Ride Comfort of Transrapid Vehicles in Shanghai

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Abstract:

According to the international standards ISO2631 and UIC513, the ride comfort of maglev vehicle is generally evaluated by vibration which reflects general dynamic performance of maglev system. The vibration is mainly generated by the interaction of vehicle-guideway and transmitted through the vehicle suspension system into the car body. Assessment measurement for ride comfort was carried out at the speeds from 100km/h to 500km/h in Shanghai in July and Nov. 2003. The statistic evaluation has shown good ride comfort and good dynamic performance of maglev system.

Keywords: Ride comfort, Vibration, Maglev, Shanghai

1. Introduction

The term "ride comfort" is generally used to describe the degree of human comfort offered by a moving vehicle. Both international standards ISO2631and UIC513 define the ways to assess the ride comfort in an object manner by evaluating vibration and give the definition of ride comfort index. And both of them were applied to the evaluation of ride comfort regarding the Transrapid vehicles used in Shanghai. In this paper, the standard UIC513 will be used more frequently than ISO2631 for evaluating the ride comfort. However, the evaluation results in accordance with ISO2631 are slightly better than those with UIC513.

The UIC513 provides three methods of measurement and its corresponding calculation for evaluating ride comfort, including two methods for seating position and standing position respectively, and a simplified method for seating (or standing) position. The simplified method for seating (or standing) position was adopted in Shanghai. Therefore the ride comfort index, denoted by N, could be obtained from the formula (1) in agreement with UIC513:

$$N = 6\sqrt{(a_{XP95}^{W_d})^2 + (a_{YP95}^{W_d})^2 + (a_{ZP95}^{W_b})^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where $a_{XP95}^{W_d}, a_{YP95}^{W_d}$ and $a_{ZP95}^{W_b}$ are the weighted r.m.s. values of the accelerations with respect to X, Y and Z directions respectively. The superscripts W_d and W_b denote that the frequencies are weighted according to the corresponding weighting curves. The subscripts $XP95$, $YP95$ and $ZP95$ denote that r.m.s values of the accelerations regarding X, Y and Z directions are contained in a 95% confidence interval. The frequency weighting curves for W_d and W_b are shown in figure 1. Therefore the ride comfort index will be available according to formula (1) by using the 95% of the 60 effective values that result from the calculation of the r.m.s values of the accelerations measured at intervals of 5 seconds over a period of 5 minutes vehicle running. Five levels of ride comfort index are defined in the UIC513 to describe the comfort perception, as listed in the table 1. Actually there are evaluation index and frequency weighting curves in ISO2631 similar to UIC513.

Table 1: Index of ride comfort evaluation

Comfort index	Comfort evaluation
$N < 1$	very good comfort
$1 \le N < 2$	good comfort
$2 \le N < 4$	moderate comfort
$4 \le N < 5$	poor comfort
$N \ge 5$	very poor comfort

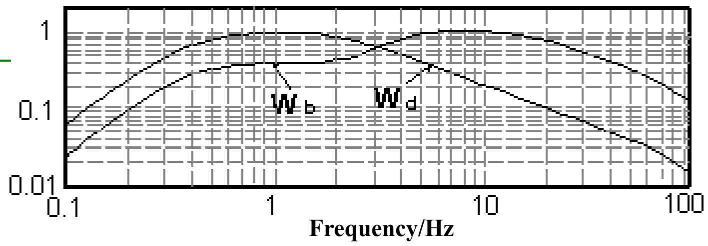

Figure 1: Frequency weighting curves

2. Preparation of Measurement

The definition made by UIC513 is the Cartesian co-ordinates for the measurement of accelerations, so sensors mounted at the measurement locations have to be in the position orthogonally according to the x-y-z reference frame as shown in figure 2. Here, x, y and z represent the longitudinal, lateral and vertical directions respectively.

