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RESEARCH ON VIBRATION CHARACTERISTICS BETWEEN HUMAN BODY AND SEAT, STEERING WHEEL, AND PEDALS (EFFECTS OF SEAT POSITION ON RIDE COMFORT)

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Experimental results are presented of the vibrational characteristics of the automotive subsystem comprising the human body, seat, steering wheel and pedals. The magnitude of the vibrations transferred to a driver from the seat, steering wheel and pedals have been measured with both sinusoidal and random excitations in the vertical direction at frequencies up to 20 Hz. Measurement points were located on the surface of the head, chest, hip, thigh, shin, upper arm and lower arm. Eleven subjects were used to investigate the effect of some variable factors, such as arm angle, that may affect human dynamic behavior. It was found that arm angle in driving posture has a substantial influence on the dynamic behavior of the human body while driving. Some results are presented in the form of parametric graphs and tables. The results are useful for improving ride comfort, maneuverability and safety.

1. INTRODUCTION

Drivers of vehicles such as automobiles, trucks, buses, tractors, taxis and locomotives, helicopter pilots and drivers of heavy construction vehicles are always in contact with the seat, the steering wheel and pedals. The vibration transfers from the seat, the steering wheels, and pedals, to human body parts. The amount of vibration transmitted to the driver is influenced by the posture of the subject in the vehicle. It is an important problem from the viewpoint of ride comfort and maneuverability to decrease the vibration transmitted to the human body.

When a driver sits on a vehicle seat, s/he chooses a positioning of the seat to operate the pedals easily. The seat may be moved backwards or forwards according to the stature of a driver in order to operate the pedals without difficulty. The spacing between the steering wheel and the body then becomes small. The driver has to bend the arm considerably to

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operate the steering wheel. Such a tendency is often seen for woman drivers and taxi drivers. To keep the space in a back seat comfortably large, the driver's seat is often moved forward as much as possible for the taxi driver. We are interested in the effect of driving posture on vibration experienced by the human body.

Several investigations of the effects of postural changes have been reported. Fairley and Griffin [1] investigated the apparent mass of the seated human body. Wilder *et al.* [2] demonstrated the effect of posture and seat suspension design on discomfort and back muscle fatigue during simulated truck driving. Paddan and Griffin [3] have investigated transmission of roll and pitch seat vibration to the head. Lewis and Griffin [4] examined the transmission of vibration to the occupants of a car seat with a suspended backrest. Differential motion between the seat surface and seat back was smaller with the moving seat back than with the fixed back. Fairley and Griffin [5] investigated the best procedure for predicting the discomfort caused by simultaneous vertical and fore-and-aft vibration. Parsons and Griffin [6] have presented the results of whole-body vibration perception thresholds. Corbridge and Griffin [7] have determined the effects of the frequency of whole-body vibration on comfort in the range 0·5–5·0 Hz.

However, reports of vibration experienced by specific parts of the human body have apparently not been published to date. For this purpose, it is desirable to investigate the vibration characteristics between the human body and seat, steering wheel, and pedals. There is a relative relation between the seat position and the arm angle. The sitting posture of a driver is therefore determined by the position of the seat. Especially, the position of the seat establishes the relative angle between the upper arm and the lower arm. This will henceforth be abbreviated to "arm angle".

It is postulated that a certain arm angle is preferred from the points of view of maneuverability, safety and ride comfort. It is not clear whether the vibration of arms and legs is an important factor or not for ride comfort. However, when a driver operates the pedals and the steering wheel, it is important to reduce the vibration from arms and legs in an emergency. When the vibration of arms and legs increases, the steering wheel and pedals cannot be operated to prevent an accident. It is therefore desirable to clarify the vibrational characteristics of the system comprising the human body and the seat, steering wheel and pedals.

This research examines the influence that the arm angle, dependent on the position of the seat, exerts on ride comfort. The seat–steering–pedals system is here represented by a device that is mounted on a rigid frame attached to the platform of a three-dimensional electro-hydraulic vibrator. The seat slides backwards and forwards, thus changing the arm angle according to seat position. In this research, the position of the seat changed the arm angle from 90 to 180° in increments of 30°. The vibration characteristic of each human subject seated on a seat is measured for each arm angle. The measurement positions are at the head, the chest, the hip, the thigh, the shin, the upper arm, and the lower arm in the sitting posture. Eleven subjects took part in the experiment. The excitation input in this research was both sinusoidal and random. The present study was conducted to determine the variation of vibration transmission from seat or steering wheel or pedals to human body parts. The effects of sitting posture and the influence of the seat position on ride comfort were investigated.

