

RIDE COMFORT EVALUATION FOR THE KOREAN EXPERIMENTAL HIGH-SPEED TRAIN

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Abstract

Ride comfort is one of the most important dynamic performance characteristics of railway vehicles and it is affected by various factors such as vibration, noise, smell, temperature, visual stimuli, humidity and seat design. Evaluating ride comfort is not simple because all these factors must be considered simultaneously. In general, vibration, which originates from vehicle motion, is taken as the primary concern. The vibration of railway vehicles becomes very complex because it is affected by the condition of vehicles, including wheel profile, suspensions and equipments in the vehicles, and the condition of track sections, including rail profile, rail irregularities, cant, and curvature. In addition, operating conditions, such as frequent starts or stops and speed restrictions, are also major factors that affect the vibration of railway vehicles. This paper deals with the ride comfort of HSR-350x, a proto-type train developed in Korea since 2002. In order to evaluate the ride comfort of a railway vehicle, it is very important to consider the correlation between passenger's feeling and vibration of the vehicle. Human feelings vary with frequencies of vibration even if the intensities for all frequencies vibration are equal, as in the case of acoustic noise. Therefore, a weighted vibration considering human feeling has been used to evaluate the ride comfort of HSR-350x. A total of 362 ride indices have been acquired by the statistical evaluation method UIC513 at train speed of 80~310 km/h from 2002 to 2006. The characteristics of ride comfort for HSR350x have been investigated considering the operation conditions, such as load/track conditions, seasons and annual variations.

1. INTRODUCTION

The demands and expectations of passengers using public transportation for faster, safer and more comfortable systems increase and many countries are developing high speed trains to meet these goals. There are two different high speed train systems in Korea: Korea Train eXpress (KTX) and HSR-350x. KTX trains have been commercially operating on the Kyongbu-line (Seoul to Pusan) and the Honam-line (Seoul to Mokpo) at 300km/h since April 1st, 2004 [1]. The HSR-350x train, developed as an independent Korean model and reached the maximum speed of 350km/h at December 2004, has been carrying out commissioning tests to insure reliability on the service line. Safety and ride comfort are very important issues, especially for the Korean high-speed trains because the service lines are comprised of both high speed and conventional lines; the ratio of the high speed line on the Kyoungbu-line is 57.5 %

and 33.8 % on the Honam-line [2].

Ride comfort of railway vehicles is affected by many factors, such as vibration, noise, smell, temperature, visual stimuli, humidity and seat design. Evaluating the ride comfort is a very difficult problem because all of the factors must be considered simultaneously. In general, vibration, which originates from vehicle motion, is considered as the primary concern [3-13].

The vibration of railway vehicles becomes very complex because it is affected by the condition of vehicles, including wheel profile, suspensions and equipments in the vehicles, and the condition of track sections, including rail profile, rail irregularities, cant, and curvature. In addition operating conditions such as frequent starting or braking of an urban train and speed restrictions are also major factors that affect the vibration of railway vehicles. In evaluating the ride comfort, the relationship between passenger's feeling and the vibration characteristics is very important, because human feeling varies with frequencies of vibration. Therefore, the frequency weighted vibration considering human feeling is needed to evaluate the ride comfort of railway vehicles [3-5, 8-10].

Evaluation of the ride comfort can be divided into two classes. One is the long-term evaluation of ride comfort which is assessed for the whole running distance or time, and it is calculated by r.m.s value of acceleration. The other is momentary evaluation which is assessed for the short duration of acceleration; deceleration and stationary lateral acceleration on curves, and it is calculated by peak values of acceleration [4].

The evaluation method which follows the procedure based on ISO 2631 and proposed by Sperling is used for the long-term evaluation of ride comfort. "Evaluation of human exposure to whole-body vibration(ISO 2631-1)", which is proposed and revised by the International Organization for Standardization (ISO), has been initiated to evaluate human exposure to whole body vibration [8]. The International Union of Railways (UIC) and the European Committee for Standardization (CEN), as well as the ISO, established standards on the evaluation of ride comfort of railway vehicles based on the study of the ISO 2631 standard by ERRI (European Railroad Research Institute [9]. UIC 513R, CEN ENV 12299 and ISO 10056 specify the statistical method of evaluation, while ISO 2631-1 specifies the r.m.s based method of evaluation procedure proposed by Sperling is basically different from the methods founded on ISO 2631.