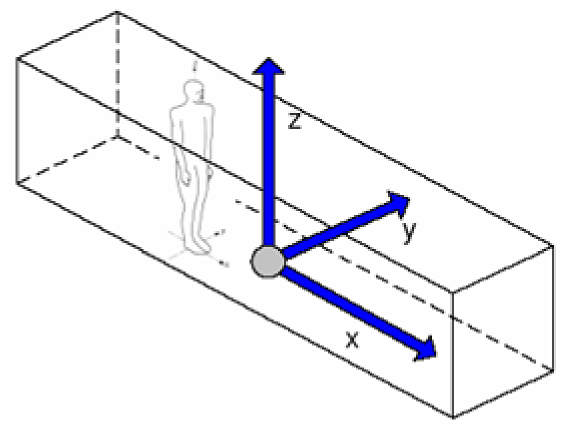

Figure 2: Reference frame for measurement

Furthermore, the configuration of the measurement points to mount accelerometers is recommended by UIC513. However, in order to minimize the cost of the measuring circuit, one x-acceleration per carriage can be used for the evaluation of every measurement point. At the same time, the y-acceleration was measured once per lateral plane. Only the z-acceleration was measured for every measurement point. Taken into account the symmetry of three-section train, the front (1st)

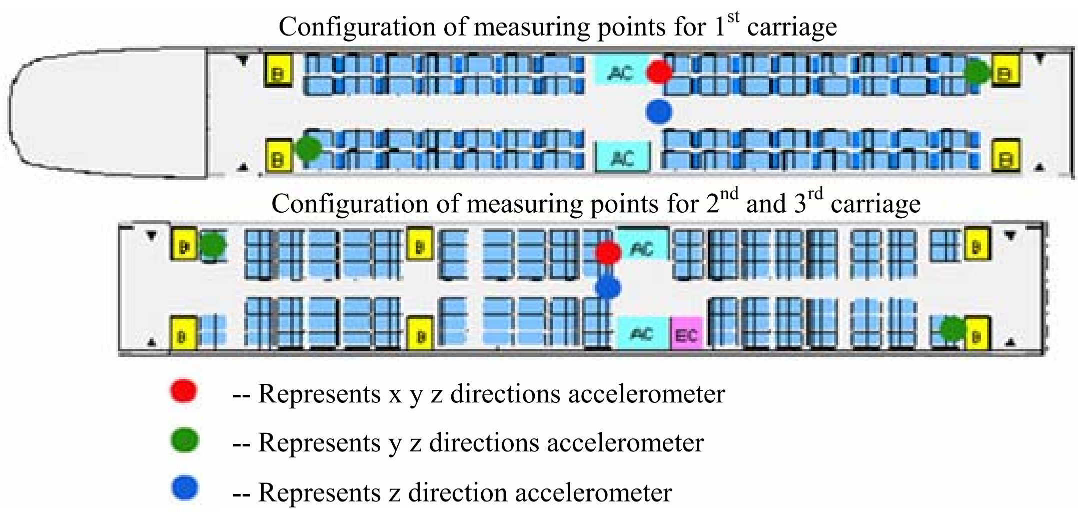

Figure 3: Configuration of measurement

carriage and middle (2nd) carriage were evaluated. As for the five-section train, the front (1st) carriage and second (2nd) carriage and middle (3rd) carriage were evaluated. For all the scheduled shuttles, forward and backward running were all measured, and it can represent nearly all the situation of vehicle traveling condition. The configuration of the measurement points is shown in figure 3.

