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Assessment of ride comfort of traction elevators using ISO 18738-1:2012 and ISO 2631-4: 2001 standards

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Abstract

Purpose – Ride comfort is one of the important factors affecting passenger health. Therefore, the elevator industry usually uses the International Organization for Standardization (ISO) 18738-1 standard to evaluate elevator ride quality and optimize elevator design. However, this method has certain limitations in its evaluation of comfort due to the problem of boundary division. The ISO 2631-4 standard is used as a general method of comfort evaluation in the current rail transit system, but it has not been applied in the elevator industry. In order to explore the difference and connection between the two standards, the author aims to conduct a detailed analysis on this.

Design/methodology/approach – Based on the elevator internet, a large amount of measured data of normal and abnormal vibration of elevator car were collected and analyzed and preprocessed; based on ISO 18738-1:2012 standard and ISO 2631-4:2001 standard, the differences of ride comfort assessment methods in the two standards were analyzed, and the ride comfort assessment study of elevator under normal and abnormal vibration conditions was carried out.

Findings – The experimental results show that the comfort assessment results of ISO 2631-4:2001 standard and ISO18738-1:2012 standard are consistent under two vibration conditions. At the same time, ISO 2631-4:2001 can not only provide a more accurate quantitative description of comfort, but also roughly determine the comfort interval of each vibration, which can provide theoretical reference for elevator vibration classification and car comfort design.

Originality/value – The authors designed an Internet of Things (IOT)-based elevator vibration signal acquisition method to address the shortcomings of the previous elevator ride comfort assessment methods, which can realize the dynamic assessment of elevator ride comfort; by comparing the assessment results of elevator ride comfort under normal vibration and abnormal vibration, the feasibility of ISO 2631-4:2001 for elevator ride comfort assessment was fully verified. In addition, the experimental results also give the influence of abnormal vibration on elevator riding comfort under the stages of start-stop, uniform speed, acceleration and deceleration, which can provide theoretical support for elevator vibration suppression and comfort transformation.

Keywords Vibration, Ride comfort, Elevator Internet, Data analysis

Paper type Research paper

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1. Introduction

As elevator ownership in China continues to grow and elevator use becomes more frequent, the safety risks posed by elevators are gradually drawing the attention of all sectors of society, and property management in some communities is also putting forward higher requirements for elevator riding experience (Oh *et al.*, 2020). Vibration is one of the most important factors affecting the ride comfort of traction elevators. They may hinder the normal operation of elevators at light and cause serious safety accidents at worst (Li *et al.*, 2019). Since the elevator is attached to the guide way and runs reciprocally under the action of the traction machine, passengers may feel obvious weightlessness or overweight phenomenon due to the presence of acceleration, thus causing certain physiological and psychological shadows (Zhou *et al.*, 2018). Therefore, a reasonable assessment and suppression of elevator vibration is essential.

With the increase in elevator operating speed and car compliance, the difficulty of maximizing elevator ride comfort is gradually increasing. Knezevic *et al.* (2017) proposed a solution to upgrade the speed controller based on jerk and band-stop filters to compensate for the loss of ride comfort due to vibration. At the same time, Qiu *et al.* (2020) used a multiobjective genetic algorithm to optimize the design parameters of horizontal vibration reduction, which improved the ride comfort of high-speed elevators. Although the optimization of elevator design is of great significance to the improvement of ride comfort, there is no clear assessment standard for elevator ride comfort at home and abroad, so it is impossible to accurately assessment the elevator comfort before and after optimization.

Experience in the elevator industry has shown that the assessment of vibration peak-to-peak value (VPPV) is specifically related to passenger comfort. Therefore, the current common elevator ride comfort assessment methods are based on this parameter to qualitatively classify vibration as “comfortable” or “uncomfortable” (Guo *et al.*, 2013). However, the human body’s perception of vibration is not nonleft is right, and discrete assessment alone is not enough to accurately express the human body’s acceptance of vibration. In addition, this method usually requires specialized instruments (e.g. Elevator Vibration Analyzer (ENV)-625) to arrive on site, and the measurement is performed without external forces and vibrations (Ouyang *et al.*, 2018), which is a static comfort assessment method. Studies have shown that elevator ride comfort has a large correlation with the number of passengers and ride time, and the probability of abnormal vibration is small, so the previous measurement methods do not provide a reasonable assessment of elevator ride comfort. For this reason, many experts and scholars have carried out research work on elevator ride comfort assessment one after another. Ling and Xu (1996) proposed a fuzzy comprehensive assessment method for elevator comfort based on the analysis of factors affecting elevator comfort such as elevator acceleration, acceleration rate of change and vibration. But Aldaia *et al.* (1996) pointed out the shortcomings of using a single indicator as the comfort assessment and suggested using International Organization for Standardization (ISO) 2631 as the basic assessment model for elevator comfort. Zhang *et al.* (2018) also used this standard as a theoretical basis to design elevator ride comfort assessment software based on cell phone gyroscopes and conducted comparison experiments with professional instruments at different floors and under different loads. However, the results of the study show that ISO 2631-1 is not fully applicable to the comfort assessment of rail transit systems (Haji Abdulrazagh *et al.*, 2022).

In summary, there are few studies on elevator vibration comfort assessment in the elevator industry, and most of them are based on the vibration measurement data of a single elevator in the vertical direction for analysis, and few scholars have validated and analyzed the elevator vibration comfort assessment method combined with big data. This paper takes a large number of cabin vibration signals collected from elevator Internet as the research object, and uses the ride comfort assessment methods in ISO 18738-1 (2012) and ISO 2631-4 (2001) standards as technical means to analyze the actual measurement data of normal vibration and abnormal vibration of elevators for comfort assessment and derive the corresponding assessment results.

