International Journal of Automotive Technology, Vol. 7, No. 3, pp. 309–314 (2006)

1229–9138/2006/027–11

COMPARISON OF RIDE COMFORTS VIA EXPERIMENT AND COMPUTER SIMULATION

W. S. YOO[1)*], S. J. PARK[2)], D. W. PARK[3)], M. S. KIM[3)], O. K. LIM[1)] and W. B. JEONG[1)]

[1)]Mechanical Engineering, Pusan National University, Busan 609-735, Korea
[2)]CAE Lab, Pusan National University, Busan 609-735, Korea
[3)]Graduated School, Mechanical Design Engineering, Pusan National University, Busan 609-735, Korea

(Received 7 October 2005; Revised 3 February 2006)

ABSTRACT–In this paper, the ride comfort from a computer simulation was compared to the experimental result. For measuring ride comfort of a passenger car, acceleration data was obtained from the floor and seat during highway running with different speeds. The measured acceleration components were multiplied by the proper weighting functions, and then summed together to calculate overall ride values. Testing several passenger cars, the ride comforts were compared. In order to investigate the effect of vibration signals on the steering wheel, an apparatus to measure the vibrations and weighting functions on the steering wheel were designed. The effect of the steering accelerations on the ride comfort were investigated and added for the overall ride comfort. For the computer simulations, Korean dummy models were developed based on the Hybrid III dummy models. For the Korean dummy scaling, the national anthropometric survey of Korean people was used. In order to compare and check the validity of the developed Korean dummy models, dynamic responses were compared to those of Hybrid III dummy models. The computer simulation using the MADYMO software was also compared to the experimental results.

KEY WORDS : Ride comfort, Simulation, Experiment

1. INTRODUCTION

Research on human vibration is concerned with the response of the human body to exerting forces, frequencies, force directions, and exposed time. The standardization processes of these research factors were developed and the typified examples are ISO2631-1 (1997) and BS6841 (1987).

Since ride comfort and human vibration are in some sense a mental and environmental problem including psychological effects, it varies from person to person. When it is defined as a physical quantity and is written as an equation, the ride comfort index is related to acceleration. There has been a great deal of research to evaluate human vibrations and ride comfort (Janeway, 1948; Griffin, 1986; 1996). Among these papers, Griffin's research (Griffin, 1986; 1996) shows a well-summarized understanding of human vibration. Recently, a new textbook about human response to vibration was published (Mansfield, 2004). In their research with the ISVR group (Griffin, 1996), ride comfort models including vibration axes, magnitudes and frequencies, and VDV (vibration dose values) are well-explained. In order to improve ride comfort of long-distance driving of heavy truck vehicles, air cells were installed in the seat. In recent days, more advanced seats were designed to improve ride comfort by adjusting air cell pressure to the vehicle speeds and road conditions (Yoo *et al.*, 2005).

Comfort while in a sitting position also depends on the stiffness of the seat foam and the shape of the seat. When the car is not moving, the seat comfort is somewhat related to the pressure distribution on the seat. The pressure-sensing device was used to get widely distributed pressure on the seat. In addition, when the car was moving, the characteristics of the seat were combined to the human vibration and appeared as dynamic seat comfort.

In this paper, the ride comfort using a computer simulation was compared to the experimental result. For measuring ride comfort of a passenger car, acceleration data was obtained from the floor and seat during highway running with different speeds. The measured acceleration components were multiplied by the proper weighting functions, are then summed together to calculate overall ride values.

2. RIDE INDEX

The RMS (Root Mean Squares) is a widely used value to

**Corresponding author.* e-mail: wsyoo@pusan.ac.kr

quantify the oscillating signal. The RMS of a component can be written as;

$$r.m.s_{\text{component}}=\left[\frac{1}{N}\sum_{i=1}^{N} a^2(i)\right]^{1/2} \tag{1}$$

where $a(i)$ is the acceleration time history of the ith vibration and N is the number of signals considered. The subscript component means one of the 12 vibrations according to the 12 axes, which include the 3 translational and 3 rotational axes on the seat surface, the 3 translational axes at the seat back and the 3 translational axes at the feet.

