Comfort evaluation and analysis of high-speed train

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Abstract: At present, the methods widely used to evaluate passenger comfort in train environment are ISO2631-1 and UTC-513R. In order to compare and analyze the application of the two standards in the actual line conditions, three-axis acceleration sensor is installed on CRH3 to collect the vibration data of the vehicle. All the ride comfort is calculated according to the standards of ISO2631-1 and UTC-513R, and mapped to the map line. The results are helpful to further improve the accuracy of comfort evaluation of high-speed trains.

1. Introduction
With the continuous development and application of railway technology, high-speed railway has been developed rapidly. Therefore, the passenger's demand for the comfort of the train is also increasing. As vibration is the most important factor affecting passenger comfort, in order to realize the objective evaluation and analysis of passenger vibration comfort, Loach [1] developed the ISO2631-1 standard through a large number of test results. ISO2631-1 was first used in automobile comfort evaluation. For example, Juan Castellanos [2] put forward the comfort evaluation system of bus lines based on the index of ISO2631-1. In the field of railway research, Suzuki et al. [3] first used ISO2631-1 as the human passenger comfort evaluation. Then Kim et al. [4] discussed and compared whether the filter curve, transfer function and correlation can meet the evaluation of railway passenger comfort, and found that due to the complexity of railway conditions and vehicle types, ISO2631-1 can't fully characterize the comfort of railway passengers. Due to the above problems, UIC-513R is developed to evaluate the vibration comfort of railway passengers. But the two methods in the actual line use effect is lack of relevant experimental research, so the line test is carried out for research.

In this paper, the test vehicle is China high-speed train type 3C, which has been serviced and already set up into several lines in China since 2008. Due to the different geographic features in China, it is necessary to evaluate the ride comfort for different lines. The tests are being carried out on four service lines: Shenzhen-Guangzhou, Chengdu-Xi’an-Beijing, Beijing-Zhengzhou-Chengdu and Chengdu-Leshan line. These lines not only contain the straight lines but also tunnels, curve and other complicated situations. During the test, the comfort of CRH3 on different service lines is evaluated by using the method of combining three-axis acceleration sensor and GPS unit, and the ride comfort results based on uic-513r and ISO2631-1 are visually displayed on the road map.
2. Methodology and experiment

2.1. Specific calculation method

According to the ISO2631-1, the frequency range for ride comfort and perception lies from 0.5 Hz to 80 Hz. The frequency weighted acceleration method is based on the acceleration measurement along three axials (x, y, z), and the position considered here is the human body sitting mode in ISO 2631-1 [1]. Also, the root means square acceleration have been calculated through the evaluation of ride comfort. And the weighted RMS acceleration for each axis based on ISO 2631-1 has been shown in following Eq.1.

\[ a_{wj} = \sqrt{\sum_{i=1}^{T} (W_i \cdot a_{ij})^2} \]  

where \( T \) are the frequencies in one-third octave bands, and \( W_i \) is the frequency weightings in one-third octave bands. Firstly, it should be selected upon the acceleration directions and positions, which has been shown in table 1. Secondly, \( a_{ij} \) is the RMS acceleration for the \( i \)-the one-third octave band for axis \( j \) (\( j \) is the three-axis (x, y, z). Finally, the value \( a_{wj} \) can be compared with the threshold ones proposed by ISO2631-1, and the thresholds for \( a_{wj} \) have been shown in table 1.

| \( a_{wj} \) values (m/s²) | Comfort level       |
|---------------------------|---------------------|
| Less than 0.315           | Not uncomfortable   |
| 0.316-0.63                | A little uncomfortable |
| 0.5-1                     | Fairly uncomfortable |
| 0.8-1.6                   | Uncomfortable       |
| 1.25-2.5                  | Very uncomfortable  |
| Greater than 2            | Extremely uncomfortable |

Moreover, the different comfort level ranges seem to have the overlapping for \( a_{wj} \), because of passenger expectations regard to trip duration and the type of activities passengers. Once the RMS values are calculated for each axis, the vibration total value can be represented in Eq.2.

