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Characterisation of short wavelength railway track horizontal misalignments in the time-frequency domain

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Abstract

This study focuses on the detection of short wavelength lateral track irregularities. For this, lateral axlebox accelerations from trains during commercial service have been gathered. This data has been further characterised in the time-frequency domain by means of STFT. This yields some useful information in terms of excited frequencies and their respective reached amplitudes.

Specific locations along a railway track with noticeable loss of horizontal alignment are compared with some track stretches with absence of defects. Lateral axlebox accelerations are firstly analysed in the time domain in order to identify the location of the main peaks. Peaks are classified upon their absolute magnitude in three levels. i.e. Alert Limit (AL), Intervention Limit (IL) and Immediate Action Limit (IAL). In terms of amplitudes, it is found that regular track stretches (i.e. with no defects) show amplitudes below -20 dB for all the analysed frequency range. In opposition, spots with track defects show amplitudes higher than -10 dB for some specific frequencies. These frequencies mainly are featured by a main isolated peak at 25 Hz, a secondary peak at 150 Hz and a set of peaks in the band of 200-350 Hz. Minor differences among the analysed stretches have been found for frequencies above 400 Hz.

This empirical featuring of lateral vehicle-track dynamics may be used for the classification an identification of a large variety of short length horizontal track defects, such as misaligned fishplate joints, bended or worn rails. This can also be used for validating a smart detection system based on image processing techniques.

Keywords: track surveying, track monitoring, axlebox acceleration, lateral dynamics, wheel-rail interaction.

1 Introduction

Nowadays, stakeholders are betting on railways as a rapid, massive and energy-efficient transport mode, leading to a higher number of track kilometres to maintain. In this context, Railway Engineers must find a compromise between ride quality and track performance (speed, comfort), and maintenance costs. In order to achieve this main goal, this work presents a methodology for assisting track condition-based procedures. By means of a proper time-frequency analysis, performed to the accelerations signal recorded at wheelset axleboxes, it is possible to identify and classify a whole set of track defects and singularities.

The suitability of using axlebox accelerations as an indicator of condition based monitoring has already been proven by some authors. By means of the analysis of axlebox accelerations, a large set of track defects can be identified, e.g. short wavelength defects occurring at discrete track locations, such as squats, insulated joints or turnout crossings [1], [2] . Nevertheless, whereas high attention is payed to the vertical dynamics and its relationship with track vertical geometry [3], much less effort is dedicated to the lateral stability [4]. For this reason, this paper focuses on the detection of short wavelength defects regarding horizontal misalignment of railway tracks. For this purpose, lateral acceleration at train wheelset level are recorded and analysed.

Analysis is firstly performed separately in the time and frequency domains, and later with a combined time-frequency analysis. For this last purpose, a proper time-frequency signal decomposition such as the short time Fourier Transform (STFT), the Wavelet Transform or the Hilbert Transform must be set up [5], [6]. Following previous experience [7], a fine tuned STFT tool is used to undertake the detection of those track horizontal irregularities which may cause severe lateral wheel flange-rail impacts leading to derailments.

2 Methods

For this study, a set of measurements were purposely carried out. Measurements took place in the line between Alcoi and Xàtiva (Spain). This secondary line mainly consists of short rail bars linked by means of fishplate joints, resting on wooden sleepers. Rails are attached via bolts directly screwed into the sleepers. Between the rails and the sleepers there is a plate which allocates a rubber pad, providing some elasticity to the track system. A Diesel Multiple Unit series 592.200 under commercial service was monitored. The monitoring consisted in a set of vertical accelerometers located at both axleboxes, plus one extra accelerometer located horizontally in the left axlebox. Wheel-rail contact was recorded with a video camera, whereas the train speed was registered by means of a GPS.