2. PROCEDURE

2.1. DEVELOPMENT OF SEAT–STEERING–PEDALS SYSTEM DEVICE

Figure 1 shows the seat–steering–pedals system device developed for the research to measure the vibration characteristics of human body parts. Table 1 shows the parameters of

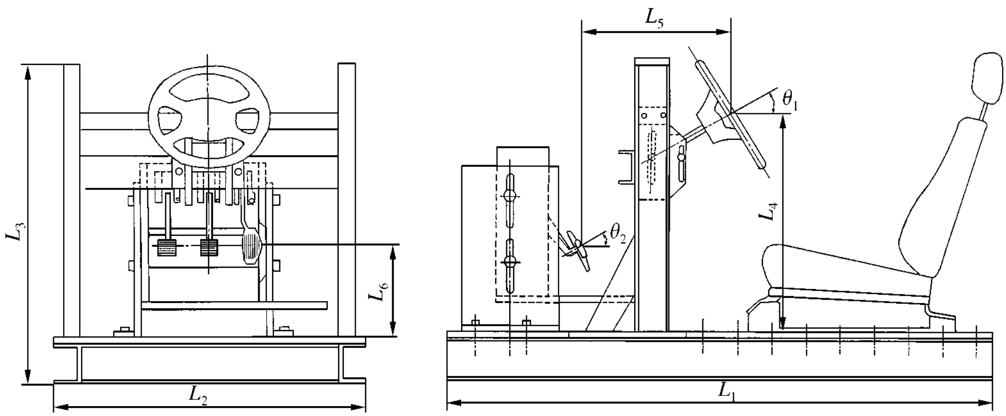


Figure 1. General arrangement of the seat–steering wheel–pedals system.

TABLE 1

Specifications of seat–steering wheel–pedals system

L_1	1600 mm	L_5	350–650 mm
L_2	920 mm	L_6	160–310 mm
L_3	975 mm	θ_1	10·5–46·5°
L_4	530–700 mm	θ_2	30°

the main parts of the device. This device is a structure allowing relative positions such as the seat, steering wheel and pedals to be varied, to represent real car situations. The size and the weight were designed in order to examine various aspects of the vibrator platform. The structure of the device was made from an aluminum frame to minimize weight whilst securing rigidity. The steering of the device was a mass production item of the M Company. The structure of the steering wheel could be adjusted for the up and down and backwards and forwards directions. The operational reject force of the steering was not considered. The pedals of the device were also mass production items of the M Company. The pedal adjustment of the up and down and backward and forward directions was enabled, and the stepping power was considered. The seat can be adjusted back and forth and in the vertical direction. Relative positions between the seat, steering, and pedals could be adjusted to represent both a truck system and a passenger car system. The total weight of the device was 100 kg.

The seat–steering–pedals system device was fixed by bolts to the platform of an electro-hydraulic vibrator.

2.2. DEVELOPMENT OF A DEVICE FOR ACCELERATION SENSOR INSTALLATION

To allow the acceleration in the direction of the three axes of the head, the chest, the thigh, and the shin, the upper arm, and the lower arm and vertical direction of the hip to be measured, specific sensor installations for each part were developed.

Figure 2 shows the device developed for the acceleration measurement of the head. This device was made from sheet material of transformer isoprene resin, which is a hard material at ambient temperature but becomes soft and compliant at about 70. Two pieces of