\[ a_v = \sqrt{k_x^2 \cdot a_{wx}^2 + k_y^2 \cdot a_{wy}^2 + k_z^2 \cdot a_{wz}^2} \]  

where \( a_{wx} \), \( a_{wy} \) and \( a_{wz} \) are the RMS accelerations along the three-coordinate axial, and \( k_x \), \( k_y \) and \( k_z \), are combination factors provided by ISO2631-1, here those values are all equal to 1 for simplified seat positions. The observation points were set on the feet floor, seat surface and back which considered as the sitting position.

Still, UIC-513 [5] is another evaluation standard for ride comfort and the ride comfort index is individual. Although the band limiting of both seat frequency weighting is the same, there are still several differences between UIC-513 and ISO2631-1. For example, the evaluation units of ISO2631-1 are the acceleration units; while the UIC-513 has its own comfort level. The limit frequency range of UIC-513 is between 0.5Hz and 100Hz. In addition, the evaluation equations are different as well. All the relative parameters, evaluation levels and equations had been shown in table 2 and the simplified method Eq.3.

\[ N_{MV} = 6\sqrt{a_{X95}^2 + a_{Y95}^2 + a_{Z95}^2} \]  

where \( a_{X95} \), \( a_{Y95} \) and \( a_{Z95} \) are the RMS frequency weighting acceleration for X, Y, Z. 95 is the confidence level, in addition, the evaluated RMS calculation is based on 5 min. All the measurement time duration has been selected based on the purpose of experiment.
Table 2: Comfort levels related to $a_{w,j}$ threshold values proposed by ISO2631

| Ride comfort index | Evaluation          |
|--------------------|---------------------|
| $N < 1$            | Optimum comfort     |
| $1 < N < 2$        | Good comfort        |
| $2 < N < 4$        | Moderate comfort    |
| $4 < N < 5$        | Uncomfort           |
| $N > 5$            | Extreme uncomfort   |

2.2. Train comfort line test

2.2.1 Test procedure and system

Firstly, calculate the uncertainties of test and work out the quality, then take the measurement of tri-xyz axial accelerations during the operation of test lines. And then two steps can be chosen, one step is input to the frequency weighting bandpass based on the standards and then set the suitable time weighting to calculate the r.m.s value for ride comfort, moreover, the feature values and peak to average ratio of the tri-xyz axial accelerations have been calculated for comparison to find a suitable measure for the ride comfort of each axis. The other one imports to the Fast Fourier transform to perform the Fourier spectra for those test line data to analyze the frequency excited and passaged for vehicle. In addition, the straight and curve acceleration signals would be accessed to the Short Time Fourier transform to determine the effect on human sensitive frequency domain during operating CRH3C vehicle. As a result, the tri-acceleration is applied as the detecting sensors to collect the acceleration data. Due to the limitation of the in-situ measurement, three Lance LC0701-2 tri-acceleration sensors had been installed in the seat back, feet floor and surface, which has been shown in Figure 1.

![Figure 1 The measured acceleration installed in-situ](image)

In addition, the frequency-sample rate should be at least equal to the double of the maximum frequency content of a sampled signal according to the Nyquist-Shannon sampling theorem. And the frequency-sampling rate of the tri-acceleration has been chosen in 2000 Hz.

2.2.2 Test operating condition and scenario

In order to analyze all operating conditions for ride comfort. It is necessary to select a rail track which contained all situation. The test rail track firstly used in this paper was the Guangzhou to Shenzhen in China. There were three curve and seven tunnels during the test track, also, two cable-stayed bridges were also across during test.

Also, the second test has been carried on the same test wagon and operated between Chengdu and Leshan. The anti-snake absorber on the bogie frame was set as unfitted for both two lines to determine whether the unfitted equipment would affect the ride comfort. The values of acceleration in lateral and vertical are larger than expected. Also, passengers have the uncomfortable feelings during the test. The
third supplement test with fitted equipment has been carried out between Chengdu and Beijing. However, there exists much more curve and tunnels during the test.

