Development and Application of New Evaluation System for Ride Comfort and Vibration on Railway Vehicles

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Vibrations related to ride comfort should be considered at the beginning of design stage. In general, ride comfort of human is mainly affected by vibration transmitted from the floor and seat. Also, vibration level is very important regarding with running safety on freight wagon. To ensure ride comfort for passenger coach and vibration level for freight wagon, tests had been repeated by different test procedures with several equipments. With different measuring and evaluations for these results, it took much time to evaluate test results. In this paper, a new evaluation procedure was developed combining several software for ride comfort and vibration level test on railway vehicles. In addition, this developed system is capable of ride comfort test and vibration test by a single integrated system that is capable of immediate reporting the test result. With this developed system, the comfort in a passenger coach and the vibration in a freight car were evaluated. And the simulation results from the proposed system are verified by a field test.

Key Words : Ride Comfort, Vibration Level, Railway Vehicle

1. Introduction

Seats in vehicles, i.e. automobiles or railway vehicles, are designed to reduce vibration transmissibility from the road or rail to the human body. Since ride comfort is in some sense a mental problem including psychological effects, it varies from person to person. When it is defined as a physical quantity, however, the ride comfort is defined as a function of acceleration (Yoo, 2005). There are many researches to evaluate human vibrations and ride comfort (Janeway, 1948 ; Griffin, 1986 ; Griffin, 1986).

Emerging Korea as one of the major car manufactures in the world, many groups in Korea actively involved researches related to the seat system to enhance the ride quality of Korean passenger cars (Cheung, 1997 ; Jang, 2002 ; Oh, 2001 ; Mo, 1999). They proposed an equation to evaluate the discomfort of a seated human body due to the vibration at the seat and the floor. As part of ride comfort on railway vehicles, some researchers (Suzuki, 1998 ; Kim, 2003) presented a research trends on the evaluation of ride comfort on railway vehicles and correlation of ride comfort evaluation methods for railway vehicles.

With a tremendous increase of its speed on railway vehicle, the vibration level and ride comfort of railway vehicles became more important

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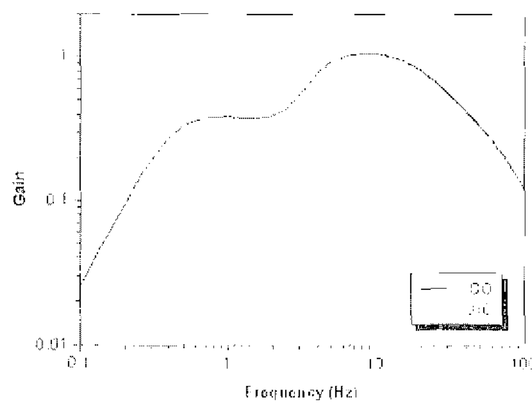
issue in these days. The running safety and ride comfort may be decreased due to the higher speed of trains. In case of passenger coach the ride comfort is become to important requirement, and the vibration level is important in case of freight wagon.

To assure the ride comfort and vibration level below the required performance, various simulations should be carried out before design and manufacturing. After then, the field test should be accomplished to verify the required performances. In general, the ride comfort and vibration level of trains are compared to regulations or required specification written by documentations or related standards. In case of passenger coach, the vibration accelerations measured on seat are mainly used to evaluate the ride comfort. For the freight wagon, the vibration accelerations measured on car-body structure are mainly used to evaluate the vibration level. For this evaluation, several measuring systems are commonly used.

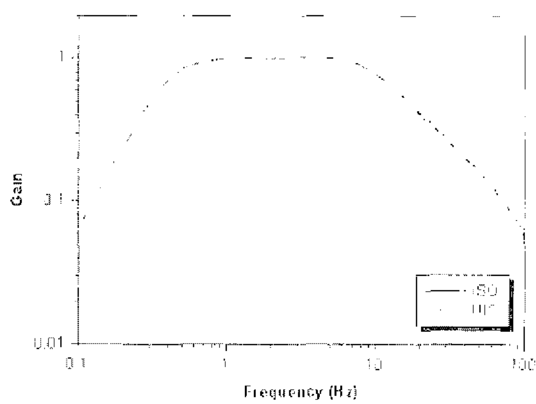
However, these systems have been used on ride comfort and vibration level separately, it took many hours to process and evaluate the test results. Thus. It was required to develop a batch-process from processing to evaluation. Therefore, in this research the ride comfort of a passenger coach and vibration level of a freight wagon have processed by a new measurement system and evaluated by the batch data processing in a short time. Also, this new evaluation system has been verified its effectiveness and usefulness by the field test on the passenger coach and freight wagon.

