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Study of the vibratory performance of a High-Speed Train bogie using EGRSC and ECBF methods

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Abstract

High-speed railway has become a strategic transport in European and Asian countries and more and more countries are developing infrastructures to enter in the 'High-Speed club'. However, keeping the current good safety record of this conveyance requires extensive maintenance. This paper studies the performance of a high-speed train before and after a major maintenance operation. A set of accelerometers is installed on the train with the aim of collecting vibration signals without disturbing the normal operation of the train. Measurements are taken in the vertical direction of space and in both directions of the Madrid-Seville High-Speed line: from Madrid to Seville and vice-versa. EGRSC and ECBF techniques are applied to recorded vibration signals and the results are analysed. Hence, several frequency regions with significant spectral power variations that are common to both travel directions are identified. These patterns should be taken as a reference for future maintenance actions. Any unexpected behaviour of these frequency regions would indicate the presence of a fault.

Keywords: EGRSC, ECBF, high-speed rail, maintenance

1 Introduction

The last available data from the International Union of Railways show that high-speed trains transported more than 1000 billion passenger-km in 2019 [1] over the more than 56 000 km of high-speed lines that are in operation currently. In addition, another 74 000 km are planned for the next years [2]. Given this incredible level of usage, extensive maintenance is required both in rolling stock and infrastructure to keep passengers safe. However catastrophic accidents can occur due to maintenance-related failures. The Eschede disaster and the Wenzhou (China) accident in 2011 are two examples of these unfortunate events.

Many works of the scientific literature focus on the vibration analysis of rail wheelset and study faulty bearings within the transmission system [3] or the axle box [4], the presence of wheel flats [5], and axle cracks [6]. Usually, these researches are performed in laboratory conditions.

Although not very common, several authors have published works carried out with high-speed rolling stock: vibration data from in-service HST are analysed in [7] to establish a procedure that allows extending the periods between wheel reprofiling. The degradation of yaw dampers and wheel wear is detected from the monitoring of the running stability of Italian HST in [8]. Empirical Mode Decomposition has been also used to establish the condition of high-speed trains from axle box vibrations [9].

This short paper presents a study on the influence of a major maintenance operation in the vibratory performance of a high-speed train bogie, so critical frequency regions for identifying faults during the normal train operation can be established. To achieve this goal, a high-speed train is equipped with an onboard measurement system that acquires and transmits vibration signals without interrupting the normal operation of the train. A set of accelerometers is installed in the axle boxes of a trailer axle of the train and oriented in the main spatial directions. The vibration signals are recorded in the Madrid-Seville High-speed line in both directions and processed by using the Enhanced Graphical Representation of State Configurations (EGRSC) and the Enhanced Chromogram of Bands of Frequency (ECBF) techniques [10].

The analysis of the results provided by these methods will allow identifying the critical frequency regions that characterize the vibratory performance of the high-speed bogie and, therefore, establishing a set of indicators of its operating condition.

2 Methods

The measurement system installed on the high-speed train is composed of 6 uniaxial accelerometers, a speedometer, two IMx-R units for data acquisition and preprocessing, and a 3G router for data transmission. The accelerometers are placed on the axle box covers of a trailer axle, so both vibrations from the roller bearing and the wheelset can be obtained. The data acquisition and transmission equipment are located inside the coach.

EGRSC and ECBF are based on the calculation of the PSD of a signal (or the average PSD if dealing with several signals). Once the spectrum is obtained, it is split into several frequency bands or power packets by using a recursive algorithm that divides the spectrum into two halves, and each half again into two halves, and so on. At the end of the process, the original spectrum is split into 2k bands, being k the decomposition level. The value of k is limited by the length of the spectrum N, so $2k \leq N$ and $N/2k$ results in an integer.

The EGRSC is a way of summarizing the evolution of the spectral power of each frequency band throughout time and representing it (Figure 1). The starting point of this method is the selection of a relevant milestone in machine time history. From this, three operating states are defined: B (Before), A (After) and L (Later). The average spectral power for a given decomposition level at the three states is computed and represented in a time-spectral power axis. The average spectral power at each operating state is represented by a circle and, then, they are joined by straight lines following always RGB colours: red for linking B and A; green for A and L; and blue for B and L. Therefore, a triangle is made. The configuration of the operating state is named using three letters that can be ‘u’ (if the slope of the straight line is positive) or ‘d’ (if the slope is negative).

The ECBF is based on the results of the EGRSC and associates a colour to each possible configuration of the operating states (Figure 2). Then, a colour map that associates the frequency, the frequency bandwidth of the power packets, the decomposition level and the colour code is plotted. A threshold allows the user to specify the minimum spectral power variation relative to the power of the operating state B.