2. Vibration comfort assessment methods

Experience in the elevator industry has shown that the assessment of vibration peaks has a specific connection with passenger comfort, Therefore, the ISO 18738-1:2012 standard specifies the corresponding expression of the quantitative VPPV, and GB/T 10058 -2009 gives the upper limit of the horizontal and vertical VPPV. ISO 2631-4: 2001 is widely used in rail systems (heavy rail and light rail), maglev rail systems and rubber-tired subway systems as an assessment standard for the comfort of passengers and crew in fixed rail transportation systems. Elevator is an important member of vertical rail transit system, but few scholars in the industry use this standard to assessment the impact of vibration on passenger comfort.

2.1 Vibration comfort assessment method based on ISO 18738-1:2012

As stated in ISO 18738-1:2012, the lift vibration signal is not an acceleration signal in the time domain, but is derived by frequency weighting the acceleration signal through the whole body x, y, z axis weighting factors and band limits. The VPPV as the sum of the absolute values of two peaks of opposite sign separated by a single over-zero point is closely related to the comfort of the passengers. Therefore, GB/T 10058-2009 stipulates the maximum vibration peak-to-peak value (Max-VPPV) of horizontal (x-axis and y-axis) and vertical (z-axis) vibration and the upper limit of A95-VPPV when the passenger elevator is running during the constant acceleration period. Passenger comfort is considered comfortable if both are less than the upper limit shown in Table 1. Among them, the Max-VPPV mainly assessments the instantaneous impact of vibration on passenger comfort at a certain moment, while the A95-VPPV assessments the overall impact of vibration in a certain interval on passenger comfort.

In the assessment process, ISO 18738-1:2012 also stipulates that the three-axis signal quantities related to acceleration, deceleration, jerk and vibration should be divided according to the four boundaries shown in Figure 1. Boundaries 0 and 3 are at least 0.5s before the elevator leaves the starting station and after arriving at the end station, respectively, and boundaries 1 and 2 are 500 mm after the elevator starts running and before it stops running, respectively. The Max-VPPV in the horizontal direction and the A95-VPPV shall be calculated from the weighted x-axis and y-axis signals between boundary 1 and boundary 2; In the vertical direction, not only the Max-VPPV and A95-VPPV of the weighted Z-axis vibration signal in the constant acceleration region between boundary 0 and boundary 3 are calculated, but also the Max-VPPV of this vibration signal in the variable acceleration region.

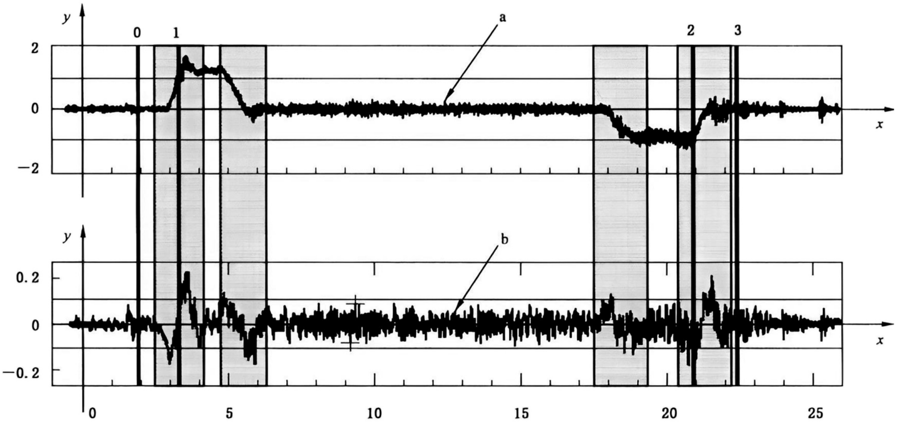
2.2 Vibration comfort assessment method based on ISO 2631-4:2001

ISO 2631-1 (1997) defines a basic model of human exposure to whole-body vibrations and comprehensively analyzes the impact of vibration frequency, amplitude and direction on passenger health, comfort and motion sickness through a basic assessment method of frequency-weighted root-mean-square (RMS) acceleration. The assessment method is generally valid for vibrations with a crest factor less than or equal to 9.

Table 1.
The upper limit of vibration peak-to-peak value in different directions

	Max-VPPV/(ms^{-2})	A95-VPPV/(ms^{-2})
Horizontal	0.2	0.15
Vertical	0.3	0.2

ISO 2631-4:2001 is a specific application of the ISO 2631-1:1997 standard to fixed rail transit systems. The assessment methods are all based on the use of frequency weighting to calculate the total vibration a_v. Frequency-weighted RMS acceleration can be determined by weighting and summing narrowband data or 1/3 octave band data. ISO 2631-4:2001 stipulates that for the data conversion of 1/3 octave band, the weighting coefficient W_d is used in the horizontal direction and the weighting coefficient W_b is used in the vertical direction, and the corresponding frequency weighting curves are shown in Figure 2.



Source(s): ISO, 18738-1:2012

Figure 1. Unweighted (a) and weighted (b) z-axis vibration signals for constant (white) and variable (gray) acceleration

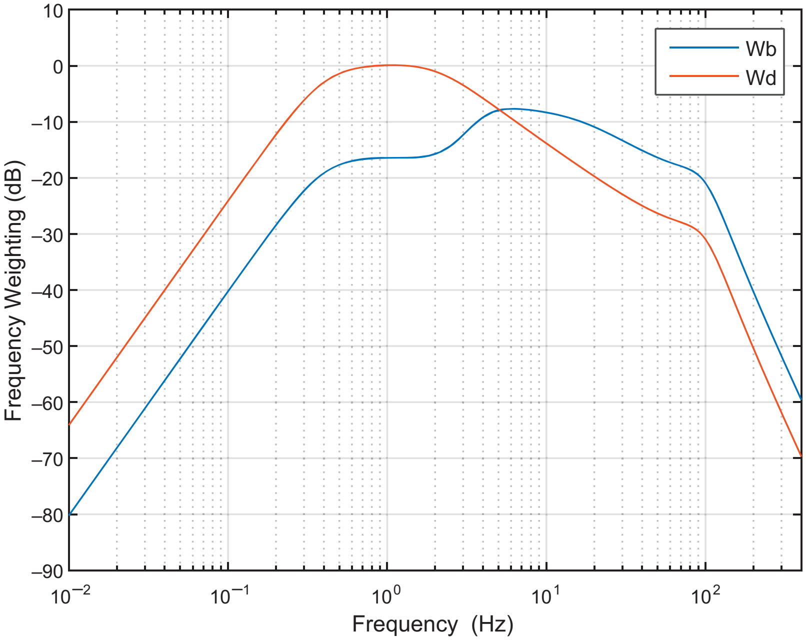


Figure 2. Frequency weighting curves of different weighting factors

Regarding the total value of the weighted acceleration in the horizontal and vertical directions, it can be calculated in the frequency domain using the following equation