Accelerations were recorded at a sampling frequency of 2.5 kHz with an anti-aliasing, 4 poles Butterworth low-pass filer of 1 kHz. Lateral axlebox accelerations are firstly analysed in the time domain in order to identify the location of the main peaks. Peaks are classified upon their absolute magnitude in three levels. i.e. Alert Limit (AL), Intervention Limit (IL) and Immediate Action Limit (IAL). The Railway Administrator has defined such thresholds at axlebox level only for the vertical accelerations (30, 50 and 70 m/s^2, respectively). Therefore, thresholds for the lateral accelerations were set up assuming a similar number of peaks in each of the intervals as in the vertical direction. This yields 6 m/s^2 for the AL, 12 m/s^2 for the IL and 20 m/s^2 for the IAL. For this peak analysis, accelerations are further filtered to 20 Hz to allow comparison with the Railway Administrator.

Once the main peaks and the instant of occurrence are identified, frequency characterisation is carried out. For this purpose, Power Spectral Densities (PSD) of time windows centred at these points are obtained. Upon previous research [7], a 0.5 s Hanning time window is selected. Peaks showing PSDs of similar appearance are grouped together, and compared with track stretches with lack of horizontal irregularities. Finally, in order to have a comprehensive look of the overall track conditions, consecutive STFT are computed and represented in subsequent spectrograms. The analysis tool is based on the conventional STFT rather than the Wavelet Transform (WT). In this particular case, STFT, represented by means of consecutive spectrograms, is preferred since main frequencies are linearly distributed throughout the frequency band, whereas the WT works on a logarithmic scale, thus hindering a proper frequency identification.

3 Results

Upon the afore-mentioned procedure, fig. 1 shows the lateral axlebox accelerations for $t \in [64, 100]$ s. This figure shows a set of singularities related to track lateral dynamics. From this set of singularities, three of them located at $\mathbf{t} = (73.80, 92.90, 93.80)$ s exceeding the IL threshold are selected, analysed and compared to time instant $t = 65.75$ s, where no singularity is found and hence used as a control point.

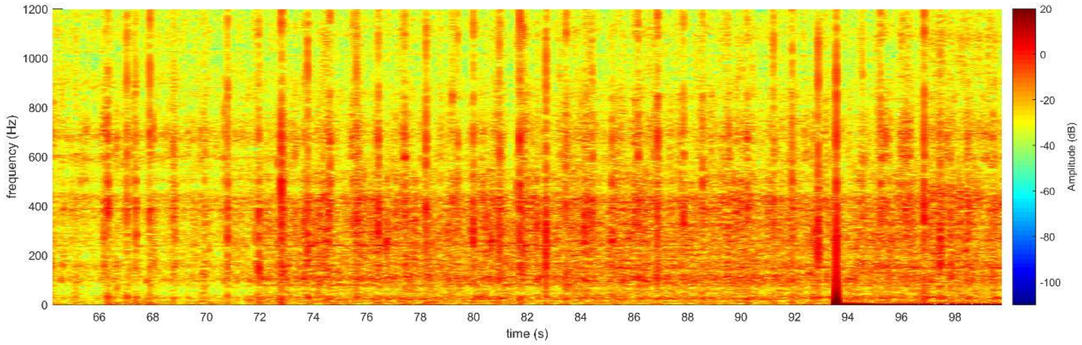

Figure 1: Spectrogram lateral axlebox accelerations for $t \in [64, 100]$ s.

Then, PSD is computed for each singularity as well as the control point. All them are shown in fig. 2

