Experimental Analysis of Ride Comfort Quality for High-speed Railway Vehicles

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Abstract. In order to study the vehicle comfort, in this investigation, the empty dynamic test is carried out on the vehicle operating line, and the conditions of air spring inflated and air spring deflated are considered respectively. On condition of air spring inflated, the test speed of vehicle starts from 60 km/h, with a speed step of 20 km/h, up to 140 km/h. On condition of air spring deflated, the test speed of vehicle starts from 40 km/h, with a speed step of 20 km/h, up to 100 km/h. Then the vehicle body vibration acceleration is measured, and data is carried out processing through the standard EN12299-2009 Railway applications – Ride comfort for passengers – Measurement and evaluation. The results of test and data processing show that: under the normal condition of air spring, the maximum values of ride comfort index of motor (D1) and trailer (M1) are 1.43 and 1.70 respectively, both less than 2.5; under the condition of airless spring, the maximum values of riding comfort index of motor (D1) and trailer (M1) are 1.94 and 2.23, both less than 3.0.

1. Introduction
Nowadays, railway vehicles have become one of the main means of transportation for people to travel. The level of vehicle comfort index is directly related to the passenger experience. Therefore, the ride comfort of railway vehicles has become a social concern. In 1974, ISO 2631¹² standard was put forward by the International Association for standardization. However, the deficiency of ISO2631 standard is that there are no relevant provisions on the running routes and vehicle conditions of vehicles. In 1994, uic513³ was adopted by the international railway union to evaluate the vibration comfort of vehicles. In 1997, the filter and evaluation method of standard UIC513 were quoted in Europe, and the standard EN12299⁴ was put forward, which was rapidly popularized in the world. This work studies the ride comfort according to EN12299 standard.

Many scholars at home and abroad have done a lot of research on vehicle comfort. In order to improve the ride comfort of the vehicle, Chi et al.⁵ studied the vibration response characteristics of the vehicle, established the vehicle system dynamics model, calculated the frequency domain modal parameters of the bogie hunting motion mode and the vehicle body natural vibration mode, and the time domain stability index of the vehicle at different speeds. In order to study the influence of the equipment under the train on the comfort of the EMU, Guo et al.⁶ established a vertical dynamic model of the high-speed EMU considering the elasticity of the car body and multiple under vehicle equipment. The comfort index was calculated by using the random track irregularity excitation power spectrum and comfort filter function. The optimal suspension frequency and damping ratio of the equipment were designed based on the optimal coherence theory and verified by numerical simulation.
For some CRH models in order to find out the effective measures to restrain the low-frequency lateral sway of the vehicle body, Huang et al.\textsuperscript{[7]} first established a multi-body dynamic model of the vehicle system, and obtained the main influencing factors of the low-frequency lateral sway of the car body based on the time-domain simulation analysis. Finally, the root locus analysis technology was used to study the influence of the main parameters on the low frequency lateral sway of the car body. In order to improve the ride comfort of light rail vehicles, Gerhard et al.\textsuperscript{[8]} proposed an active vibration reduction system of light rail vehicles based on piezoelectric actuators, and carried out simulation research. Kim et al.\textsuperscript{[9]} studied the relationship between several comfort evaluation methods by using the vibration model obtained from frequency analysis and statistical analysis of railway vehicle acceleration measurement.

In this work, the empty dynamic test is carried out on the vehicle operating line, and the conditions of air spring inflated and air spring deflated are considered respectively. On condition of air spring inflated, the test speed of vehicle starts from 60 km/h, with a speed step of 20 km/h, up to 140 km/h. On condition of air spring deflated, the test speed of vehicle starts from 40 km/h, with a speed step of 20 km/h, up to 100 km/h. Then the vehicle body vibration acceleration is measured, and data is carried out processing through the standard EN12299-2009 Railway applications – Ride comfort for passengers – Measurement and evaluation.

2. Test conditions

2.1. Tested vehicle
The tested vehicle adopts configuration of 2 motors and 2 trailers. The first 2 cars (D1 and M1) were selected with measuring points arranged for ride comfort tests.

2.2. Tested track
The test is carried out on vehicle operation line.

2.3. Speed profile
On condition of air spring inflated, the test speed of vehicle starts from 60 km/h, with a speed step of 20 km/h, up to 140 km/h. On condition of air spring deflated, the test speed of vehicle starts from 40 km/h, with a speed step of 20 km/h, up to 100 km/h.