$$\begin{cases} a_{w\_x} = \left[\sum_i \left(W_{d\_i} \cdot a_{x\_i}\right)^2\right]^{\frac{1}{2}} \\ a_{w\_y} = \left[\sum_i \left(W_{d\_i} \cdot a_{y\_i}\right)^2\right]^{\frac{1}{2}} \\ a_{w\_z} = \left[\sum_i \left(W_{b\_i} \cdot a_{z\_i}\right)^2\right]^{\frac{1}{2}} \end{cases} \tag{1}$$

where: a_{w_x}, a_{w_y} and a_{w_z} are the weighted RMS accelerations on the x, y and z axes of the orthogonal coordinate systems, respectively, W_{b_i} and W_{d_i} are the weighted coefficients at the i-th 1/3rd octave band corresponding to Figure 2, respectively, and a_{x_i}, a_{y_i} and a_{z_i} are the RMS accelerations at the i-th 1/3rd octave band on the corresponding coordinate system, respectively.

The multidirectional synthetic vibration is determined by the total amount of vibration of the weighted root mean square acceleration in the orthogonal coordinate system, expressed as

$$a_v = \left(k_x^2 a_{w\_x}^2 + k_y^2 a_{w\_y}^2 + k_z^2 a_{w\_z}^2\right)^{\frac{1}{2}} \tag{2}$$

Where: a_v is the total value of the weighted RMS acceleration and k_x, k_y and k_z are the direction factors. For different posture, the direction factors shown in Table 2 are given in ISO 2631-1:1997. Since most of the passengers in the elevator maintain their standing posture, the direction factor in Eq. (2) is taken as 1 when evaluating comfort.

ISO 2631-4:2001 recommends the use of the total value of weighted RMS acceleration a_v for the assessment of human comfort. The approximate description of passenger responses corresponding to different values of the weighted RMS acceleration in this standard is shown in Table 3.

Table 2.
Direction factor in different poses

Posture	k_x	k_y	k_z
Sitting	1.4	1.4	1
Standing	1	1	1
Lying	1	1	1

Table 3.
The relationship between total value of weighted RMS acceleration and human comfort

RMS acceleration total value/ms^{-2}	Human comfort
<0.315	Feel no discomfort
0.315–0.63	A little uncomfortable
0.5–1	Quite uncomfortable
0.8–1.6	Uncomfortable
1.25 to 2.5	Very uncomfortable
>2	Extremely uncomfortable

2.3 Comparison of two standard comfort assessment methods

According to the description of the vibration comfort assessment methods in the above two standards, it can be concluded that there are certain differences between the two standards in terms of calculation boundaries, crest factor, passenger posture, assessment type, assessment area and assessment results. The comparison of the assessment methods of the two standards is shown in Table 4.

It can be seen from Table 4 that when the test data does not meet the crest factor of the ISO 2631-4:2001 comfort assessment method, the comfort assessment method of ISO 18738-1:2012 is recommended; When the impact of instantaneous vibration and interval vibration on passenger comfort needs to be comprehensively considered, the comfort assessment method of ISO 18738-1:2012 is recommended; When it is necessary to consider the more accurate description of human comfort from different poses or vibrations in the whole range, it is recommended to use the comfort assessment method of ISO 2631-4:2001.

3. Vibration data acquisition and preprocessing based on elevator internet

3.1 Vibration signal acquisition

The traditional elevator vibration signal acquisition not only requires staff to enter the scene with professional instruments, but also this method can usually only give a corresponding objective assessment for a certain elevator trip. Studies have shown that elevator ride comfort is usually closely related to the number of passengers and ride time. For example, during the rush hour, with the gradual increase in the number of people taking the elevator, the comfort of the elevator will show a significant downward trend; at the same time, the probability of accidents will also increase accordingly (Lan *et al.*, 2021). Therefore, an occasional anomaly does not determine the overall quality of an elevator. In order to solve this problem, this paper develops an elevator vibration signal acquisition device based on the internet of Things, which can realize the dynamic acquisition of elevator operation data within 24 h. The working principle of the device is shown in Figure 3 below. Firstly, the elevator three-axis vibration acceleration is collected by installing an acceleration sensor on the elevator; secondly, the sensor communicates with the elevator gateway through the RS485 protocol; thirdly, the elevator gateway sends the collected vibration signals to the cloud platform through the Modbus protocol for preliminary vibration signal analysis; finally, a corresponding database is established to store the normal and abnormal vibration signals of the elevator.

The running process of the elevator can be subdivided into start, acceleration, uniform speed, deceleration and stop phases. Figure 4 shows the changing trend of speed and acceleration during the whole running process of the elevator. Among them, zone ① corresponds to the parking zone, including the starting and stopping phases; zone ② corresponds to the acceleration and deceleration zones, including the acceleration and deceleration phases; zone ③ corresponds to the uniform speed zone.