2. Ride Comfort Evaluation Method

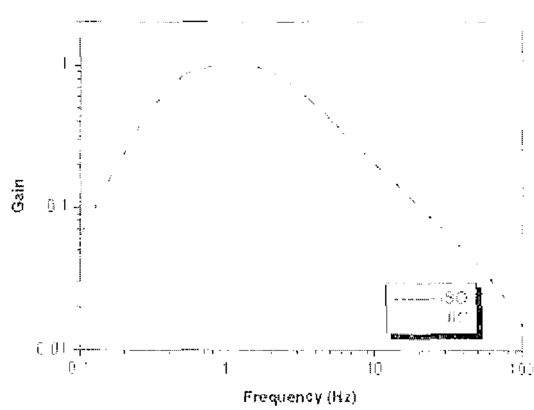
The measurement and evaluation methods for railway vehicles are widely used in accordance with UIC513R standard (UIC Code 513R, 1995) and ISO2631 standard (ISO 2631-1, 1997) currently. The measuring methods and weighting on sensitivity are very similar with each standard. However, the presented evaluation methods have a difference on each standard. In accordance with UIC513R standard, the ride index is indicated as ride comfort level. In case of ISO2631 standard, the rms (root mean square) values of vibration accelerations are indicated as the ride comfort level. The sensitivity weighting curves corresponding to each frequency are shown Fig. 1. As shown in the figure, the W_b curve applied to vertical direction has a difference within 10 Hz.



(a) Vertical direction (W_b)



(b) Longitudinal direction (W_c)



(c) Horizontal direction (W_d)

Fig. 1 Sensitivity weighting curves

However W_e and W_d curves applied to horizontal direction are nearly same.

2.1 UIC Evaluation method

Based on UIC513R standard, the vertical and horizontal accelerations are checked at the interface between the vehicle and the passenger, which is located on the floor and the seat in passenger coach. The main axes of the human body in seated and standing position are shown in Fig. 2.

After measuring accelerations, two evaluation methods are performed. The simplified method is based solely on accelerations measured at the floor. On the other hand, the full method is based on accelerations measured at floor level and at the seat including seat-pan and seat-back. These measured accelerations are scaled by frequency weighting curve W_d on horizontal and curve W_b on vertical direction, and evaluated by ride index as N_{mv}, N_{va} and N_{vd} on each method, respectively as shown in Table 1.

And then, the rms values are calculated every 5 seconds, and representative percentile values are calculated by statistical analysis with rms values. Finally, the ride comfort indices are calculated by formula corresponding to (1) to (3).

$$N_{mv}=6\sqrt{(a_{xp95}^{W_d})^2+(a_{yp95}^{W_d})^2+(a_{zp95}^{W_b})^2} \qquad (1)$$

$$N_{va}=4\cdot(a_{zp95}^{W_b})+2\sqrt{(a_{yq95}^{W_d})^2+(a_{zq95}^{W_b})^2}+4\cdot(a_{xd95}^{W_c}) \qquad (2)$$

$$N_{vd}=3\sqrt{16(a_{xp50}^{W_d})^2+4(a_{yp50}^{W_d})^2+(a_{zp50}^{W_b})^2}+5\cdot(a_{yp95}^{W_d}) \qquad (3)$$

where subscript as 95 and 50 are representative percentile values corresponding with 95% and 50%. The produced ride indices are evaluated in accordance with UIC standard as shown in Table 2.