3. Evaluation Results

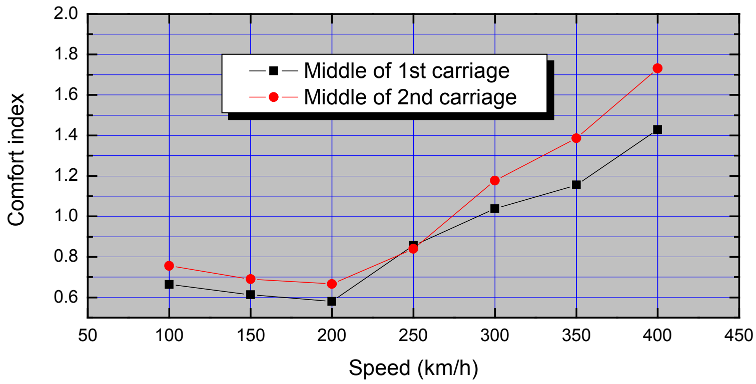

Figure 4: Evaluation results of PV1 (3-section train) on Track A

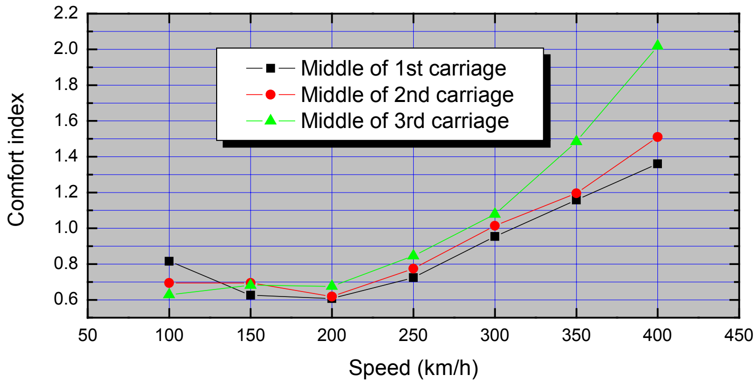

Figure 5: Evaluation results of PV2 (5-section train) on track A

Ride comfort measurements in Shanghai were both carried out in the train PV1 (3 sections) and train PV2 (5 sections) on the track A and track B at different speeds from 100km/h to 500km/h. For the tracks in Shanghai don't have sufficient length (approximate 30 km) for higher speed, there are only a few samples at speeds from 430km/h to 500km/h. Thus the evaluation results of the speeds from 430km/h to 500km/h are beyond the discussions because of poor statistical precision. Figure 4 and figure 5 have shown the evaluation results in a 95% confidence interval, which derive from the calculation according to formula (1) with 45 samples. Actually, the evaluation results of trains PV1 and PV2 on track B are almost well confirmed with those on track A.

4. Discussion

The evaluation results have shown that most values of ride comfort index are smaller than 2.0 and they indicate a "very good comfort" level (<300km/h) and a "good comfort" level (300-400km/h) in accordance with UIC513.

The minimum values of ride comfort index occur nearly at the speed of 200km/h. Moreover the values of ride comfort index increase with the speed over 200km/h. It is shown in figure 4 and figure 5. When the values of the longitudinal, lateral, and vertical comfort index are compared according to ISO2631, it can be seen that the proportion of these parameters is 1:2.5:6 when the vehicle speed is slower than 200km/h. On the other hand, the proportion is 1:4:6 when the vehicle speed is over 200km/h. Therefore, it is the evidence to show that the relatively poor ride comfort at a higher speed is mainly caused by the lateral vibration probably due to the deviation of the guidance rail or the suspension system.

As shown in figure 4 and figure 5, the ride comfort in the middle carriage is worse than that in any other carriage. This was perhaps caused by local resonance frequencies and it reflected general dynamic performance of maglev system.

Referring to UIC513, the sample size shall be at least 60 for the calculation of comfort index. The duration at high speed is short because of the insufficient length, as a result the samples were acquired from several runs and the sample size for calculation at every designated speed was 45. The process of vibrations along x, y and z axes can be considered ergodic at every specified speed. The confidence interval expression for the ride comfort index will be deduced. It is supposed that some measuring mean square value $\tilde{x}^2$ can be obtained as:

$$\tilde{x}^2 = \frac{1}{T}\int_0^T x^2(t)dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where $x^2(t)$ is a sample function of mean square values, when the integration interval is evenly divided into n sections, mean square value $\tilde{x}^2$ will be written as:

$$\tilde{x}^2 = \frac{1}{n}\left[\frac{n}{T}\int_0^{\frac{T}{n}} x^2(t)dt + \frac{n}{T}\int_{\frac{T}{n}}^{\frac{2T}{n}} x^2(t)dt + \cdots + \frac{n}{T}\int_{\frac{T}{n}}^{T} x^2(t)dt\right] \quad \ldots\ldots\ldots(3)$$