2.4. Load case
Test vehicle load consists of only empty (AW0) load case. Both the inflated and deflated air spring cases were examined. Air spring deflation means all air springs are deflated.

3. Measurements and processing

3.1. Measuring locations

![Image of accelerometer installation positions]
3.2. Processing
The ride comfort index $N_{MV}$ is a measurement method of average comfort degree of passengers on railway vehicles, and in this work the ride comfort index is processed according to EN12299-2009.

The calculation formula of comfort index is as follows:

$$
N_{MV} = 6\sqrt{(a_{XP95}^{w_a})^2 + (a_{YP95}^{w_a})^2 + (a_{ZP95}^{w_a})^2}.
$$

Where $a$ is the root mean square value of vibration acceleration ($m/s^2$); $W_d$ and $W_b$ are frequency weighted filters; and $P95$ is the probability statistics of 95% confidence degree of vibration acceleration in all directions.

4. Test Results of Ride comfort quality

4.1. Empty load and air spring inflated
The ride comfort quality for the tested vehicles under the load condition of empty load is shown in Tab 1. and Tab 2. It can be concluded that the maximum ride comfort index of D1 and M1 car with air spring inflated is 1.43 and 1.70, respectively, which are all within the limit value of 2.5.

Table 1. Comfort quality $N_{MV}$ under the load condition AW0 (Air spring inflated)

| Vehicle No. | Position | Value | Speed (km/h) | Evaluation value |
|-------------|----------|-------|--------------|-----------------|
| D1          | Body I   | 1.41  | 140          | 2.5             |
|             | Body II  | 1.19  | 140          |                 |
|             | Body III | 1.43  | 140          |                 |
| M1          | Body I   | 1.79  | 140          | 2.5             |
|             | Body II  | 1.33  | 140          |                 |
|             | Body III | 1.70  | 140          |                 |

Table 2. Ride comfort index NMV under AW0 with air springs inflated for various speed

| Vehicle No. | position | Speed (km/h) |
|-------------|----------|--------------|
|             |          | 60 80 100 120 140 |
| D1          | Body I   | 0.78 0.96 1.02 1.04 1.41 |
|             | Body II  | 0.65 0.90 1.02 1.02 1.19 |
|             | Body III | 0.88 0.94 1.00 1.14 1.43 |
| M1          | Body I   | 0.90 1.03 1.11 1.19 1.79 |
|             | Body II  | 0.92 1.09 1.23 1.19 1.33 |
|             | Body III | 0.99 1.18 1.18 1.28 1.70 |

Figure 2. installation of the sensors
4.2. Empty load and air spring deflated
The ride comfort quality for the tested vehicles under the load condition of empty load is shown in Tab 3. and Tab 4. It can be concluded that the maximum ride comfort index of D1, and M1 car with air spring deflated is 1.94, and 2.23, respectively, which are all within the limit value of 3.0.

Table 3. Comfort quality NMV under the load condition AW0 with air spring deflated

| Vehicle No. | Position | Value | Speed (km/h) | Evaluation value |
|-------------|----------|-------|--------------|------------------|
| D1          | Body I   | 1.79  | 80           | 3.0              |
|             | Body II  | 1.83  | 100          |                  |
|             | Body III | 1.94  | 100          |                  |
| M1          | Body I   | 1.85  | 80           | 3.0              |
|             | Body II  | 1.88  | 100          |                  |
|             | Body III | 2.23  | 100          |                  |

Table 4. Ride comfort index NMV under AW0 with air springs deflated for various speeds

| Vehicle No. | Position | Speed (km/h) |
|-------------|----------|--------------|
|             |          | 40           | 60              | 80              | 100             |
| D1          | Body I   | 0.97         | 1.43           | 1.79            | 1.71            |
|             | Body II  | 0.79         | 1.20           | 1.76            | 1.83            |
|             | Body III | 0.82         | 1.24           | 1.75            | 1.94            |
| M1          | Body I   | 0.96         | 1.28           | 1.85            | 1.73            |
|             | Body II  | 0.90         | 1.21           | 1.85            | 1.88            |
|             | Body III | 1.01         | 1.20           | 1.86            | 2.23            |

5. Conclusions
Under the normal condition of air spring, the maximum values of ride comfort index of motor (D1) and trailer (M1) are 1.43 and 1.70 respectively, both less than 2.5; under the condition of airless spring, the maximum values of riding comfort index of motor (D1) and trailer (M1) are 1.94 and 2.23, both less than 3.0.

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