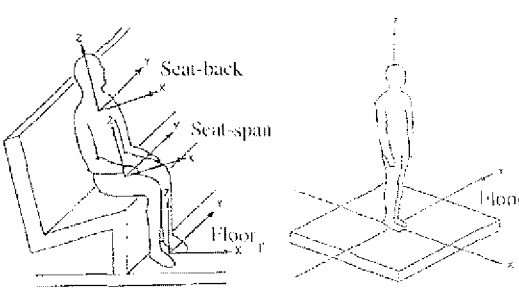


Fig. 2 Axes of human body

Table 1 UIC weighting curves

(a) Simplified method (Ride index Nmv)

Weighting Curve	Position	Direction	Symbol
W_b	Floor	Vertical	$a_{zp}^{W_b}$
W_d	Floor	Longitudinal	$a_{xp}^{W_d}$
		Lateral	$a_{yp}^{W_d}$

(b) Full method in seated position (Ride index N_{va})

Weighting Curve	Position	Direction	Symbol
W_b	Floor	Vertical	$a_{zp}^{W_b}$
	Seat		$a_{zq}^{W_b}$
W_c	Seat back	Longitudinal	$a_{xd}^{W_c}$
W_d	Seat	Lateral	$a_{yq}^{W_d}$

(c) Full method in standing position (Ride index N_{vd})

Weighting Curve	Position	Direction	Symbol
W_b	Floor	Vertical	$a_{zp}^{W_b}$
W_d	Floor	Longitudinal	$a_{xp}^{W_d}$
		Lateral	$a_{yq}^{W_d}$

Table 2 Evaluation of ride index

Ride Index (N)	Evaluation
N<1	Very comfortable
1<N<2	Comfortable
2<N<4	Medium
4<N<5	A little uncomfortable
N>5	Uncomfortable

2.2 ISO Evaluation method

According to the ISO2631 standard, vertical and horizontal accelerations on the seat are measured and weighted by W_d curve on horizontal and W_b curve on vertical, which is shown in Table 3.

The ride comfort level is evaluated by equation (4) using weighted RMS values.

$$RCL=20\log\frac{a_w}{a_{ref}} \qquad (4)$$

Table 3 ISO weighting curves

Weighting Curve	Position	Direction	Symbol
W_b	Seat	Vertical	$a_{zq}^{W_b}$
W_c	Seat-back	Longitudinal	$a_{xd}^{W_c}$
W_d	Seat	Longitudinal	$a_{xq}^{W_d}$
		Lateral	$a_{yq}^{W_d}$

Table 4 Evaluation of ride comfort level

Ride comfort level	Evaluation
Less than 100	Very comfortable
100 ~ 105	Comfortable
105 ~ 110	Medium
110 ~ 120	Uncomfortable

where RCL is ride comfort level in dB, a_w is weighted rmsvalue in m/s^2 and a_{ref} aref is reference value corresponding 10^{-6} m/s^2. The ride comfort level is evaluated by the KS standard shown in Table 4.

2.3 Procedures of ride comfort evaluation

The procedure of ride comfort evaluation for passenger coach is as shown in Fig. 3. Firstly, the accelerations and running speed are measured by accelerometer and speed sensor. These measured accelerations are 0.1 ~ 100 Hz band-pass filtered to exclude high frequency signal generated by unexpected shock vibration at the crossing section or bridge. These filtered data are processed by an FFT analysis.

After that, two methods are applied on evaluation of ride comfort. The first one is the UIC method based on UIC513R standard, the other one is the ISO method based on ISO2631 standard.

According to UIC method, the frequency weighting curves are applied to low-pass filtered accelerations. The rms values are calculated in every 5 seconds and produced the representative percentile values that are applied to calculation of ride indices classified by simplified method and full method. Finally, the ride comfort is evaluated by a test report, which is produced automatically by the developed software.