There are commonly used international standards for the evaluation of the long-term ride comfort of railway vehicles, but none for the momentary ride comfort. This is because the dynamic characteristics of railway vehicles are different at each country due to the differences in the vehicle conditions, track conditions and operational conditions. Also of importance is the difference in concerns for the ride comport issues. For instance the momentary evaluation of ride comfort is an interesting matter for urban and mountain areas in Korea and Japan, but it is not such important in the other countries. As a result, the momentary evaluation procedures have been developed independently.

In the present paper, the total 362 ride indices have been acquired by the statistical evaluation method UIC513 at train speed of $80 \sim 310$ km/h on KTX commercial line from 2002 to 2006. The characteristics of ride comfort for HSR350x have been investigated considering the operation conditions, such as load/track conditions, seasons and annual variations.

2. TEST OF RIDE COMFORT

2.1 Condition of ride comfort test

To verify the design requirements for the performance of the test train, qualification tests had been conducted throughout 16 categories such as running stability, traction, braking and

resistance to motion, etc., at incremental speeds from 80 km/h to 350 km/h. As of December 2006, a total of 357 test runs had been carried out and the accumulated mileage of the train became 164,000km. Figure 1 shows the maximum speed, travelling distance and accumulated travelling distance of HSR350x through total 357 test runs.

As shown in figure 2, HSR350x is composed of 7 trains. It has adopted a push-pull type power system and articulated bogies which are equipped 1st and 2nd suspensions (see figure 3) to improve travelling safety of train and to reduce the vibration generated by wheel/rail contact.

At least 5 minutes continuous acceleration measurement is required to evaluate the long term ride comfort of railway vehicles by the statistical method.



Figure 1. Maximum speed, travelling distance and accumulated travelling distance of HSR350x.



Figure 2. Formation of HSR350x.

2.2 Statistical evaluation procure

The acceleration signals, measured at the centre of the vehicle floor or at the floor above the bogie centre, are filtered using a low-pass filter to eliminate possible distortion before they are digitalized. A block of digitized signals, measured over 5 sec, is converted to the frequency domain by Fourier transform and the x, y, z components of r.m.s weighted values are calculated after applying the frequency weighting curves as shown in figure 4. Similarly, r.m.s weighted values for successive 60 blocks are also calculated, and then a ride index is evaluated by using 95th percentile from 60 r.m.s weighted values of accelerations in the x, y and z directions.

2.3 Measurement system of ride comfort

The measurement system for long-term ride comfort is shown in figure 5. Its sampling frequency is 400 Hz and hence the each block is 5.12 seconds long [14]. Acceleration signals measured on the floor at the rear side of TT3 were recoded to calculate the ride indices by a statistical method. The measuring system receives pulse signal from the sensor mounted on the wheel axle as shown in figure 5(a), and generates 62 signals per wheel rotation. This pulse signal is processed using a frequency-voltage converter to obtain train speed.



Figure 3. Articulated bogie system of HSR350x.



Figure 4. Frequency weighting curves.



Figure 5. Measurement system for ride comfort: (a) experimental set-up, (b) schematic diagram.

2.4 Calculation of the ride index

Figure 6 shows an example of determination for 95th percentile value out of 60 r.m.s accelerations in x, y and z directions. The ride indices are calculated by using these values and the average speed of the train during the same period is calculated at the same time. If there are no specific comments train speed means an average speed of the train.

Table 1 shows the number of ride indices acquired by ride comfort test between year 2002 ~ 2006. Total number of ride indices obtained from the high speed line and the conventional line are 310 and 52, respectively.



Figure 6. Distribution histogram of the RMS values during 5 minutes.

Table 1. Number of ride indices (N_{mv}) data obtained from tests.