A compatible mean of quantifying the severity of high crest factors is to use a vibration dose value (VDV) as;

$$VDV_{\text{component}}=\left[\frac{T_s}{N}\sum_{i=1}^{N} a^4(i)\right]^{1/4} \tag{2}$$

where T_s is the measured time for the vibration.

The overall ride values for the vibration can be obtained by summation of each component as;

$$r.m.s_{\text{overall}}=[\sum r.m.s^2_{component}]^{1/2} \tag{3}$$

$$VDV_{\text{overall}}=[\sum VDV^4_{component}]^{1/4} \tag{4}$$

The percent vibration is used to compare overall ride values of several seats (Woo *et al.*, 1997). It is calculated from the difference of overall ride value by dividing the overall ride value of the seat track as shown in equation (5).

$$Vibration(\%)=\frac{ORV_{seat\ \text{contact area}}-ORV_{vibration\ \text{table}}}{ORV_{vibration\ \text{table}}}\times 100 \tag{5}$$

where ORV means the overall ride value and the subscript means the location of the vibration measurement point. In equation (5), ORV value is calculated from frequency weighting functions and axes multiplying factors.

SEAT (Seat Effective Amplitude Transmissibility) value for the vertical vibration is determined using the PSD (Power Spectral Density) of the seat $\{P_{ss}(f)\}$ and the PSD of the floor $\{P_{ff}(f)\}$ as;

$$S.E.A.T.=\left[\frac{\int_{f_0}^{f_1} P_{ss}(f)w_b(f)^2df}{\int_{f_0}^{f_1} P_{ff}(f)w_b(f)^2df}\right]^{1/2} \tag{6}$$

where $\omega_b(f)^2$ is the frequency weighting function. If the SEAT value is less than 1, the vibration level on the seat is less than the floor, which means that the seat is effective in reducing vibration. If the SEAT value is greater than 1, the seat is ineffective in reducing vibration. Therefore, the smaller the SEAT value is, the better the seat efficiency is.

3. FREQUENCY WEIGHTINGS

Four vehicles are compared for the ride values in the cement and asphalt roads. The RMS values and VDV are compared for the ride comfort. Since the roads contained many curves, the x-direction (longitudinal) and y-direction (lateral) values appeared larger. The procedure to calculate component ride values and overall ride values are well-explained in the reference (Griffin, 1996).

Plugging the overall RMS values to the overall VDV in equation (5), the percent vibrations were calculated and compared in Table 1. Since the axis multiplying factors for the seat track and the seat were assigned as 0.4 and 1.0 respectively (Cheung *et al.*, 1977), as shown in Figure 1, the percent vibrations from equation (5) may be larger than 100%.

When a car is running on a roads, the road is acting as white noise, containing most frequencies. Passing through the tire, the suspension, and the chassis, the vibration is reduced and transmitted to the floor and the seat track. In these transmitted vibrations, many kinds of vibration modes-pitching, bouncing, shake, shimmy, and harshness - are contained. These vibrations are then transmitted to the human body through the seat. The vibrations transmitted to the seat are then combined to the human vibration characteristics and generate discomfort for the passenger.

Vibrations are transmitted to the foot, hip and back of

Table 1. Frequency weighting functions and axis multiplying factors in BS 6841.

Acceleration time history (m/s^2)	Frequency weighting function (BS 6841)	
	Symbol	Axis multiplying factor
Feet (a_{xf})	W_b	0.25
Feet (a_{yf})	W_b	0.25
Feet (a_{zf})	W_b	0.40
Hip (a_{xs})	W_d	1.00
Hip (a_{ys})	W_d	1.00
Hip (a_{zs})	W_d	1.00
Hip (a_{rx})	W_e	0.63
Hip (a_{ry})	W_e	0.40
Hip (a_{rz})	W_e	0.20
Back (a_{xb})	W_c	0.80
Back (a_{yb})	W_d	0.50
Back (a_{zb})	W_d	0.40