Let $\sigma_x^2 = \frac{n}{T}$, $\chi_i^2 = \int_{\frac{(i-1)T}{n}}^{\frac{iT}{n}} x^2(t)dt$, where $i = 1,\cdots,n$ and formula (3) can be simplified as:

$$\tilde{Z}(t) = \frac{\sigma_x^2}{n}(\chi_1^2 + \chi_2^2 + \cdots + \chi_n^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Transpose for formula (4), hence, a new variable X_n^2 can be described as:

$$X_n^2 = \frac{n\tilde{Z}(t)}{\sigma_x^2} = \chi_1^2 + \chi_2^2 + \cdots + \chi_n^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Therefore, the variable X_n^2 satisfies Chi-square distribution according to formula (5), moreover the confidence interval estimates for the true mean square value is given by the formula (6) according to the properties of Chi-square distribution.

$$\frac{n\tilde{Z}(t)}{X_{n,1-\alpha/2}^2} > \psi_x^2 \geq \frac{n\tilde{Z}(t)}{X_{n,\alpha/2}^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Where: ψ_x^2 stands for the true mean square value; $\tilde{Z}(t)$ denotes measuring mean square value; n represents the degree of statistical freedom; α is significance level and $1-\alpha$ is the level of confidence; $X_{n,1-\alpha/2}^2$ is the value acquired under the situation that the level of confidence is designated as $1-\alpha$ and the degree of statistical freedom *n*; The same process is for $X^2_{n,\alpha/2}$.

Let $\widetilde{Z}(t)=\left[6\sqrt{(a^{W_d}_{XP95})^2+(a^{W_d}_{YP95})^2+(a^{W_b}_{ZP95})^2}\right]^2$, then a confidence interval of the value of ride comfort index is reached by:

$$\sqrt{\frac{n}{X^2_{n,1-\alpha/2}}}\cdot\widetilde{N}>N\geq\sqrt{\frac{n}{X^2_{n,\alpha/2}}}\cdot\widetilde{N} \quad \text{........................(7)}$$

Where: n=45, $\widetilde{N}$ represents the value of comfort index calculated from 45 samples, N is the true value of comfort index. Hence, according to the formula (7) the 95% confidence interval of the value of comfort index at every designated speed can be obtained. The 95% confidence intervals of the value of comfort index regarding the middle (3rd) carriage of PV2 on track A and the corresponding comfort evaluation in accordance with UIC513 are listed in table 2, for the ride comfort in this carriage is the most unfavorable in all the measured carriages.

Table 2: 95% confidence interval of the value of comfort index and the corresponding comfort evaluation in middle (3rd) carriage of PV2 on track A

Speed (km/h)	95% Confidence interval of N	Comfort evaluation according to UIC513
100	[0.522, 0.792)	very good comfort
150	[0.566, 0.859)	very good comfort
200	[0.561, 0.851)	very good comfort
250	[0.702, 1.066)	very good comfort or good comfort
300	[0.894, 1.358)	very good comfort or good comfort
350	[1.232, 1.870)	good comfort
400	[1.674, 2.542)	good comfort or moderate comfort

5. Conclusion

The ride comfort of maglev system in Shanghai is generally good in accordance with UIC513. The evaluation results illustrate the good dynamic performance of maglev system. However, further research work is necessary to answer the following two questions.

- The lateral vibration increases quickly at running speed over 200km/h.
- The ride comfort in the middle carriage is worse than that in any other carriage.

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