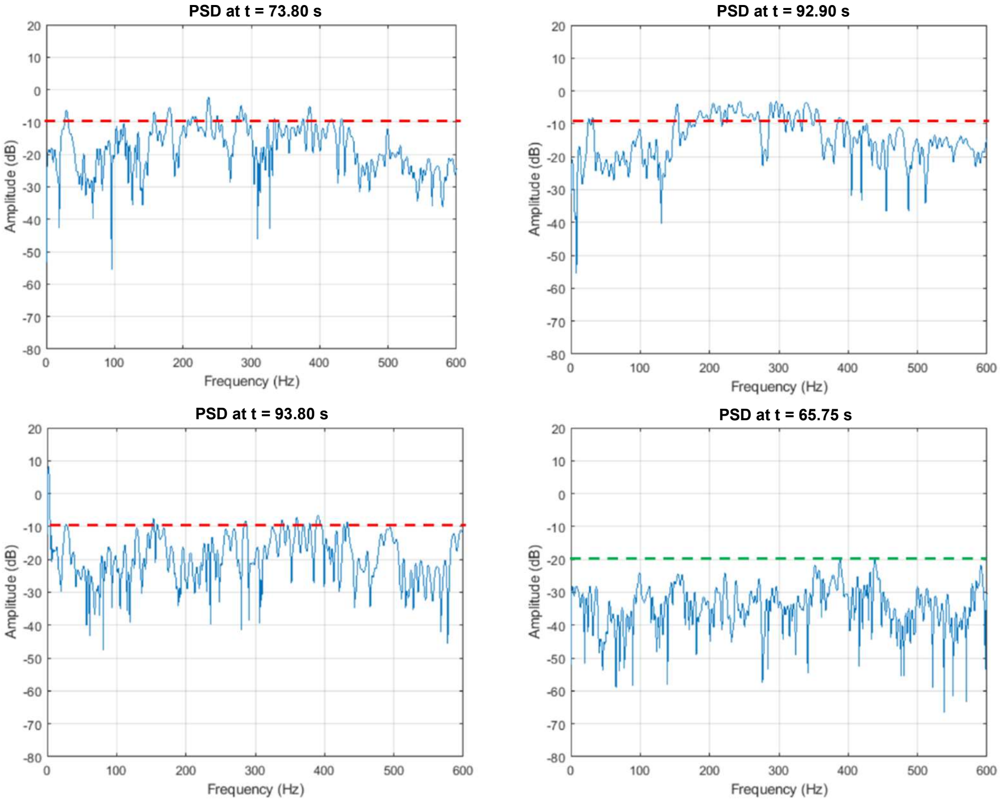

Figure. 2: PSD for the selected time instants

Singularity at *t* = 73.80 s corresponds to a misaligned fishplate joint. Singularity at *t* = 92.90 s corresponds to a rail horizontal misalignment, and so does the singularity located at *t* = 93.80 s but with a higher degree of severity. PSD computed at *t* = 65.75 s corresponds to a track stretch with no relevant singularities. From fig. 2, one can see that PSD amplitudes for points with no singularities remain below the threshold of -20 dB, whereas track stretches with singularities have some of their PSD amplitudes over -10 dB. For the case of the severe horizontal misalignment at *t* = 93.80 s, there is a large peak almost reaching 10 dB at very low frequencies, reflecting a huge impact. Between -20 dB and -10 dB there is a transition zone in which minor track defects and singularities are found.

In terms of frequency content, horizontal misalignment are firstly featured by an isolated peak located at 25 Hz. A secondary peak arises at 150 Hz. After these, some other peaks may arise in the frequency band 200-350 Hz. Beyond 400 Hz, less significant differences among track spots with defects and without them are found.

4 Conclusions and Contributions

This study has been focused on the detection of short wavelength lateral track irregularities. For this, lateral axlebox accelerations from trains during commercial service have been gathered. This data has been further characterised in the time-frequency domain by means of STFT. This yields some useful information in terms of excited frequencies and their respective reached amplitudes.

Specific locations along a railway track with noticeable loss of horizontal alignment are compared with some track stretches with absence of defects. In terms of amplitudes, it is found that regular track stretches (i.e. with no defects) show amplitudes below -20 dB for all the analysed frequency range. In opposition, spots with track defects show amplitudes higher than -10 dB for some specific frequencies. These frequencies mainly are featured by a main isolated peak at 25 Hz, a secondary peak at 150 Hz and a set of peaks in the band of 200-350 Hz. Minor differences among the analysed stretches have been found for frequencies above 400 Hz.

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