level spectra from the three sites at Vretstorp, Södertälje and Töreboda are shown in Fig. 1(a). All three sites are on tangent track with 60E1 (R260) rails, nominal sleeper distance 0.65 m, Pandrol fastenings and concrete monobloc sleepers (250 kg) on ballast. It is observed that the spectra have a common local maximum in the wavelength interval 3–8 cm with levels in the order of 20 dB re 1 μm indicating severe short-pitch corrugation. The energy mean (mean of mean squares) of the three spectra was calculated and is denoted the "Corrugated rail" spectrum. In the following, it is used as a reference for a severely corrugated rail. In Fig. 1(a), it is compared with the roughness spectrum of a moderately rough rail measured at Järna and the ISO 3095 spectrum [11] that is corresponding to a smooth rail.

In parallel, the roughness on five X2 trailer wheels and 14 freight wheels (used on vehicles with the freight bogie design G66) have been measured [12]. All wheels had a minimum travelled distance of 100 000 km. The evaluated wheel roughness level spectra are shown in Fig. 1(b). It is observed that the X2 trailer wheels (with disc brakes) are smooth compared to the corrugated rails, whereas the freight wheels are relatively rough due to tread braking with cast iron brake blocks.

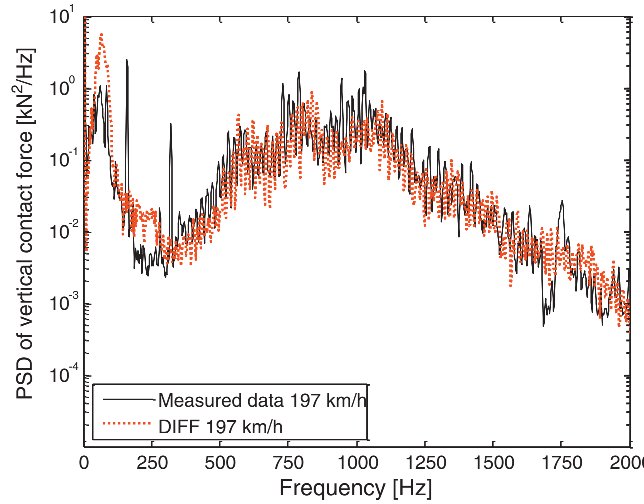

Fig. 2. Power spectral densities of measured and simulated (DIFF) vertical wheel–rail contact forces. X2 trailer bogie at speed 197 km/h on track at Vretstorp.

2.2. Vertical wheel–rail contact force

Wheel–rail contact forces were measured for an X2 trailer bogie operating on the line Stockholm–Gothenburg in October 2002 [3]. Measurement wheels instrumented with strain gauge bridges on each side of the wheel disc were employed. The sampling frequency was 9.6 kHz. The wheels were calibrated for vertical and lateral static wheel–rail contact forces.

Based on measurements at Vretstorp at speed 197 km/h, the Power Spectral Density (PSD) spectrum of the vertical wheel–rail contact force is shown in Fig. 2. It is observed that contributions to the contact force are significant in the frequency range 500–1350 Hz. These contributions are caused by the rail corrugation with wavelengths 3–8 cm. Note that the peaks at 157 Hz and 314 Hz are explained by the assessment procedure that derives the vertical force by alternatively using information from the strain gauge bridge on either side of the wheel disc. These spurious peaks are thus not caused by the dynamic vehicle–track interaction and should be ignored. The so-called P2 resonance (wheelset, rail and sleepers vibrating in phase on the sleeper support stiffness) is observed as a wide peak at around 100 Hz. The local maxima at around 570 Hz, 830 Hz and 1100 Hz are caused by the excitation of bending modes in the rail that occur between the two wheels in a bogie [13]. Such modes seem to be important in the generation of short-pitch rail corrugation [13,14].