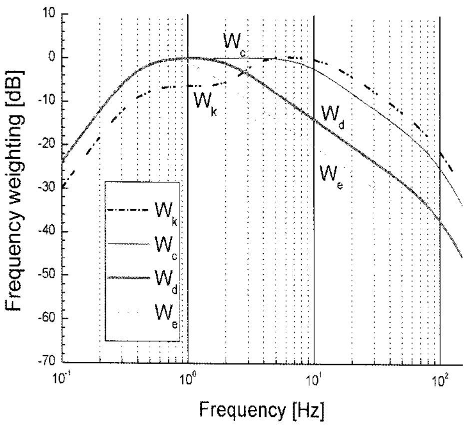

Figure 1. Frequency weightings for a human body.

the human body from the seat. The human body recognizes these vibrations, but the sensitivity for each vibration is different. Many researchers have investigated the weightings for these vibrations and proposed axis multiplying factors. Also, the human sensitivities according to the frequency were defined as a frequency weighting functions shown in Figure 1. Depending on the location and direction, these different frequency weighting functions were applied with a multiplying factor shown in Table 1.

4. EXPERIMENTS FOR RIDE COMFORT

In this study, real experiments were carried out with a Korean man to test the ride comfort. The car was tested over a 28 km distance on the highway near the suburb of metropolitan city of Busan. The person subjected to the test was a male 175 cm in height and 78 kg in weight. In the experiments, vibrations were measured at the seat track and at the seat surface, respectively. A B&K 4321 accelerometer and a B&K 4322 accelerometer were

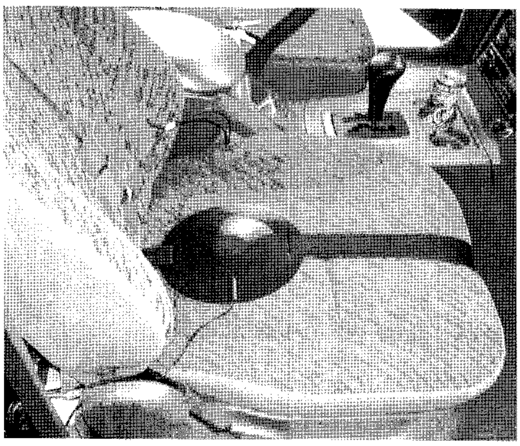

Figure 2. Accelerometers at seat.

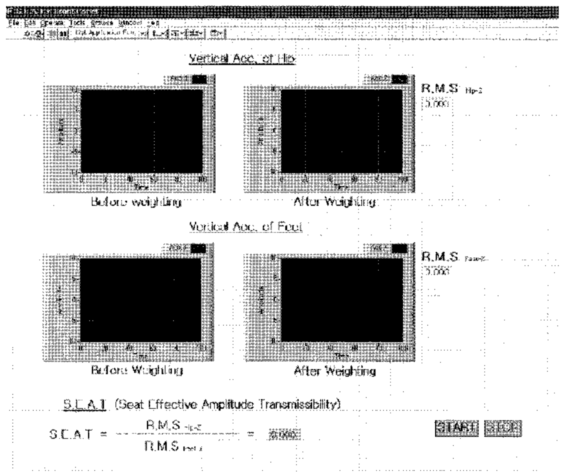

Figure 3. Computer program to calculate SEAT value.

installed at the seat track and on the seat, respectively. The sensor at the hip was installed at the ischiadic tuberosity as shown in Figure 2, and the sensor at the back was located at the lumbar support.

A 4-channel NEXUS system was used for data recording. The output signals were recorded for 1 minute with a 2.5 kHz sampling rate by an 8-channel DAQ card 6036E form NI (National Instrument). Each accelerometer was connected to the amplifier and the signals were recorded in a laptop computer. The stored data was processed to calculate ride comfort using Labview software from National Instruments Inc. In Figure 3, the system to calculate SEAT value on the line is shown.

5. KOREAN DUMMY SCALING

A Korean dummy was scaled and generated from the Hybrid III dummy to compare the experimental results to the MADYMO (1999) simulation. To get the body data for Korean people, the Korean anthropometric survey (KRISS, 1997) data of 1997 was used. For the survey, the South Korean peninsula was divided into 3 regions; the northern part including Seoul, the middle part including Daejeon, and the southern part including Busan. For each region, the populations were sampled from a big city, a small city, and a country. The ages of the 13,062 selected people were from 0 to 70, and included 6,578 men and 6,484 women. The 120 items were measured according to the Korean standards of KS A7003 and A7004, which state the terminology and measurement method for the survey.