	Standards ISO 18738-1:2012	ISO 2631-4:2001
Calculation boundaries	Have	None
Crest factor	Not consider	Consider
Passenger posture	Not consider	Sitting, standing and lying
Assessment type	Instantaneous, interval	Interval
Assessment area	Constant acceleration area	All area
Assessment results	VPPV	Total value of weighted RMS acceleration

Table 4.
Comparison of comfort assessment methods

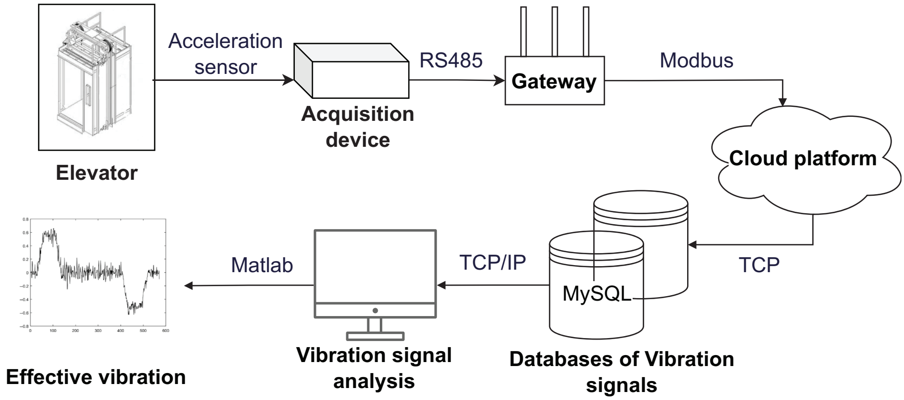


Figure 3.
Vibration signal acquisition flow chart

Studies have shown that the horizontal vibration of the elevator during the running process has little effect on the ride comfort; while the vibration signal generated in the vertical direction always includes obvious acceleration, deceleration and uniform stages, which has a greater impact on the ride comfort. In order to further explore the influence of the vibration generated by the elevator in different running stages on the ride comfort and the similarities and differences of using different standards to assessment the elevator ride comfort. The author obtained a total of 7 types and more than 4,200 elevator vibration signals from the database described in Figure 3, among them, there are 1 normal vibration signal and 6 abnormal vibration signals, and the ratio of each type of data is 1:1. For various types of abnormal vibration, Figure 5 shows an example diagram of the *z*-axis vibration signal. Compared with the normal vibration signal, the six types of abnormal vibration are all shown as follows: the amplitudes of the respective corresponding stages are all greater than the threshold specified for the safe operation of the elevator.

3.2 Vibration signal denoising

Although the vibration signals collected during elevator operation mainly come from the car, other factors such as guide rails, traction machines, wire ropes, etc., will cause the collected vibration signals to contain noise. For such nonstationary signals, the traditional Fourier transform denoising method is no longer adequate, but the wavelet transform (Rhif *et al.*, 2019), which has the advantages of multiresolution, de-correlation and base selection flexibility, is strongly superior in dealing with such signal noise. Since the inherent vibration of the elevator itself is a low-frequency signal, this paper considers using a wavelet packet multithreshold denoising method suitable for extracting low-frequency signals to preprocess the vibration signal.

The denoising process is realized based on the MATLAB platform. After preliminary analysis, db4, which is widely used in practical engineering, is selected as the wavelet base. Because db4 is orthogonal, it can perform random decomposition, and at the same time, it also has a high support ability, which can prevent the loss of high-frequency signals (Qifeng *et al.*, 2016). Figure 6(a) shows the vertical acceleration signal of an elevator. It can be seen from the figure that the signal contains obvious noise.

By analyzing the signal characteristics, it was finally determined that three-layer wavelet packet decomposition was performed on all the collected vibration signals. At the same time, due to the existence of the high-pass filter, the phenomenon of signal “flipping” will occur every time the wavelet decomposition is performed, that is, the signal is arranged from small to large in the low-frequency part and the high-frequency part is arranged from large to small

