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Ride comfort evaluation on Alfa Pendular trains during the Porto – Lisbon connection

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Abstract

Comfort is a key condition to keep customers satisfied. On train journeys this parameter is highly influenced by vibration transmission from the vehicle to the user, resulting in whole-body vibration. ISO 2631 standard is specially dedicated to the measurement and evaluation of this type of vibration.

In the present study, this methodology was applied to evaluate the whole-body vibration on the Portuguese Alfa Pendular trains during the Porto – Lisbon connection. Measurements were performed on 3 different seat locations inside the train. Regarding total acceleration, the obtained results were very low, and the comfort of the journeys was confirmed. Moreover, the seat surface showed to amplify the floor vibration. The acceleration measurements were also classified according with the comfort level and highlighted the trip comfort and vibration transmission.

This was the first whole-body vibration study performed on Portuguese trains.

Keywords: Comfort analysis, whole-body vibration, trains, ISO 2631.

1 Introduction

In the rail industry the comfort, safety and user conditions are the key to keep the costumers satisfied [1, 2]. Vibration is the common factor that influences these three parameters, once it is derived from train motion, it is considered a primary concern. Vibration is transmitted to the user through the body contact with the seat and floor causing whole-body vibration (WBV) [3, 4]. Besides affecting the comfort, multiple studies show evidence that vibration can lead to fatigue and diseases [3, 6–10].

Therefore, study the whole-body vibration transmission and comfort levels on train journeys is a concern and it is crucial to assess the harmful consequences of vibration on passengers which can be evaluated by the standard ISO 2631, for both health and comfort [5].

The purpose of this study was to evaluate the whole-body vibration related with comfort on the Portuguese Alfa Pendular trains under normal operating conditions. The objective was to evaluate the comfort during the Porto – Lisbon connection, compare different seat types (comfort and standard) and seat localization.

1.1.WBV evaluation – ISO 2631

The ISO 2631 method is based on the acceleration measurement along three axis (x, y, z). The measurements are used to determine the root mean square (RMS) acceleration. Depending on the human tissue's characteristics, vibrations with identical intensities but different spectral content will produce different dynamic responses. Therefore, to quantify this effect, the standard applies weighting curves, which will induce different weights to the RMS accelerations depending on their impact on the human body [11]. The result of this process is the weighted RMS acceleration, Equation (1):

$$a_w = \left[\sum (W_i a_i)^2\right]^{1/2} \tag{1}$$

Where W_i represents the weighting frequencies and a_i the RMS accelerations. The weighting curves are dependent on the measurement site and purpose. Once the RMS acceleration is calculated for each axis, the total vibration (a_v) is obtained following Equation (2):

$$a_v = \left(k_x^2\, a_{wx}^2 + k_y^2\, a_{wy}^2 + k_z^2\, a_{wz}^2\right)^{1/2} \tag{2}$$

Where a_w are the RMS accelerations for each axis and k is the multiplying factor of the measuring position. The comfort level is evaluated by a defined scale, table 1 [5].

$a_v (m/s^2)$	Ride comfort
≤ 0.315	Not uncomfortable
0.5 – 0.63	Little uncomfortable
0.63 – 0.8	Little uncomfortable to fairly uncomfortable
0.8 – 1.0	Fairly uncomfortable to uncomfortable
1.0 – 1.25	Uncomfortable
1.25 – 1.6	Uncomfortable to very uncomfortable
1.6 – 2.0	Very uncomfortable
2.0 – 2.5	Very uncomfortable to extremely uncomfortable
≥ 2.5	Extremely uncomfortable

Table 1: ISO 2631 comfort evaluation scale. Adapted from [10].

2 Methods

To realize the evaluation of the WBV and ride comfort analysis on the Alfa Pendular trains, the ISO 2631 approach was followed. Thus, 3-axial accelerometers were placed on the interface superficies between the user and the vibration source (feet, seat surface and seatback). The Alfa Pendular of 4000 series train is operated as a single unit divided into 6 cars where the 1st and 2nd cars are the comfort class, on the 3rd car is placed the bar and, the 4th, 5th and 6th cars are classified as standard class. The procedure consisted in taking 3 full journeys, according to the location and class on the begging (1st car), middle (4th car) and end (6th car) of the train. The experiments run regarding the Porto Campanhã - Lisbon Oriente connection. The track presents a total length of 275km, divided into 5 stations, and takes approximately 2h50m to complete.