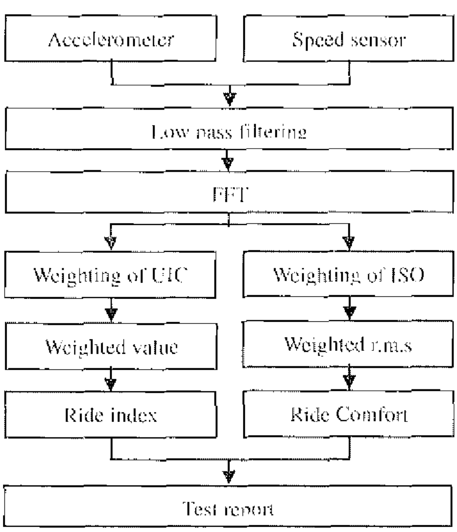


Fig. 3 Procedure of ride comfort evaluation

3. Vibration Evaluation Method

3.1 Peak-to-peak method

The accelerations and running speed are measured to evaluate the vibration level of freight wagon. The vertical and lateral accelerations are measured on the car-body structure, and the running speed is measured by speed sensor. The evaluation is accomplished by peak-to-peak method using these accelerations and running speed.

The data processed in statistics was evaluated by assessment curve according to running speeds, as shown in Fig. 4, in accordance with evaluation standard in technical specification of freight wagon.

3.2 Procedure of vibration evaluation

The algorithm of vibration evaluation developed in this research is shown in Fig. 5.

Firstly, the accelerations and running speed are measured by accelerometer and speed sensor. These measured accelerations are low-pass filtered to exclude high frequency signal generated

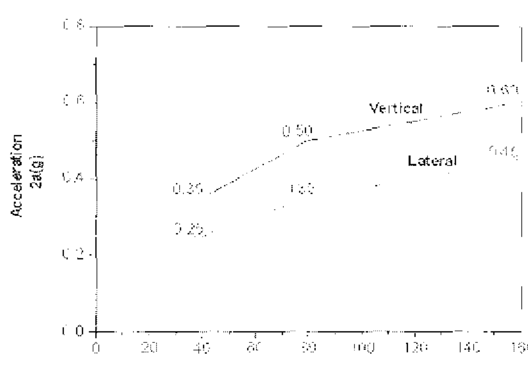


Fig. 4 Evaluation curve of vibration level

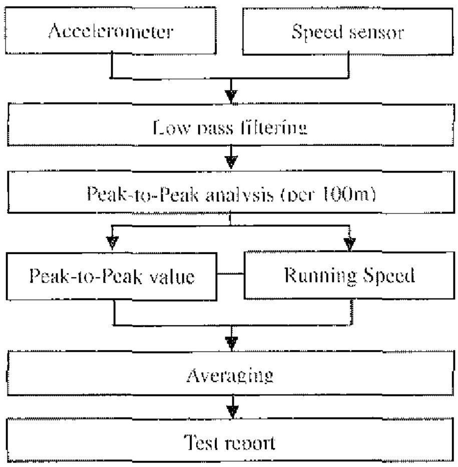


Fig. 5 Procedure of vibration level evaluation

by unexpected shock vibration at the crossing section or bridge. The peak-to-peak values are extracted every 100 m section. Also, the running speeds corresponded with peak-to-peak values are extracted. These speeds are averaged in the same band. Finally, the peak-to-peak values with running speed are plotted on the assessment graph. The vibration level on freight wagon is written as a test report, which is produced automatically by the developed software.

4. Test and Analysis

4.1 Measurement and evaluation system

This system is capable of measuring and evaluation on ride comfort and vibration by a single system. This system consists of accelerometer, speed sensor, data acquisition system, data-processing system and evaluation program. The specification of measuring hardware is listed in Table 5.

Table 5 Specification of measuring system

Component	Model	Performance
Accelerometer	8305A10	• ±20g
Seating Accelerometer	356B40	• ±10g
Speed sensor	ACT-1B	• Max. 100,000 rpm
Data acquistion system	c-DAQ	• Sampling rate : Max. 2,500 Hz • Memory : 512 Mbyte
Portable computer	TF2100	• CPU : 1.8 GHz • RAM : 512 Mbyte

The measured data on passenger coach and freight wagon are analyzed and evaluated by batch work in nCL (nSoft Command Language) supported by nSoft software (nSoft version 5.3, 2003). Also, the report of evaluation result is produced automatically after processing.

4.2 Validation of the developed program

To test the developed measuring system, the test results are compared to another measuring device. As shown in Table 6, the maximum error remains within 0.5%.

Since the nSoft software used in the program provides the user defined filtering function, the users are easy to apply several kinds of filtering. The developed program also obtains efficiency by adapting a batch process in data processing, which gives the developed program keep higher speed in processing and result reporting.