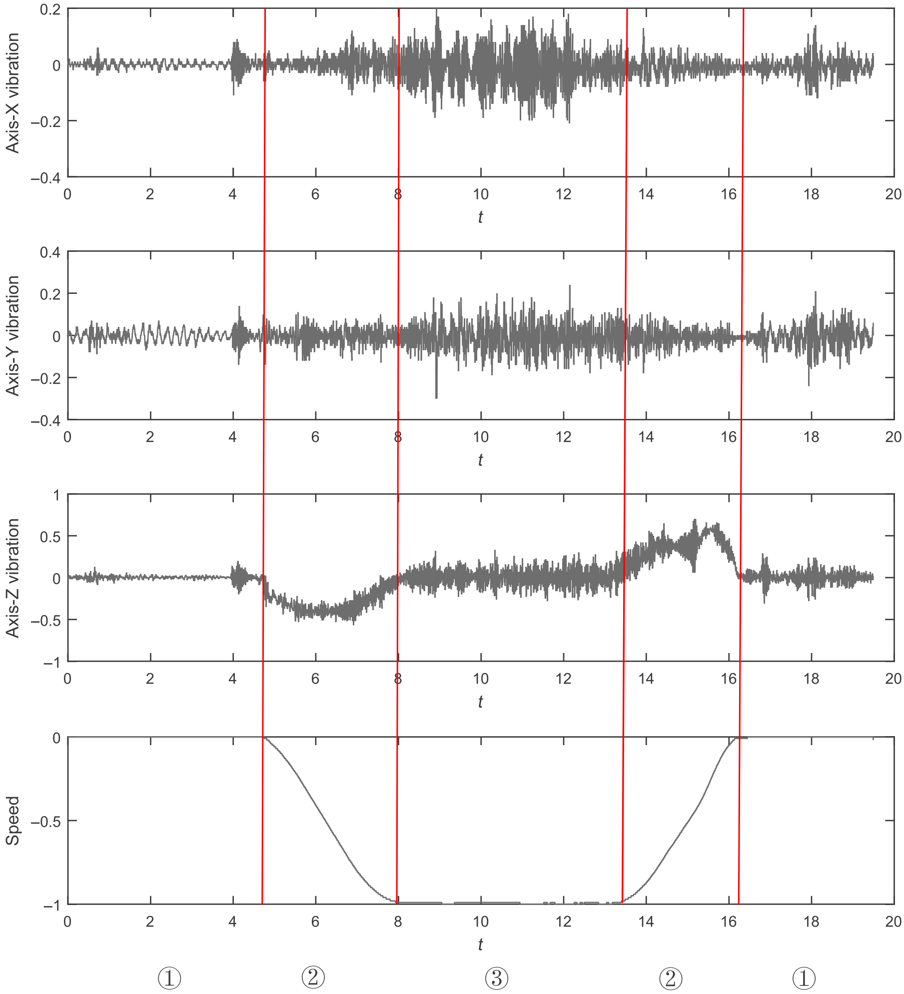


Figure 4.
Elevator vibration signal interval division

(Sun and Zhang, 2021). In order to solve the “flip” problem, after each decomposition, this paper will rearrange the corresponding frequency bands of this layer of nodes from small to large, and the changes of each layer of nodes before and after the arrangement are shown in Figure 7. Among them, the signal corresponding to node 7 is the approximate value of the original signal, and the noise exists in other nodes. By selecting appropriate thresholds for different frequency bands to filter out the noise, and then reconstructing the wavelet packet, the denoised vibration signal shown in Figure 6(b) can be obtained.

4. Comparative analysis of ride comfort under different vibration conditions

4.1 Ride comfort assessment and analysis of normal vibration signals

4.1.1 Assessment results of ride comfort based on ISO 18738-1:2012. Based on the 600 normal elevator vibration signals collected in Section 2.1 and processed by the denoising algorithm in Section 2.2, the assessment method described in ISO 18738-1:2012 is used to calculate the

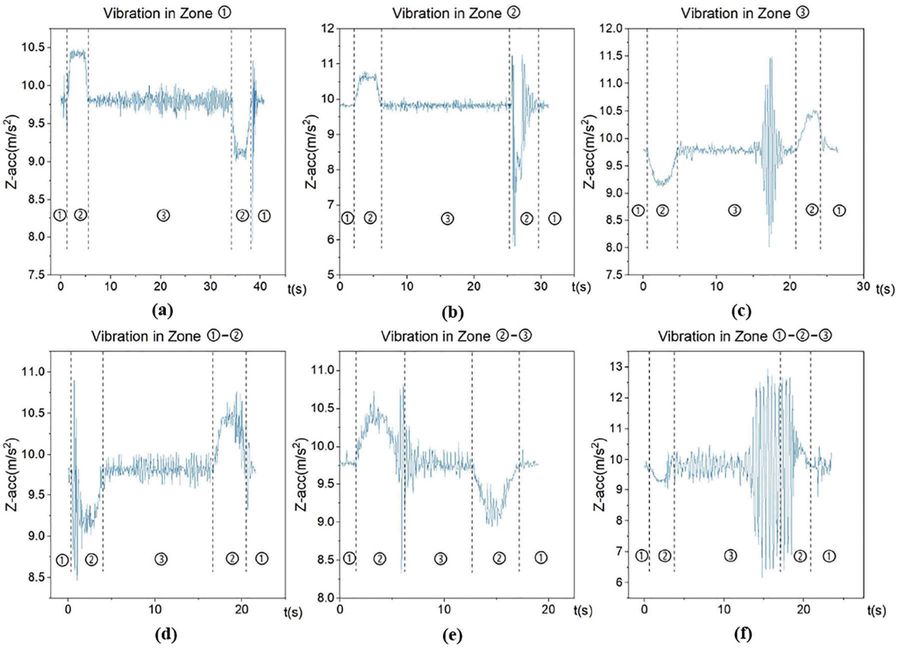
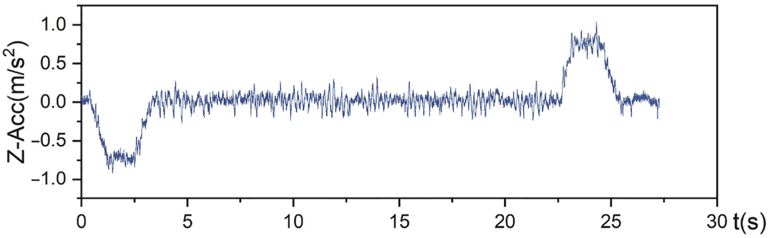
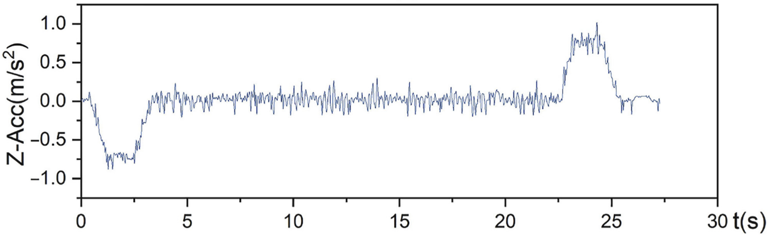


Figure 5.
Example diagram of *z*-axis vibration signal of 6 types of abnormal interval vibration



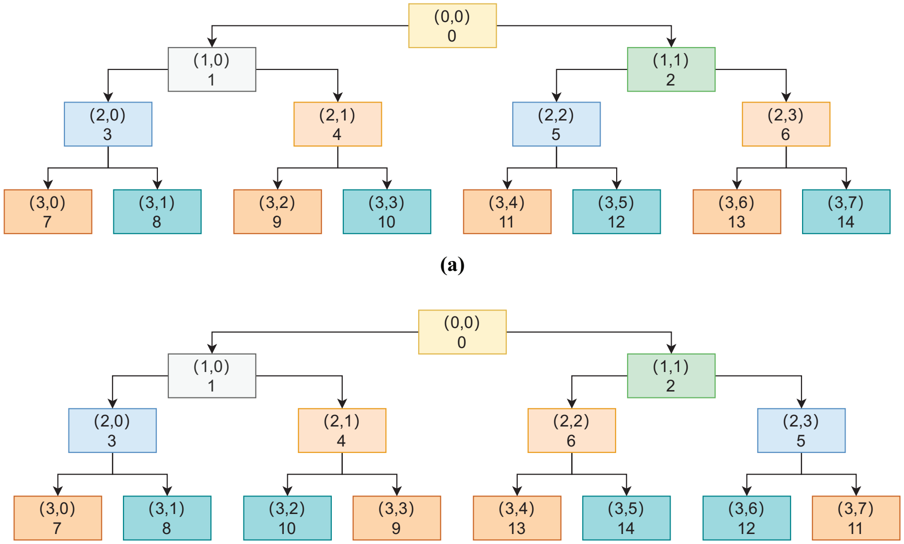
Z-axis acceleration before denoising
(a)