In order to eliminate the influence of the complex operating geographical environments on ride comfort between Chengdu and Beijing, here author added a supplementary experiment on the ride comfort test rig in lab with the same CRH3C vehicle.

3. The result analysis and discussion of experiment

3.1. The analysis of the measured acceleration

The measured tri-axial acceleration for Shenzhen-Guangzhou and Chengdu-Leshan have been showed in Figure 2. There are some fluctuations in y axis acceleration, which refers to the vehicle shaking. Compared with each axis, the value of acceleration in Shenzhen-Guangzhou is greater than that in Chengdu-Leshan.

![Acceleration data of Shenzhen-Guangzhou](image1)

![Acceleration data of Chengdu-Leshan](image2)

Figure 2: The measured tri-axial acceleration

All the analysis were conducted by MATLAB software. The speed and time duration between Shenzhen and Guangzhou has been shown in Figure 3. The whole test line contains three parts: Shenzhen to Guangzhou forward, garage maintenance, Guangzhou to Shenzhen backward. Each test takes 50-60 min, also, the red and blue line pointed in the graph are curve and straight line. Briefly, the velocity of the whole testing track has been divided into three parts, which are acceleration part, constant...
and the de-acceleration part. Also, the most of duration time is 15 minutes which lied on the range of 275 km/h and 300km/h. Moreover, there existed a short deacceleration between 20 and 30 minutes. For the backwards, similar as forwards, the most of duration time is 12 minutes which lied on the same speed range.

3.2. The discussion of different lines in ride comfort
Combined with the collected GPS data, the whole line ride comfort based on ISO2631-1 and UIC-513R has been visualized on the map shown in Figure.4. The ride comfort index in UIC-513R were more meticulous compared with ISO 2631-1. But it did not mean that the ride comfort evaluation in UIC 513R is larger than that in ISO2631-1. Also, there exits more highlight points in curve line compared with in straight lines, and the further analysis would be made in next section. Generally speaking, the ride comfort for Shenzhen and Guangzhou is good both in ISO 2631-1 and UIC 513R.

3.2.1. The ride comfort for Shenzhen and Guangzhou ISO2631-1
3.2.2. The ride comfort for Shenzhen and Guangzhou UIC513R

All the ride comfort results in test lines have been shown on Figure.5 and Figure.6. All the color areas had been shown on the graph were ride comfort levels for standards.
According to the graphs, ISO 2631-1 has the overlapped evaluated areas compared to the UIC 513R. The comfort levels Between Chengdu and Xi’an all lied in the “Not uncomfortable” and “optimum comfort” areas for different standards. And there still exits the areas in “a little uncomfortable”, “Good comfort” and “Moderate comfort” between Shenzhen and Guangzhou. Also, compared with the ride comfort percentages shown in Table. The ranges of determining the uncomfortable evaluation in UIC-513R are wider than those in ISO2631-1. Which means the UIC-513 R is a little bit more sensitive compared with ISO2631-1. However, the trends of those two figures are the same. The ride comfort between Chengdu and Beijing attends a satisfied result both in UIC-513R and ISO2631-1. Compared with those above, the comfort conditions in Shenzhen and Guangzhou depicted a little bit uncomfortable situation.

4. Conclusion
In this test, the evaluation of ride comfort on the railway infrastructures was investigated inside trains travelling along the track. All vibration data would be collected by tri-xyz acceleration sensors. The uncertainties of test have been considered and it was found that it has less effect on the line experiment and made sure the accuracy of test. Also, the ride comfort of CRH3 vehicle under different speed levels has been performed, more uncomfortable areas had appeared during the 150km/h to 250km/h. This indicated that the uncomfortable feel ings normally occurred in high speed level. In order to maintain the condition of an infrastructure in the rail, it is necessary to locate those critical areas and the appeared
uncomfortable points.

Acknowledgments
The work was supported by Sichuan Science and Technology Program (2019JDRC0024)

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