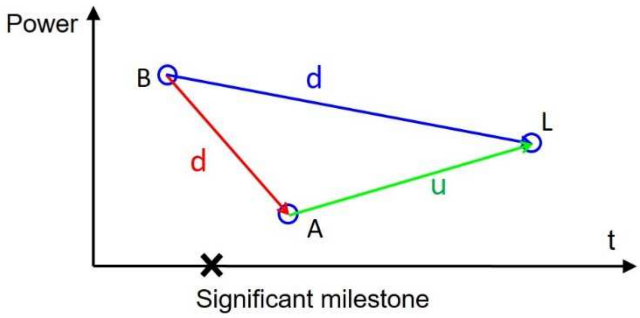

Figure 1: Generating EGRSC.

Configuration	Colour	Shape
ddd		
dud		
ddu		
duu		
udd		
uud		
udu		
uuu		

Figure 2: Colour coding.

3 Results

The monitored axle was reprofiled during scheduled maintenance. Signals are analyzed before and after that maintenance action. Three operating states are defined by considering the date on which the vibration signals were collected:

- State B groups all the vibration data that were collected during the two weeks before maintenance works.
- State A groups the vibration data collected the first day the train returned to service after the maintenance works.
- State L groups the vibration data recorded from state A to one month after the maintenance works.

Vibration data are collected in a sector of the Madrid-Seville High-Speed line in which the train travels at a speed of 270 km/h in both directions (Madrid to Seville and Seville to Madrid). Given the limited space and the fact that vertical vibrations are the most sensitive to variations, we will focus on these only. Also, only the results of the ECBF are discussed. A 10% threshold is used.

Figures 3 to 6 show the ECBF of the vertical accelerometers of the left and right-hand sides in both travel directions. All the ECBF exhibit three big frequency regions with similar performance:

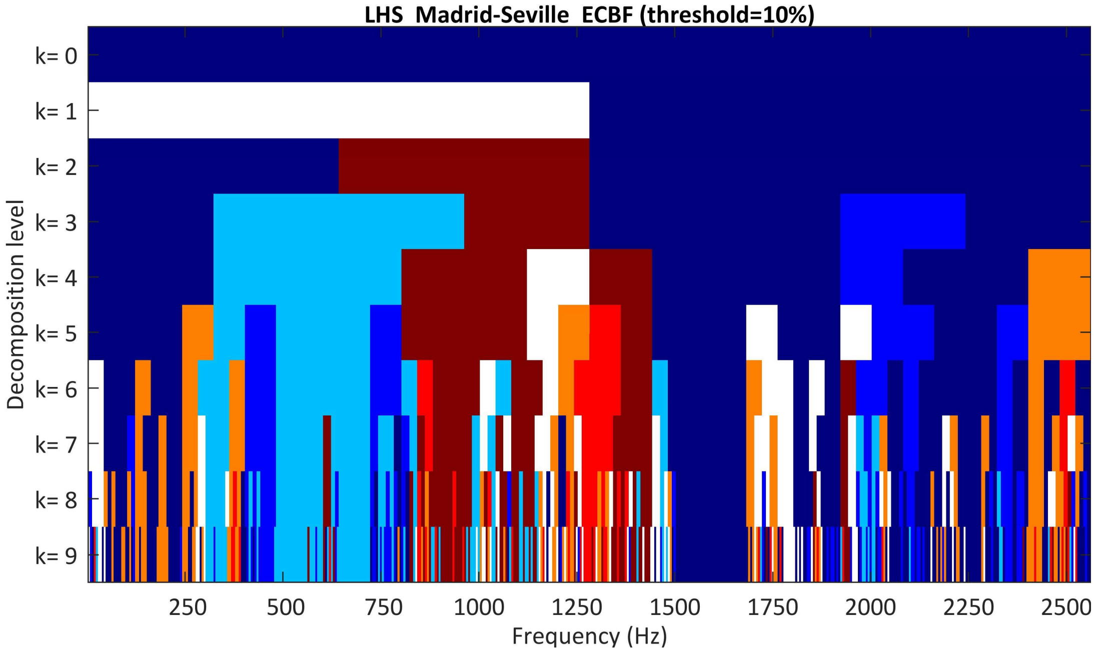

Figure 3: LHS ECBF (Madrid- Seville)