Z-axis acceleration after denoising
(b)

Figure 6.
Comparison of *z*-axis vibration signals before and after denoising

Max-VPPV and A95-VPPV in the constant acceleration area in the horizontal and vertical directions of the elevator car, which is used as the assessment basis for passenger comfort. After calculation and analysis, the A95-VPPV and Max-VPPV corresponding to 600 normal



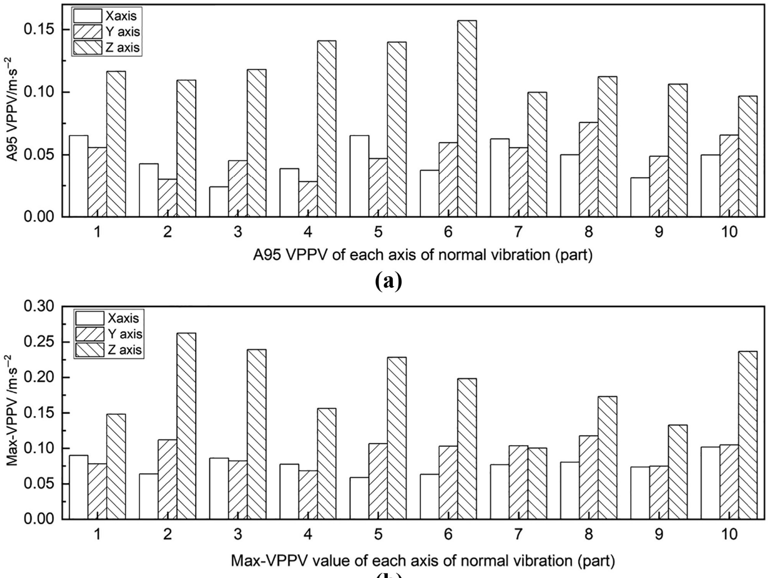
(a)

(b)

Figure 7.
Corresponding node changes before and after wavelet packet coefficient rearrangement

vibration measured data can be obtained. Figure 8 shows a partial display of the VPPV calculation results of this experiment.

Among them, the abscissa represents the *i*-th normal vibration signal, and the ordinate represents the A95-VPPV and the Max-VPPV of each axis corresponding to this vibration



(a)

(b)

Figure 8.
The VPPV of the normal vibration signal (part)

signal. Figure 9 shows the overall distribution of the VPPV of each axis of the 600 pieces of normal vibration measured data.

Combining the results of Figures 8 and 9, it can be seen that the A95-VPPV and the Max-VPPV of each axis of the 600 pieces of normal vibration measured data are both smaller than the upper limit shown in Table 1, so the comfort assessment results of these 600 normal vibration signals are all shown as comfortable. At the same time, it can be seen from Figure 9 that during the normal operation of the elevator, the vibrations generated by the *x*-axis and the *y*-axis have a certain similarity, while the vibration generated by the *z*-axis is much larger than the other two axes. Therefore, the *z*-axis vibration is the main factor affecting passenger comfort.

4.1.2 Assessment results of ride comfort based on ISO 2631-4:2001. The research results show that the crest factor in the elevator operation process meets the conditions of use of the basic assessment method of ISO 2631-1:1997. Therefore, the ISO 2631-4:2001 standard as the basic assessment method in the fixed rail system can also be used for the assessment of elevator comfort. After the same preprocessing operation as in Section 3.1.1, the measured data of elevator normal vibration is assessmented using the comfort assessment method in ISO 2631-4:2001, and the vibration comfort assessment results shown in Figure 10 can be obtained. Among them, Figure 10(a) is the comprehensive vibration value of the 600 pieces of normal vibration measured data, and Figure 10(b) is the probability density function of the 600 pieces of data.

Comparing Figure 10(a) with the vibration total value in Table 3, as can be seen that when using ISO 2631-4:2001 to assessment 600 pieces of normal vibration measured data, all the comfort assessment results show that there is no discomfort. This assessment result is consistent with the vibration comfort assessment results of ISO 18738-1:2012. From Figure 10(b), as can be seen that the assessment results of this group of elevator normal vibration measured data approximately obey the normal distribution, so the comfort level of normal vibration can be further determined.

4.2 Ride comfort assessment and analysis of abnormal vibration signals

4.2.1 Assessment results of ride comfort based on ISO 18738-1:2012. Due to the scarcity of data resources for abnormal vibration in a single elevator, each type of abnormal interval

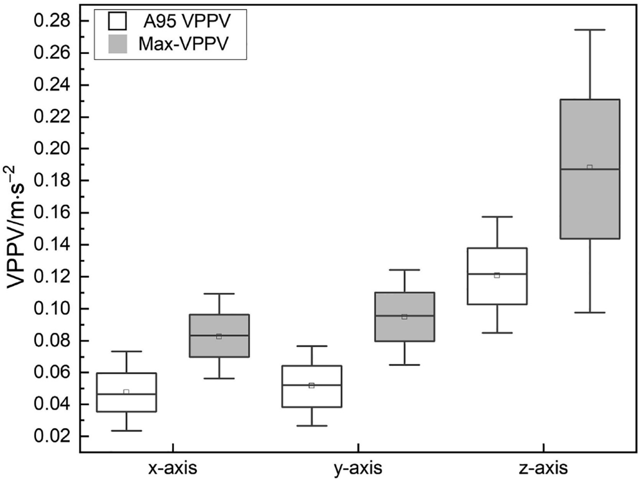


Figure 9.
The comprehensive distribution of the VPPV of each axis of the normal vibration signal