The data measured was categorized for infants (0-5), elementary school students (6-11), high school students (12-17), youth 1 (18-24), youth 2 (25-39), middle-aged (40-59), and elderly (over 60). The ages under 17 were tabulated according to the age. Additionally, the measur-

Table 2. Parameters for MADYSCALE input.

No.	MADYSCALE Input Parameters	Body Names from MADYSCALE
1	Weight	Lower torso
2	Standing height	Abdomen
3	Shoulder height	Lower lumbar
4	Armpit height	Upper lumbar
5	Waist height	Upper torso
6	Seated height	Ribs
7	Head height	Lower neck bracket
8	Head breadth	Lower neck sensor
9	Head to chin height	Neck
10	Neck circumference	Nodding plate
11	Shoulder breadth	Head
12	Chest depth	Clavicle left
13	Chest breadth	Clavicle right
14	Waist depth	Upper arm left
15	Waist breadth	Upper arm right
16	Buttock depth	Lower arm left
17	Hip breadth, standing	Lower arm right
18	Shoulder to elbow length	Hand left
19	Forearm-hand length	Hand right
20	Biceps circumference	Femur left
21	Elbow circumference	Femur right
22	Forearm circumference	Knee left
23	Wrist circumference	Knee right
24	Knee height, seated	Upper tibia left
25	Thigh circumference	Upper tibia right
26	Upper leg circumference	Middle tibia left
27	Knee circumference	Middle tibia right
28	Calf circumference	Lower tibia left
29	Ankle circumference	Lower tibia right
31	Foot breadth	Foot right
32	Foot length	Sternum
33	Hand breadth	
34	Hand length	
35	Hand depth	

ed data for the adults (youth, middle-aged, and elderly) were averaged to the body components, and those were divided to the percentiles (5, 10, 25, 50, 75, 90, and 95 percentile).

The Hybrid III dummy, which is based on western people, has many different characteristics than Korean people. The same situation will appear for all Asian people. The typical aspect shows that the circumferential length of the head in the Korean 50 percentile is smaller than the Hybrid III, but the width and the length of the head are bigger than the Hybrid III. Also, the height of the Korean dummy when seated was higher than the Hybrid III. But the shoulder point, elbow length, and the knee were shorter than the Hybrid III.

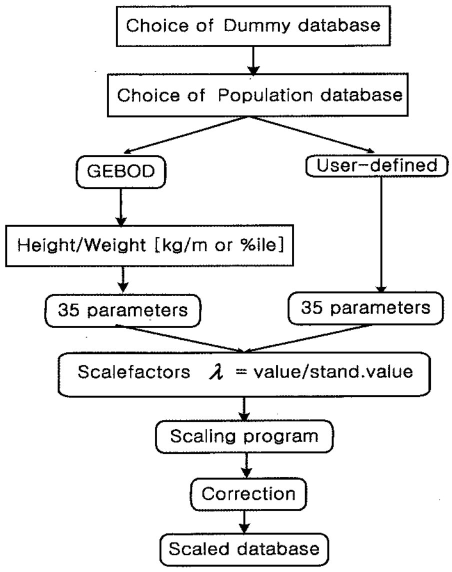

Figure 4. Flow chart of MADYSCALE.

The averaged weight and height of Korean people were used to generate a Korean dummy from the Hybrid III. When 35 body parameters shown in Table 2 were inputted for the MADYSCALE program for the scaling, the program generated dummy data in a HYBRID II format with 32 bodies, which is also listed in Table 2.

A more detailed scaling process is shown in Figure 4. When the dummy database and population database were input, a program called GEBOD (Generation of Body Data) was created to generate body data. Using GEBOD, body data was generated using 35 input parameters, including height and weight, with a scale factor. The material properties were assumed to be constant in the

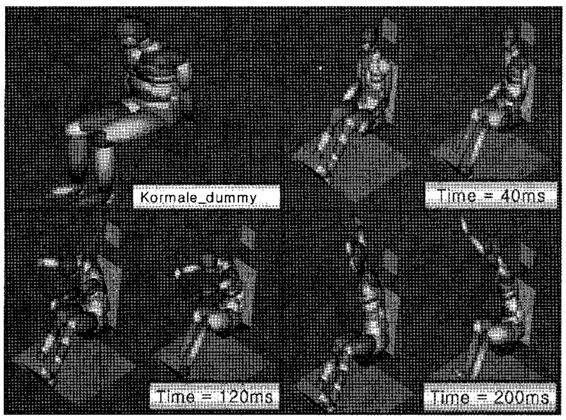

Figure 5. Hybrid III (left) and Korean dummy (right).