4.3 Test on passenger coach

The field test on new Mugunghwa passenger coach is accomplished to verify the effectiveness

Table 6 Validation of the developed program

Directions	Developed Method	B & K Device	Error {dB}	Error {%}
For-After	94.9 dB	94.5 dB	0.4 dB	0.4
Right-left	99.4 dB	98.9 dB	0.5 dB	0.5
Up-down	106.2 dB	106.4 dB	0.2 dB	0.2

Fig. 6 Installation of measuring system

the developed system. The accelerometers are installed on the seat and floor of the human sits on the cushion containing an accelerometer. The accelerations were measured in direction of longitudinal (X-axis), lateral (Y-axis) and vertical (Z-axis) in real time during running. The evaluation report with the measured data was produced automatically after test, and a sample report produced by the system is shown in Fig. 7. This report shows the information regarding raw signal in time-domain, the sensitivity weighting curves, weighted signals in time-domain, PSD (Power Spectral Density) in frequency-domain and ride comfort level by calculated from rms data in three directions. According to this report, the ride comfort level of passenger coach can be evaluated conveniently.

4.4 Analysis of ride comfort

In Table 7, the weighted values and ride index obtained from the UIC method are shown. According to these results, the ride index obtained with simplified method has the biggest value compared with those of two full methods. On the other hand, the ride comfort according to full method in seated position shows most comfortable condition with lower value.

Also, according to ISO method, the weighted rms values and ride comfort level are obtained over whole test routine, which is shown in

Table 7 Ride index results

(a) Simplified method

Symbol	Weighted value (m/s^2)	Ride index
$a_{xp\,95\%}^{W_d}$	0.078	
$a_{yp\,95\%}^{W_d}$	0.164	$N_{mv}=1.53$
$a_{zp\,95\%}^{W_b}$	0.178	

(b) Full method in seated position

Symbol	Weighted value (m/s^2)	Ride index
$a_{zp\,95\%}^{W_d}$	0.178	
$a_{yq\,95\%}^{W_d}$	0.173	$N_{va}=1.39$
$a_{zq\,95\%}^{W_b}$	0.238	
$a_{xd\,95\%}^{W_c}$	0.023	

(c) Full method in standing position

Symbol	Weighted value (m/s^2)	Ride index
$a_{xp\,50\%}^{W_d}$	0.033	
$a_{yp\,50\%}^{W_d}$	0.068	$N_{vd}=1.47$
$a_{zp\,50\%}^{W_b}$	0.103	