2.1. Equipment and methodology

As previously stated, 3-axial accelerometers were used to perform in-situ measurements. Specifically, the used equipment was the PCE-VDL-24I Accelerometer (scale range: ±16g, sample rating between 0 – 2400Hz, precision: ±0.24g, resolution: 0.0039g). Each accelerometer was fixed into a disc format flexible silicone seat pad. The equipment's were attached according with the ISO 2631 indications on the superficies where the vibration transmission from the train to the passenger occurs, namely on the floor, seat surface and seatback. An illustration of the experimental setup can be found in figure 1.

Figure 1: Experimental setup.

Once the ISO 2631 states that the relevant frequency spectrum for human comfort analysis is between 0.5 and 80Hz, a sample rate of 200Hz was defined, obeying this way to the Nyquist theorem. Moreover, the measurements occurred synchronously which allows to study the evolution of the vibration on the seat.

For the data analysis, a script was developed in Matlab following the ISO 2631 recommendations and applying its frequency analysis spectrum, frequency weighting curves and multiplying factors, table 2.

	X - axis	Y - axis	Z - axis
Floor	W_k and $k_x = 0.25$	W_k and $k_y = 0.25$	W_k and $k_z = 0.40$
Seat surface	W_d and $k_x = 1.0$	W_d and $k_y = 1.0$	W_k and $k_z = 1.0$
Seatback	W_c and $k_x = 0.80$	W_d and $k_y = 0.50$	W_d and $k_z = 0.40$

Table 2: Frequency weighting curves and multiplying factors concerning the measurements.

Besides the comfort analysis of the journey, it was also calculated the maximum and minimum acceleration value per axis. Calculating the instantaneous comfort, it was possible to develop an observation concerning the acceleration % for each comfort level.

3 Results

Results are presented according to the vibration measurement place.

Measurement results for the floor

Ride comfort evaluation was ranked as “Not uncomfortable” for all journeys, table 3.

	$a_v (m/s^2)$	Ride comfort
Car 1	0.0656	not uncomfortable
Car 4	0.0556	not uncomfortable
Car 6	0.0610	not uncomfortable

Table 3: Ride comfort evaluation.

The max and minimum acceleration also revealed the same standard and, the results were similar depending on the axis, table 4.

	Maximum acceleration			Minimum acceleration		
	X	Y	Z	X	Y	Z
Car 1	0.2533	0.2316	3.0903	-0.2214	-0.2484	-0.6579
Car 4	0.2762	0.2188	3.0809	-0.2470	-0.2484	-0.5473
Car 6	0.2017	0.2385	3.0857	-0.2334	-0.1876	-0.5361

Table 4: Maximum and minimum acceleration values.

Concerning the acceleration % per comfort level, results evidenced the analogy of the measurements, figure 2.