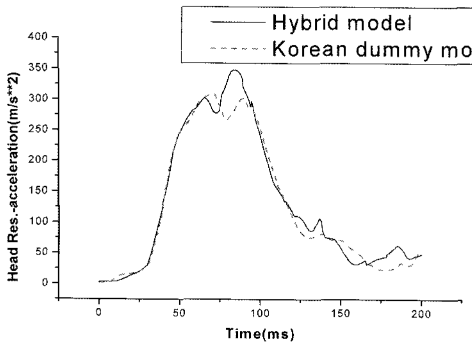

Figure 6. Accelerations at head.

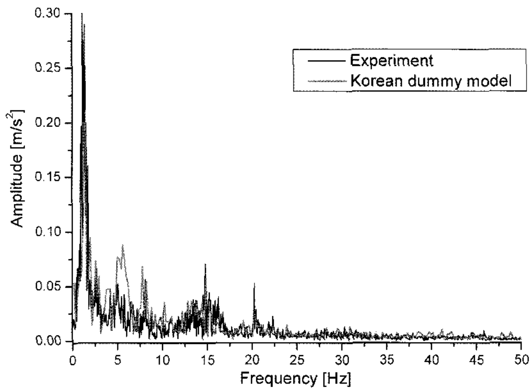

Figure 8. Comparison of spectra at seat z-direction.

scaling process.

A sled test was carried out to verify the scaled Korean dummy. A Korean dummy of 75.5 kg and the Hybrid III dummy of 75 kg were compared from the sled test in MADYMO software. Seated and belted for both dummies, the frontal crash was simulated for 200 msec with a speed of 50 km/hr. Figure 5 shows and compares the simulation results between the two dummies. The animations were captured for 40 msec, 120 msec, and 200 msec. As shown in Figure 6, the two results show are in good agreement. Therefore, it was concluded that there was no mistake in the generating process for the Korean dummy. For the accelerations of the head, very similar results were found.

6. EXPERIMENT VS COMPUTER SIMULATION

The simulation results were compared to the real experiments to see the accuracy of the computer simulation. The vertical acceleration data at the seat track of the vehicle running over the asphalt road at 80 km/hr was input to the MADYMO seat model.

In order to model the seat contact in the MADYMO simulation, the contacts between the dummy model and the seat are described first. Then the measured force-displacement curves for the seat foam and for the back (Gurram and Vertiz, 1997) were applied for the seat deformation. Also, to consider damping in the seat cushion, damping coefficients were measured by using attenuation experiments (Figure 7).

By dropping a hip-shaped dummy on the seat, the vertical displacements were measured by the LVDT. The decrement of amplitudes was used to calculate the damping ratio of the seat.

In Figure 8, the vertical (z-direction) accelerations from the experiment were compared to the simulation, which showed a nice trend in the frequency spectrum. For the MADYMO simulation, the measured damping ratio was used.

7. EFFECT OF STEERING WHEEL ON RIDE

For calculating ride comfort explained in Sections 2 and 3, the acceleration measured on the steering wheel was not included. There is no reason why the acceleration on

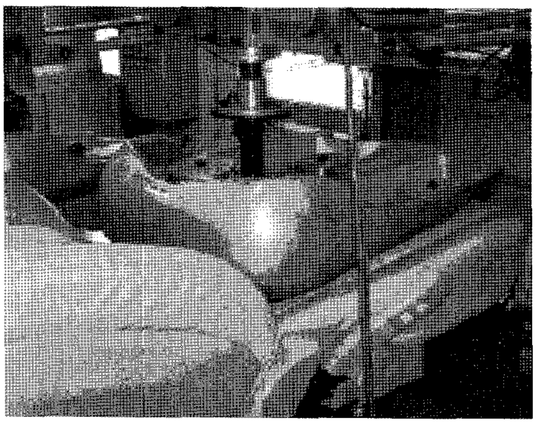

Figure 7. Attenuation experiment to measure damping.