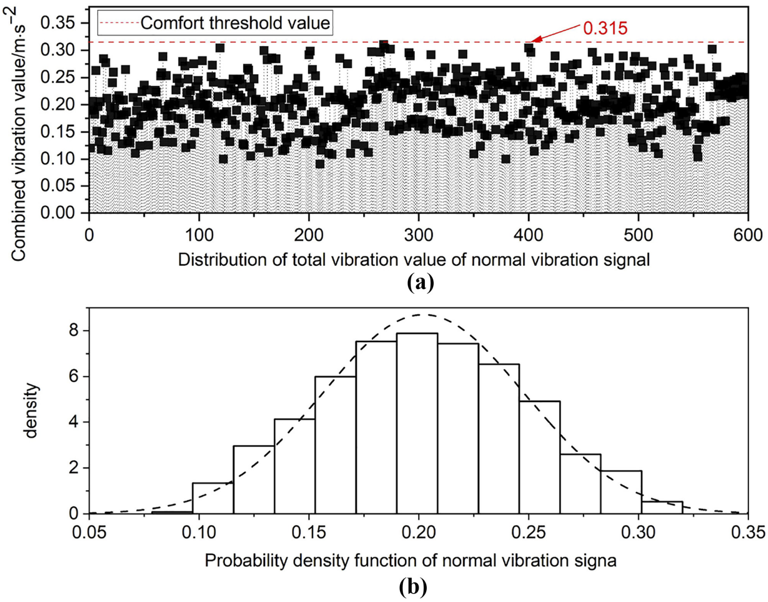


Figure 10. Comprehensive vibration total value and probability density function of normal vibration

vibration signal collected in section 2.1 does not originate from the same elevator, but is a collection of vibration data from different lifts under the same abnormal conditions. Although each lift has different design specifications, the effect of the same type of vibration on passenger comfort is physiologically consistent (Duarte *et al.*, 2018).

Since the acceptable amount of vibration for passengers is different, the comfort assessment experiment in this section aims to explore the average description of ride comfort for each type of abnormal vibration. Therefore, the peak-to-peak value of vibration used to assessment the comfort of each type of abnormal vibration is the average value of the peak-to-peak value of vibration of each axis under this type of abnormal vibration. The A95 peak-to-peak value of vibration and the assessment results of vibration comfort for different abnormal vibrations are listed in Table 5.

As it can be seen from Table 5 that when the A95-VPPV is used to assess the comfort level, the assessment results of the vibration in zones ① and ①–② are comfortable, while the assessment results of the other 4 types of abnormal vibration are all uncomfortable. Table 6 shows the mean values of the Max-VPPV for the different anomalous zones and the results of the comfort assessment.

Vibration interval	*x*-axis/ms^{-2}	*y*-axis/ms^{-2}	*z*-axis/ms^{-2}	Feeling
①	0.0823	0.0954	0.1848	Comfort
②	0.1636	0.1562	0.2154	Uncomfortable
③	0.1515	0.1446	0.2311	Uncomfortable
①–②	0.1067	0.0916	0.1936	Comfort
②–③	0.1665	0.1583	0.2043	Uncomfortable
①–②–③	0.2115	0.2367	0.6084	Uncomfortable

Table 5. A95-VPPV and comfort description under abnormal vibration

As can be seen from Table 6 that the Max-VPPV is used for comfort assessment, the riding comfort results of the 6 types of abnormal vibration are all uncomfortable.

The results of the assessment of vibration in zones ① and ①–② are different, while the assessment of vibration in other anomalous zones is consistent. The reasons for this are as follows:

(1) For the calculation of the VPPV in the horizontal direction, the calculation boundaries in the standard do not include the areas of severe vibration in zones ① and ①–②, resulting in the horizontal A95 vibration peaks and maximum vibration peaks for these two anomalous zones being small;

(2) For the calculation of the vertical vibration peaks, zone ① may only contain part of the anomalous signals, so the overall A95-VPPV for this zone may be small, but the Max-VPPV is not affected. ①–② area vibration belongs to the vibration of the variable acceleration region, the standard only considers its Max-VPPV, and the calculation of the A95-VPPV does not take this section of vibration into account.

Passenger discomfort differs to a certain extent depending on the mode of transport: when traveling in a car, the main consideration is the overall feeling of the car's vibration on the passenger in a certain interval, while when traveling in a lift, the violent vibration at a certain moment may cause a huge psychological shadow to the passenger. Therefore, its main consideration is the impact of transient vibration on passenger comfort. In summary, when using ISO 18738-1:2012 to assess passenger comfort in lifts, the Max-VPPV assessment method is recommended.

4.2.2 Assessment results of ride comfort based on ISO 2631-4:2001. After preprocessing the measured data from the 6 types of anomalous zones, the comfort level of the vibration data from each type of anomalous zone was assessed using the comfort assessment method in ISO 2631-4:2001, resulting in the overall vibration values for the different vibration conditions shown in Figure 11. As the amount of vibration acceptable to passengers varies, the overall vibration values for the same conditions in Figure 11 may vary slightly, but the vibration comfort levels for each of the anomalous zones are approximately normally distributed. The comfort levels for each of the abnormal zones can therefore be roughly determined from Figure 11.

Combining the total value of weighted RMS acceleration with the human comfort relationships given in Table 3, the overall vibration values for the different abnormal zones shown in Figure 11 are averaged to obtain the comfort assessment results for the different abnormal zones shown in Table 7.

As can be seen from Table 7, among the 6 abnormal interval vibrations, the vibration comfort of ①, ②, ③, ①–② and ②–③ zones are all shown to be a little uncomfortable, while the assessment result of vibration comfort in ①–②–③ zone is shown to be quite uncomfortable. The results are consistent with the Max-VPPV assessment results in ISO 18738-1:2012.