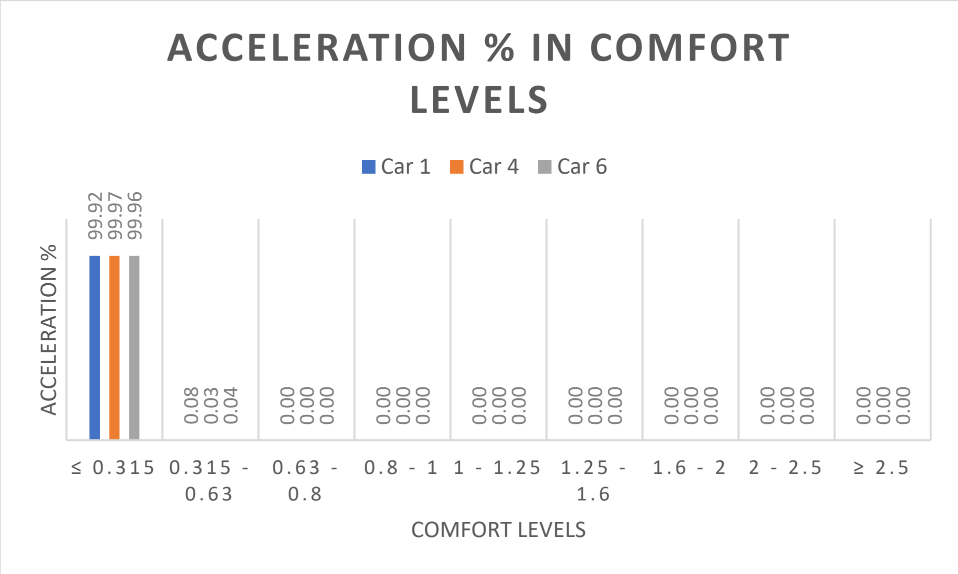

Figure 2: Comfort levels.

Measurement results for the seat surface

Regarding the seat surface, the journeys were revealed to be “Not uncomfortable”, table 5.

	$a_v(m/s^2)$	Ride comfort
Car 1	0.2593	not uncomfortable
Car 4	0.2783	not uncomfortable
Car 6	0.2716	not uncomfortable

Table 5: Ride comfort evaluation.

Compared with floor results, an increase of around 0.200 m/s^2 was observed. Thus, the seat surface is amplifying the vibration. The same trend was observed for the maximum and minimum values, once they also increased when compared with the floor results, table 6.

	Maximum acceleration			Minimum acceleration		
	X	**Y**	**Z**	**X**	**Y**	**Z**
Car 1	0.6022	0.9161	7.0951	-1.8200	-1.2032	-2.2171
Car 4	0.7274	0.8380	7.1682	-1.5170	-1.3564	-3.0202
Car 6	0.5886	1.1592	6.9677	-1.4720	-0.9690	-3.0142

Table 6: Maximum and minimum acceleration results.

The comfort levels percentages showed a higher number of records attending higher discomfort levels, figure 3.

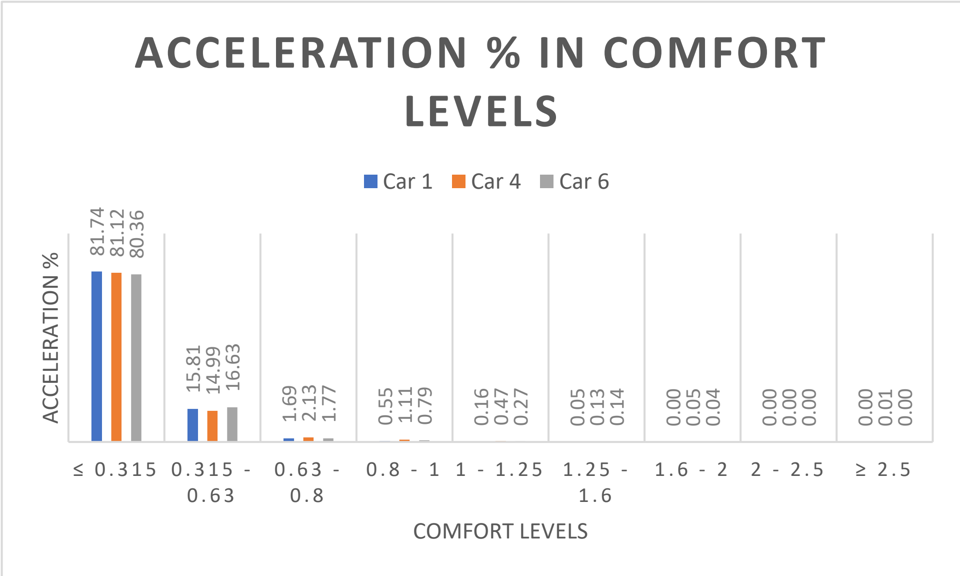

Figure 3: Comfort levels.

Measurement results for seatback

All journeys were ranked as "Not uncomfortable", table 7.

	$a_v (m/s^2)$	Ride comfort
Car 1	0.1727	not uncomfortable
Car 4	0.1684	not uncomfortable
Car 6	0.1460	not uncomfortable

Table 7: Ride comfort results.

Results showed a 0.100 m/s^2 decrease when compared with seat surface results, traducing on vibration mitigation.

Maximum and minimum results presented the higher peaks for the X-axis, table 8.