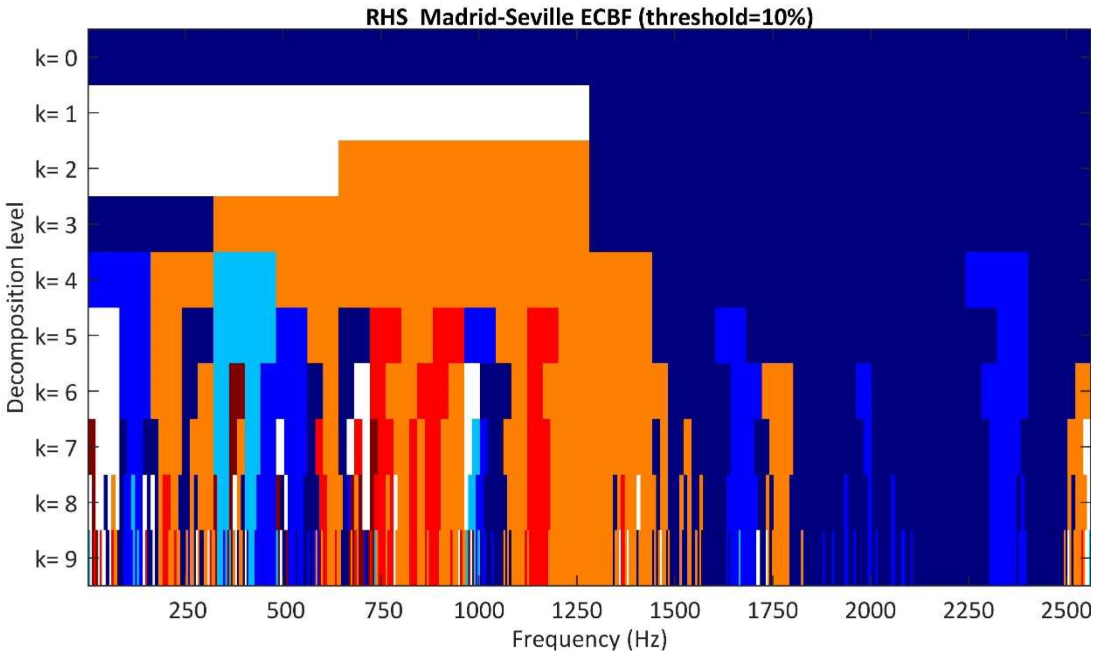

Figure 4: RHS ECBF (Madrid-Seville)

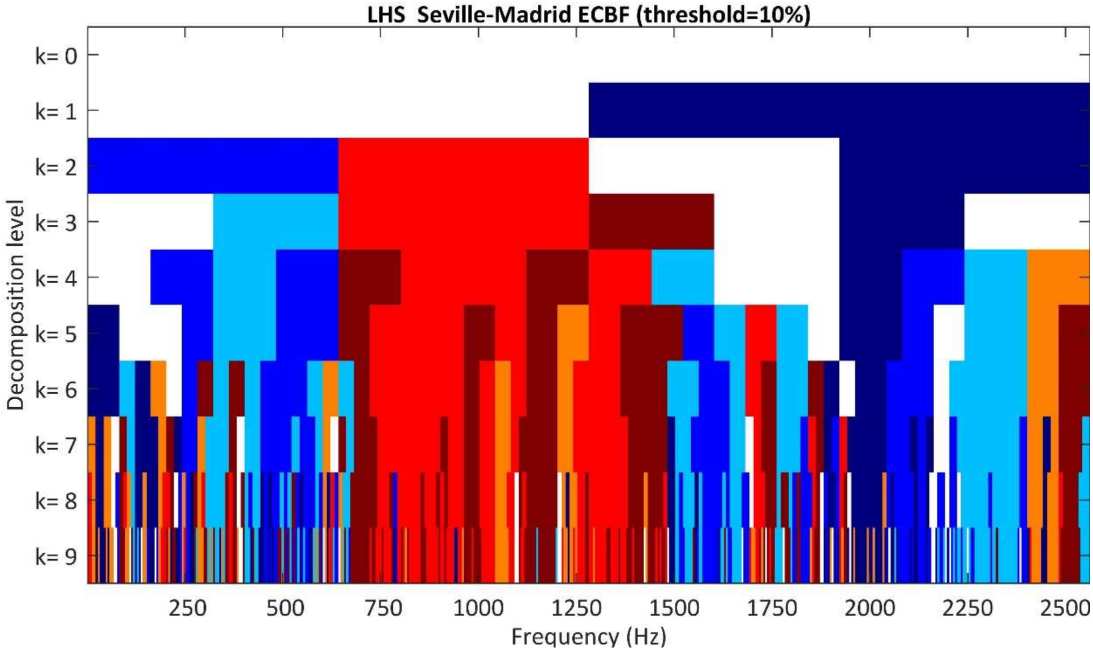

Figure 5: LHS ECBF (Seville-Madrid)