Table 6. The max-VPPV and comfort description under abnormal vibration

Vibration interval	x-axis/ms^{-2}	y-axis/ms^{-2}	z-axis/ms^{-2}	Feeling
①	0.1123	0.1147	0.3032	Uncomfortable
②	0.2196	0.2262	0.3553	Uncomfortable
③	0.2215	0.2146	0.3215	Uncomfortable
①–②	0.1364	0.1305	0.3304	Uncomfortable
②–③	0.2162	0.2276	0.3407	Uncomfortable
①–②–③	0.3220	0.3153	1.0136	Uncomfortable

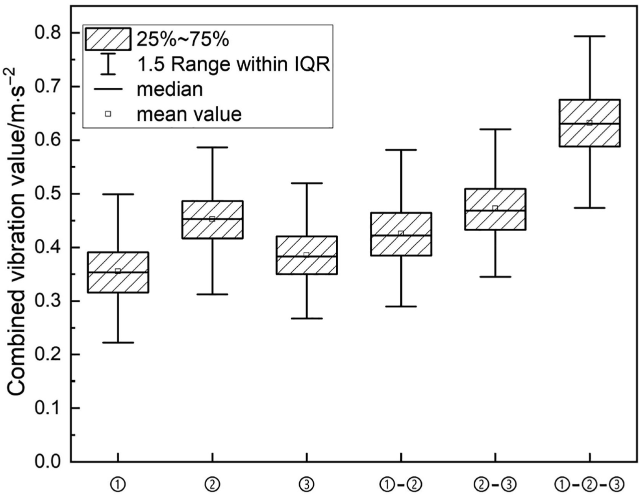


Figure 11.
Total value of comprehensive vibration under different vibration conditions

Vibration interval	Total integrated vibration value/ms^{-2}	Comfort
①	0.3536	A little uncomfortable
②	0.4533	A little uncomfortable
③	0.3843	A little uncomfortable
①–②	0.4240	A little uncomfortable
②–③	0.4719	A little uncomfortable
①–②–③	0.6313	Quite uncomfortable

Table 7.
Comprehensive vibration value and comfort level in abnormal range

4.3 *Comparative analysis of the assessment results of the two standards*

Table 8 shows the ride comfort assessment results of the above two standards under 7 vibration conditions.

(1) From the consistency of the assessment results: for the comfort assessment of normal vibration signals, the assessment results of ISO 18738-1:2012 and ISO 2631-4:2001 are consistent; For comfort assessment of vibration in abnormal intervals, the Max-VPPV assessment method of ISO 18738-1:2012 can accurately assessment the impact of various vibration in abnormal intervals on ride comfort, and the assessment results are consistent with ISO 2631-4:2001.

	ISO 18738-1:2012		ISO 2631-4:2001
Vibration conditions	A95-VPPV	Max-VPPV	Overall vibration value
Normal vibration	Comfort	Comfort	Comfort
Zone ①	Comfort	Uncomfortable	A little uncomfortable
Zone②	Uncomfortable	Uncomfortable	A little uncomfortable
Zone③	Uncomfortable	Uncomfortable	A little uncomfortable
Zones ①–②	Comfort	Uncomfortable	A little uncomfortable
Zones ②–③	Uncomfortable	Uncomfortable	A little uncomfortable
Zones ①–②–③	Uncomfortable	Uncomfortable	Quite uncomfortable

Table 8.
Comparison of the comfort assessment results of the two standards

(2) From the point of view of the differences in assessment results: for the comfort assessment of normal vibration signals, there are no differences between the Max-VPPV assessment method of ISO 18738-1:2012 and the A95-VPPV assessment method. However, for abnormal interval vibration, the two-vibration VPPV assessment methods have great differences in the assessment results of ① zone and ①–② zone vibration. At the same time, the comfort assessment method of ISO 18738-1:2012 focuses more on dividing passenger comfort into two levels from the perspective of safety; the comfort assessment method of ISO 2631-1:2001 divides human vibration comfort into 5 levels. Although it only occupies the first 3 levels in the assessment of elevator vibration comfort, it has covered the stage of passenger comfort, a little uncomfortable and quite uncomfortable.

(3) From the perspective of scalability of the assessment results, ISO 18738-1:2012 needs to calculate bounds to assist the solution of vibration VPPV, and the assessment results need to synthesize VPPV in three directions, so it is difficult to summarize functional or quantitative comfort descriptions. ISO 2631-4:2001 integrates the impact of vibration in the full frequency band on passenger comfort. Even instantaneous vibration can be accurately divided into the corresponding frequency band for weighting, and the assessment result is the specific quantified value of comfort. At the same time, the comfort assessment results of ISO 2631-1:2001 for each vibration shown that the total vibration value of each vibration is roughly normal distribution. Therefore, the comfort confidence interval of each vibration can be further determined.

5. Conclusion

In this paper, according to the current ISO 18738-1:2012 standard and ISO 2631-4:2001 standard, the author studies the differences of the comfort assessment methods in the two standards; And based on the elevator measured data collected by the elevator Internet, two standards were used to assessment the influence of the elevator’s normal vibration and abnormal vibration on the ride comfort. The results showed that: The assessment results of normal and abnormal vibration in the vibration range of the two standards are consistent, but ISO 2631-4:2001 can not only give specific quantitative values of comfort, but also roughly estimate the comfort interval of each vibration, and this method can provide the theoretical basis for future elevator vibration classification and optimal design, etc.

In terms of the realization principle of the comfort assessment methods in the two standards, both standards combine the weighted acceleration in three directions to assessment the passenger comfort. ISO 18738-1:2012 comprehensively considers the impact of instantaneous vibration and interval vibration on passenger comfort, and is more rigorous in methodology, but its calculation boundaries have certain limitations for certain vibrations. Compared with ISO 18738-1:2012, the calculation process of ISO 2631-4:2001 standard is simpler, but this method is easy to bring subjective factors into the classification of comfort level. The two assessment methods have their own advantages and disadvantages, and further improvement is needed for the assessment of elevator comfort.

Research and prospect for the evaluation method of elevator ride comfort: to divide the elevator vibration signal into more specific intervals, to design the subjective evaluation experiment of elevator ride comfort and to count the correspondence between the total value of frequency-weighted acceleration of the vibration signal under different intervals and the subjective feeling evaluation by psychophysical methods, so as to obtain the comfort evaluation model dedicated to traction elevators.

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