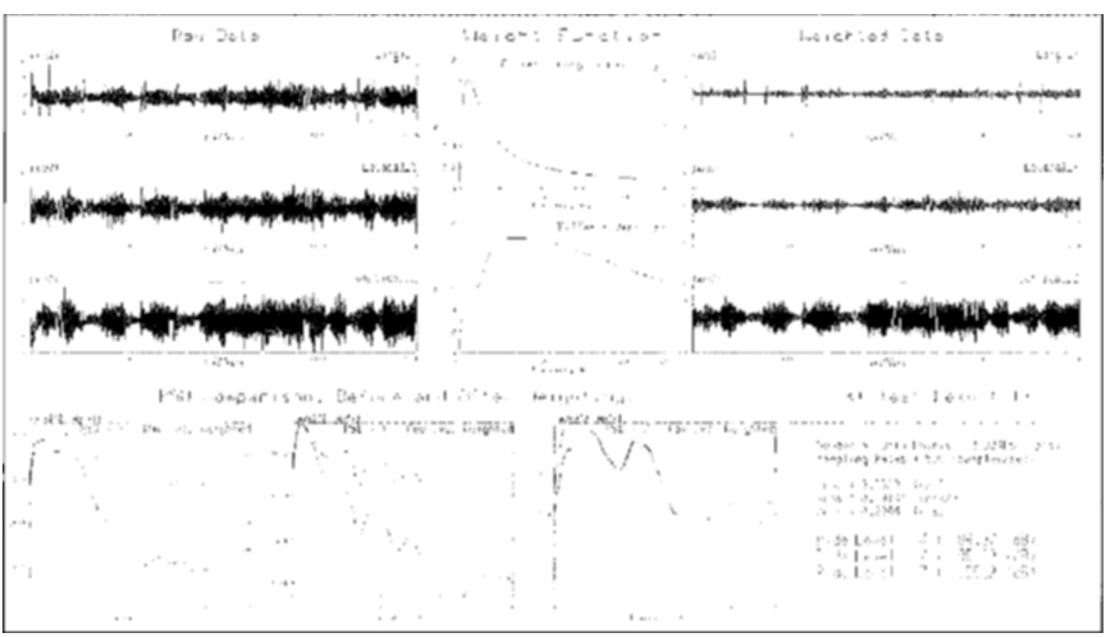


Fig. 7 Test report of ride comfort

Table 8.

The ride comfort test was performed at the various running speeds of the vehicle currently in service line. From this test results, the ride comfort was analyzed by UIC method and ISO method using this developed system.

Table 8 Ride comfort level results

Symbol	Weighted r.m.s (m/s^2)	Ride comfort level
$a^{W_d}_{xq,rms}$	0.049	93.81
$a^{W_d}_{yq,rms}$	0.095	99.6
$a^{W_d}_{zq,rms}$	0.165	104.4

The change of ride index and ride level according to running speed are shown in Fig. 8 and Fig. 9, respectively. According to these results, it can be shown that the vertical direction is most uncomfortable.

The change of the ride comfort depends on running speed. With the increase of running speed, the ride comfort becomes more uncomfortable.