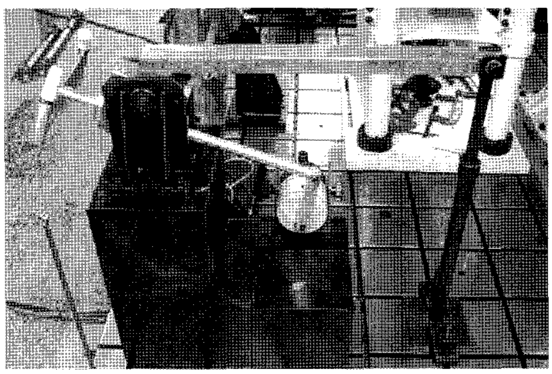

Figure 9. Vibration measurement on steering wheel.

the steering wheel should be neglected. As drivers, vibrations measured on the steering wheel seem to affect the ride quality in many ways. Therefore, research to measure weighting functions for the steering wheel vibration was initiated at Pusan National University.

In order to investigate the effect of vibration signals on the steering wheel, an apparatus to measure the vibrations and weighting functions on the steering wheel were designed as shown in Figure 9. The effect of the steering accelerations on the ride comfort will be investigated and added for the overall ride comfort.

8. CONCLUSION

For the computer simulations, Korean dummy models were developed based on the Hybrid III dummy models. For the Korean dummy scaling, the national anthropometric survey of Korean people was used. To compare and check the validity of the developed Korean dummy models, dynamic responses were compared to those of Hybrid III dummy models. In addition, the computer simulation using MADYMO software was compared to the experimental results.

In order to investigate the effect of vibration signals on the steering wheel, an apparatus to measure the vibrations and weighting functions on the steering wheel were designed. The effect of the steering accelerations on the ride comfort will be investigated and added for the overall ride comfort.

ACKNOWLEDGEMENTS–This research was supported by the Korean Ministry of Science and Technology (grant M1040-0000-274-05J0000-27410) under the National Research Laboratory project and the Korean Ministry of Commerce, Industry and Energy (grant 10016789) under the Korea Automotive Technology Institute project.

REFERENCES

BS6841 (1987). *Guide to Measurement and Evaluation of Human Exposure to Whole-Body Mechanical Vibration and Repeated Shock.* British Standards. London.

Cheung, W. S., Cho, Y. G., Yoon, Y. S. and Park, S. J. (1997). Evaluation of the ride values of passenger cars on the unevenness and endurance roads. *Trans. KSNVE* **7, 6**, 1025–1030.

Griffin, M. J. (1986). Evaluation of vibration with respect to human response. *SAE Paper No.* 860047.

Griffin, M. J. (1996). *Handbook of Human Vibration.* Academic Press. London.

Gurram, R. and Vertiz, A. M. (1997). The role of automotive seat cushion deflection in improving ride comfort. *SAE Paper No.* 970596.

ISO2631-1 (1997). *Mechanical Vibration and Shock Evaluation of Human Exposure to Whole-body Vibration.* Int. Organization for Standardization. Geneva.

Janeway, R. N. (1948). Vehicle vibration limits to fit the passenger. *SAE Paper No.* 480061.

KRISS (1997). *National Anthropometric Survey of Korea* 1997. KRISS-97-114-IR. Korea Research Institute of Standards and Science.

MADYMO (1999). *Database Manual 5.4 Version.* TNO Automotive. Delft.

Mansfield, N. J. (2004). *Human Response to Vibration.* CRC Press. London.

Woo, C. K., Cheung, W. S., Park, S. J. and Kim S. H. (1997). Ride quality assessment of automotive seats by simultaneous 3-axis excitation. *Trans. KSNVE* **7, 1,** 143–152.

Yoo, W. S., Park, D.W., Kim, M. S. and Hong, K. S. (2005). Optimum air pressure for an air-cell seat to enhance ride comfort. *Int. J. Automotive Technology* **6, 3**, 251–257.