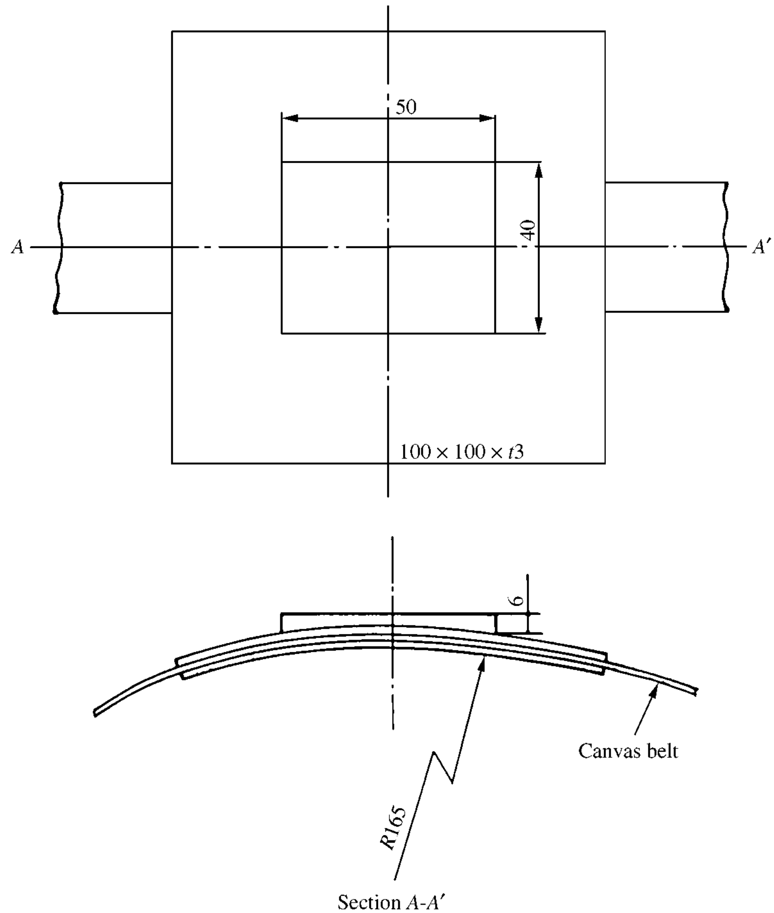


Figure 2. Device developed to measure acceleration of head. Dimensions in mm. t = thickness (mm).

transformer isoprene resin of thickness 3 mm (sheet material 100 mm square) were formed into a globular shape of 165 mm outside diameter, thus modeling a curved surface. A canvas belt allowed the attachment to be fixed to the head. Total weight when the acceleration sensor was installed was 260 g.

Figure 3 shows the design of the sensor installation for measurement of the chest acceleration. A plastic board of size 250 × 120 mm was used to make this device. Felt of 2 mm thickness was stuck to the lower side. Moreover, the shape was selected to be a trapezoid in consideration of the configuration of the seat back. Total weight when the acceleration sensor was installed was 400 g. The canvas belt was used and attached to the body part.

Figure 4 shows the device for sensor installation by which the acceleration of the hip was measured. The 10 mm thick felt was positioned on both sides of the aluminum board of size 100 × 150 and 8 mm in thickness, with a 10 mm thick sponge layer on the lower side. The upper surface was adhered to a rectangular rubber sheet of size 300 × 200 mm. To ensure contact with the whole surface of the seat, the rubber board was shaped into a trapezoid. The acceleration sensor installed in this device was a charge-type accelerometer. Total weight of this device was 1700 g.

Figure 5 shows the device for sensor installation by which the accelerations of the thigh and shin were measured. The devices for measurement of the thigh and shin had the same

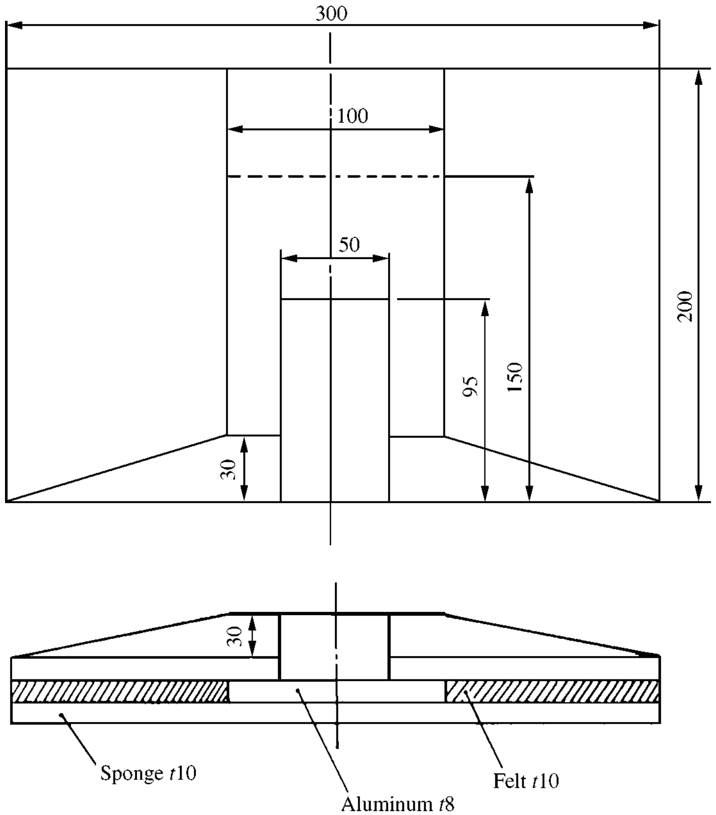


Figure 3. Device developed to measure acceleration of chest.