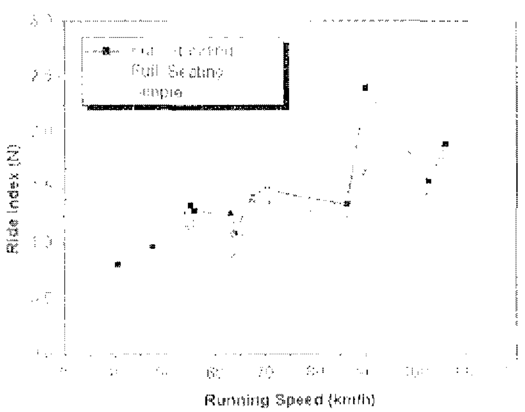


Fig. 8 Ride indices on running speed

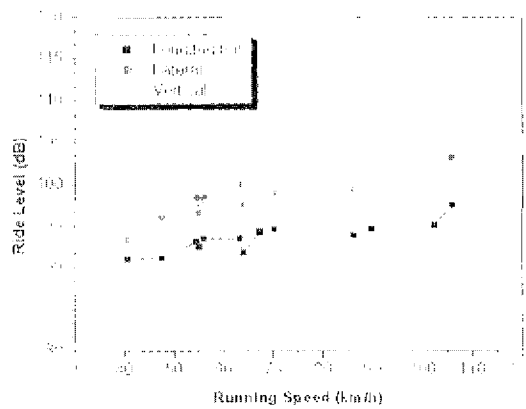


Fig. 9 Ride comfort levels on running speed

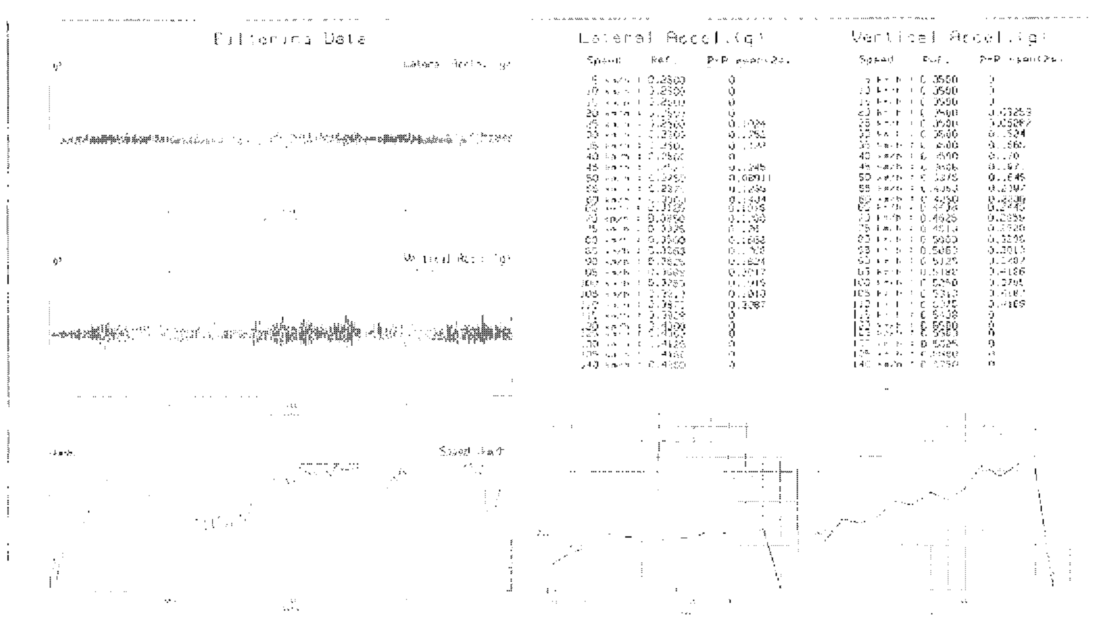


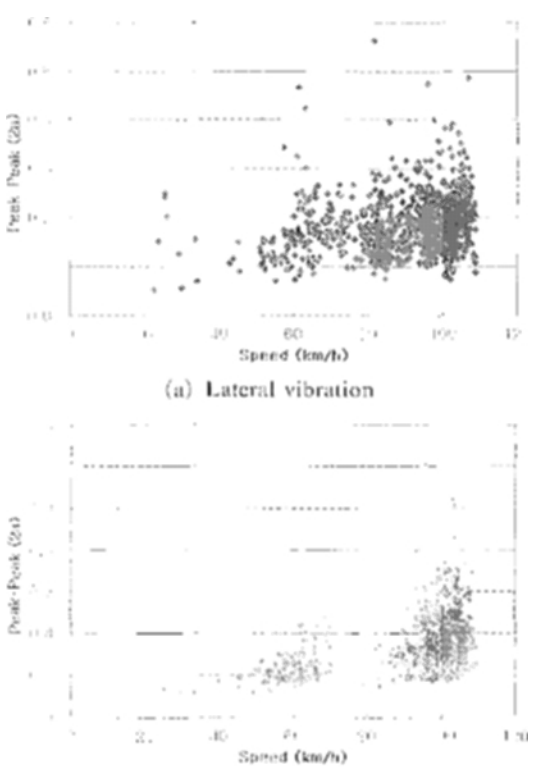
Fig. 10 Test report of vibration level

4.5 Test on freight wagon

The vibration level test on hopper wagon was performed at the various running speeds of the freight wagon currently in service line. The accelerations are installed on the floor of the upside bogie where the vibration is more severe than other positions. Also, the speed sensor is installed on the bogie frame where is a good position to count the revolution of wheel. The angular velocity is converted to calculate the running speed. After the measurement is finished, the evaluation report is produced automatically, which is shown in Fig. 10.

This figure includes vibration filtered with 10 Hz low-pass filter, running speed, peak-to-peak data, corresponding running speeds, and evaluation state curves.

According to test results, the distributions of peak-to-peak values on lateral and vertical direction are obtained as Fig. 11. According to these results, the vibration levels of lateral and vertical direction seem proportional to the running speed.



(a) Lateral vibration

(b) Vertical vibration

Fig. 11 Distribution of peak-to-peak value

5. Conclusions

This paper explains a new evaluation system of ride comfort and vibration level, and the effectiveness of the developed system was validated through field test. Compared to field test, it was proved that the developed system is very effective to save time and money in field test of the passenger coach and freight wagon. Since the developed evaluation system can also be used for both tests, it is advantageous to discard two different evaluation systems on ride comfort and vibration level. The evaluation of ride comfort and vibration level becomes much easier by the test report produced automatically from the developed system.

From this research, it was also proved that the batch work by nCL is capable of rapid processing on the ride comfort and vibration level.

Acknowledgments

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