	High speed line		Conventional line	
Load condition	W_1	W_2	W_{l}	W_2
Number of data	306	4	44	8
* W_1 : tare weight in running order				
* W_2 : train-set weight at normal load				

3. ANALYSIS OF THE RIDE COMFORT TEST RESULT

Figure 7 shows the r.m.s acceleration value to the train speed in the vertical and the lateral direction measured at wheel-set, bogie and car body. The symbols $(\Box, \bigcirc \text{ and } \bigtriangleup)$ and the lines(solid, dot and chain line) show the test results and the fitted curves estimated by measurement results. The accelerations measured at wheel-set is the largest and those at car body is the smallest in the y and z directions. It is caused by the damping effect of 1st and 2nd suspension of the bogie as shown in Figure 3.



Figure 7. Acceleration(RMS) for wheel-set, bogie and body according to train speed: (a) vertical direction, (b) lateral direction.

Figure 8 shows the ride indices versus train speed measured on the high speed and the conventional line with an empty weight condition (W_l) . In the high speed line, fifty percent of data are concentrated between 280 - 300 km/h, and seventy seven percent are located in 100 -140 km/h in the conventional line. As shown in figure 8, the ride indices for HSR350x are less than 2 in the high speed line and the conventional line. Those are "GOOD" condition and enough to satisfy "Deluxe Rolling Stock" according to UIC 315R. However, the ride comforts level in the conventional line is much larger than that of the high speed line at identical speed. It has been found that the ride comfort indices at 300km/h in the high speed line are equivalent to those the conventional line 140 - 150 km/h. It is inferred that the conventional line has worse operational conditions than the high speed line: curve radius less than 600R, intersection, plate bridge type, rail juncture, rail irregularity, and operation speed limitation. Figure 9 shows the ride indices for an empty weight and a fully seated weight (W_2) at specific speed. The ride comfort tests on W_2 condition have not been implemented enough on the various train speeds. As shown in figure 9, the ride indices for HSR350x on W_2 condition are less than 2 and almost same as those on W_1 condition in the high speed line and the conventional line. It is preferred the weight condition is not effective enough to on the ride indices because the weight difference between W_1 and W_2 is 1 % only.

Figures 10 and 11 show the ride indices in the high speed line (over 290 km/h) and conventional line (between 110 km/h to 142 km/h) for different seasons. Data set are rare for spring season. As shown in figures 10(b) and 11(b), the mean values of train speed is uniform; it has no reference to vary seasons, but the mean and standard deviation values of ride indices in winter are higher than the others as shown in figures 10(a) and 11(a). It is inferred that the stiffness of the roadbed of rail and the suspensions, such as rubber spring, air spring and damper, are increased as the temperature decreased.

Figure 12 shows ride indices for high speed line (over 290km/h) and figure 13 shows the maximum and minimum train speed from 2004 to 2006. Mean values of train speed has not been changed as shown in Fig. 12(b), but the mean values of ride indices were increased nearly

4 % in 2005 and 13 % in 2006, compared to data in 2004 as shown in Fig. 12(a), which means that the performances of the components of the 1st and 2nd suspensions has been gradually decreased.





(a) (b)Figure 8. Ride indices according line conditions:(a) the high speed line, (b) the conventional line.

Figure 9. Ride indices and train speed according to load conditions.



Figure 10. Ride indices and train speeds according to variations in season in the high speed line: (a) ride index, (b) train speed.



Figure 11. Ride indices and train speeds according to seasons in the conventional line: (a) ride index, (b) train speed.





Figure 12. Ride indices and train according to test year in the high speed line: (a) ride index, (b) train speed.

Figure 13. Minimum and maximum train speed according to test year in the high speed line

4. CONCLUSIONS

The following conclusions can be made from the experimental study for ride comfort of HSR350x:

(1) The total 362 ride indices data have been acquired by ride comfort test at the train speed of 80 - 310 km/h on commercial line from 2002 to 2006 to evaluate the ride comfort of HSR350x.
(2) The ride indices for HSR 350x are lower than 2 in both the high speed line and the conventional line regardless of the load conditions (empty weight and fully seated weight conditions) below 310 km/h, which is "GOOD" condition and enough to satisfy "Deluxe rolling stock".

(3) The ride indices at speed of between 140 - 150 km/h in the conventional line and at 300 km/h in the high speed line are in the same range, which means the track condition of the conventional line is worse than that of the high speed line.

(4) The ride comfort during winter is worst. It is inferred that the stiffness of suspensions and the roadbed of rail increases during winter.

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