	Maximum acceleration			Minimum acceleration		
	X	**Y**	**Z**	**X**	**Y**	**Z**
Car 1	3.4936	0.5019	2.3140	-1.3464	-0.7130	-0.7183
Car 4	2.5963	0.3742	2.4926	-1.3399	-0.6853	-0.7697
Car 6	2.6818	0.5861	2.4748	-1.1189	-0.5170	-0.7908

Table 8: Maximum and minimum results.

Comfort levels % revealed to be similar with results found concerning floor measurements, figure 4.

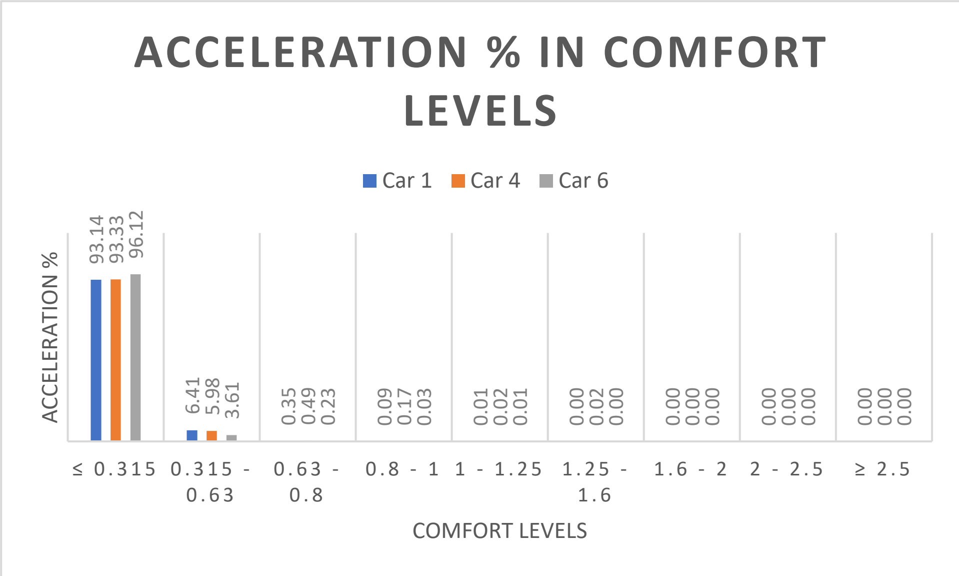

Figure 4: Comfort levels.

4 Conclusions

ISO 2631 approach was used to evaluate the ride comfort on the Alfa Pendular trains concerning the Porto – Lisbon connection. Whole-body vibration measurements and results indicated that the journey can be considered as comfortable and so, the user is exposed to a safe vibration level.

Considering the ride comfort evaluation, all journeys were ranked as “Not uncomfortable” level, with the highest value of 0.2783 m/s2 obtained for the seat surface on coach 4 seat. The presented results highlight the comfortable journeys in terms of vibration exposure.

Comparing the total acceleration results concerning the three accelerometers location, it was observed that the seat surface amplifies the vibration when compared with both floor and seatback. Moreover, the floor presented lower vibration values. Max and minimum accelerations were also obtained as a complementary analysis. The results showed that for both floor and seat surface these peaks appeared on the Z-axis, while for the seatback the same occurred at the X-axis.

The acceleration percentage for comfort level demonstrated that the floor is the most comfortable location. Its higher accelerations are ranked on the second analysis level, “Little uncomfortable”. The seat surface presented higher discomfort levels ranked as “Extremely uncomfortable”. While the maximum accelerations for the seat back were slightly lower and defined as “Uncomfortable to very uncomfortable”. The percentage of each comfort level also highlights the vibration amplification on the seat surface and the comfort of the entire journey.

Relatively to the seat location on the train, the similarity of the ride comfort results pointed that this parameter doesn’t influence the overall journey comfort.

The literature review conducted for the elaboration of this study didn’t show references on the ride comfort analysis in Portuguese trains, suggesting this as a pioneer study in Portugal. The development of this topic in other trains can result in an improvement of quality and comfort for the users of the Portuguese trains.

The developed study verified that the passengers of the Alfa Pendular trains are travelling in a comfortable and healthy environment concerning vibration levels.

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