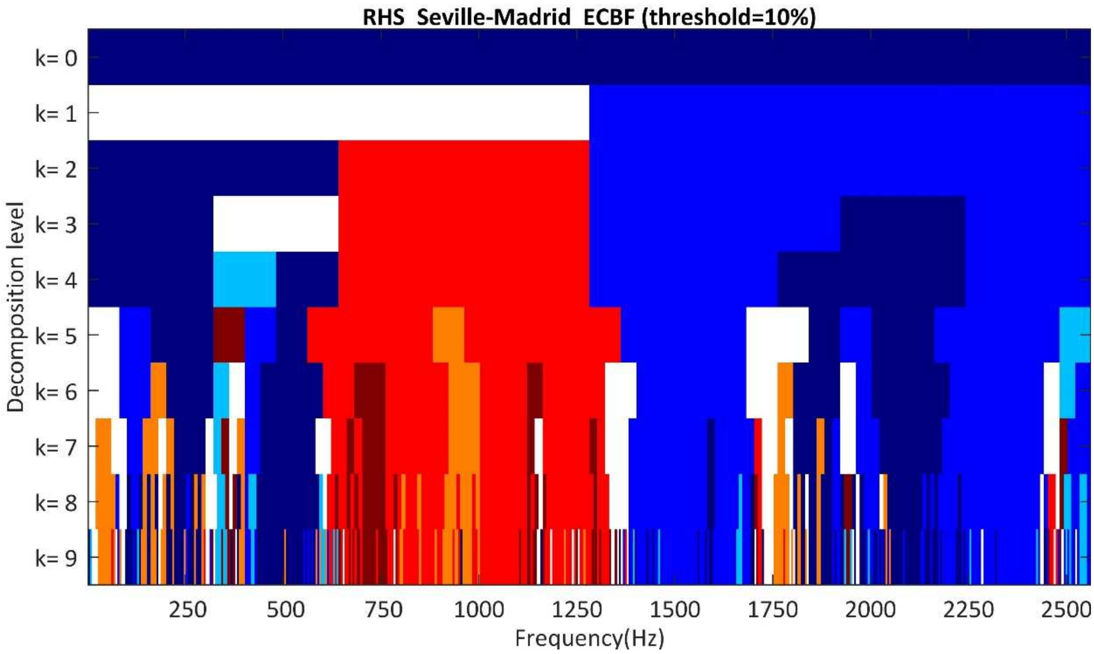

Figure 6: RHS ECBF (Seville-Madrid)

- 0 Hz – 650 Hz: the dominant colours are blues in the lower decomposition levels. This indicates that the power is reduced after the maintenance operation. However, at higher decomposition levels, they appear some frequency bands in which the power is increased after the maintenance, as the warm colours denote. This behaviour is specially marked on the vibrations of the right-hand side in the Madrid-Seville direction.

- 650 Hz – 1500 Hz: warm colours (orange, red) are the dominant ones in this region, which imply that the spectral power is increased in this frequency region after the wheels reprofiling.
- 1500 Hz – 2560 Hz: the prevailing colour is blue or dark blue, which means that the spectral power of the signals is reduced not only just after the maintenance process (operating state A), but also in the following weeks (operating state L). This is consistent with the wheel reprofiling according to the literature.

White stripes mean that the power variation of that band is lower than the threshold. A look at the figures shows that they are usually at decomposition level 1, which means that the power variation in the 0-1280 Hz is small.

4 Conclusions and Contributions

A high-speed train bogie is studied before and after a major maintenance operation that consisted of reprofiling the wheels. In order to achieve this goal, accelerometers are installed on both axle box covers of a trailer axle. Vibrations recorded in the vertical direction are analysed by using EGRSC and ECBF techniques.

Considering the results given by these methods, it is confirmed that the wheels reprofiling improves the dynamic performance of the bogie, as a lower vibration level is recorded. This phenomenon is observed in both accelerometers and travel directions.

The track has a great influence on the signals recorded as it can be deduced from the ECBFs. They show similar patterns, but also significant differences when a detailed study is done by observing the higher decomposition levels.

The reduction of the spectral power in the frequency range between 1500 Hz and 2560 Hz agrees with the expected performance after a wheel reprofiling operation. This is most noticeable in lower decomposition levels.

On the other hand, the low-frequency region (0-1280 Hz) is less sensitive to wheel reprofiling. This region is coloured in white in the ECBF (for low decomposition levels), which indicates the power variation is under 10% of the spectral registered before performing the maintenance operation.

The vibration level is also reduced in the frequency bands that contain the frequencies of the sleeper pass frequency and the ball spin frequency of the roller bearing, which are both around 125 Hz at 270 km/h.

Finally, a comprehensive analysis focused on medium and higher decomposition levels shows the existence of particular frequency regions with the same performance in both sides and travel directions: the spectral power decreases significantly in the frequency ranges: 450 to 550 Hz, 1500 to 1700 Hz and 1800 to 2400 Hz. Additionally, the spectral power is significantly raised in the 600 to 800 Hz frequency range. These four frequency bands should be used as indicators of the bogie condition on future maintenance actions.

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