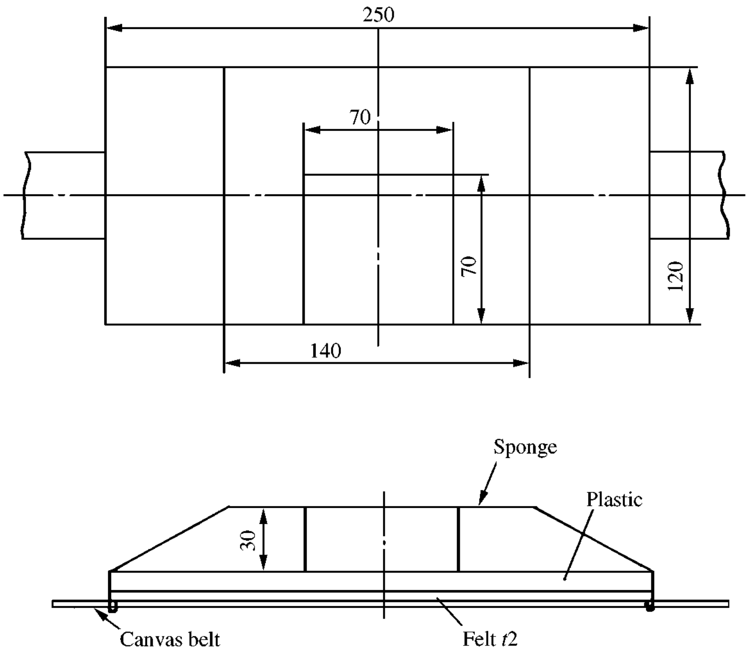


Figure 4. Device developed to measure acceleration of hip.

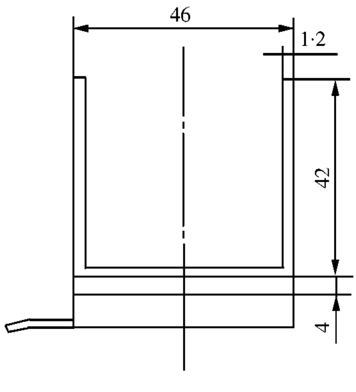


Figure 5. Device developed to measure acceleration of thigh and shin.

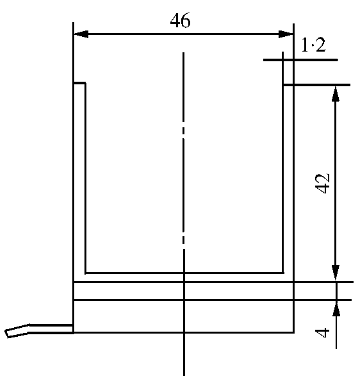


Figure 6. Device developed to measure acceleration of upper arm and lower arm.

shape. An aluminum board 1·2 mm in thickness and 50 mm in width was bent into a rectangle; the sheet material of transformer isoprene resin was placed on the buckle of the canvas belt, and the sensor installed in it. The acceleration sensor was maintained horizontally for each posture. Total weight was 270 g.

The accelerations in the three co-ordinate axes for each body part were measured about the head, the chest, the thigh, and the shin with dynamic strain-type accelerometers. The devices for sensor installation which measured the head, the chest, the thigh, the shin, the hip had been used and their performance confirmed in former reports [8, 9].

The installation device shown in Figure 6 was developed in this research. The device for the sensor installation of the upper arm and the lower arm had the same shape. The aluminum board 1·2 mm in thickness and 50 mm in width was bent into a rectangular shape, transformer isoprene resin sheet material was placed on the buckle of the canvas belt, and the sensor was installed in it. The sensors were installed in the devices so that the acceleration sensors of the upper arm and the lower arm were kept horizontal according to each arm angle. The sensors were fixed with double-sided tape. The total weight of acceleration sensors for the upper arms and the lower arms were each 270 g.

2.3. EXCITATION INPUT

In practice, few vehicles impart a pure sinusoidal input to the driver. Instead, most vehicles transmit a complex vibration containing many impact shocks. However, two kinds (sine wave and random) are measured as excitation input. In the frequency response, the frequency is assumed to be 2–20 Hz, and a sine wave of amplitude 3 mm is used. In order to present errors of 5% or more is not caused in the size of the response in the frequency range within $\pm 10\%$ of resonance frequency fr, speed of sweep time $\mathrm{d}f/\mathrm{d}t$ is specified in ISO 7626 [10] as:

$$\mathrm{d}f/\mathrm{d}t = 77{\cdot}6 fr/Q^2 \quad \text{(octave/min)}, \tag{1}$$

where, the Q factor is defined as the ratio of the size of the resonance peak regularly reached to the size of the response at the quietness load.

Defining the frequency band Δfr, separating the frequencies of which transmission becomes half the peak values, and damping ratio as ζ, we obtain the following expressions:

$$\Delta fr = 2fr\zeta \quad \text{(Hz)}, \qquad Q = \frac{1}{2\zeta} = fr/\Delta fr, \tag{2, 3}$$

where fr and Δfr are estimated from the frequency response function measured by a preliminary test by an adult male driver. Next, the Q factor is calculated from equation (3). Then, the sweep speed is decided from equation (1).

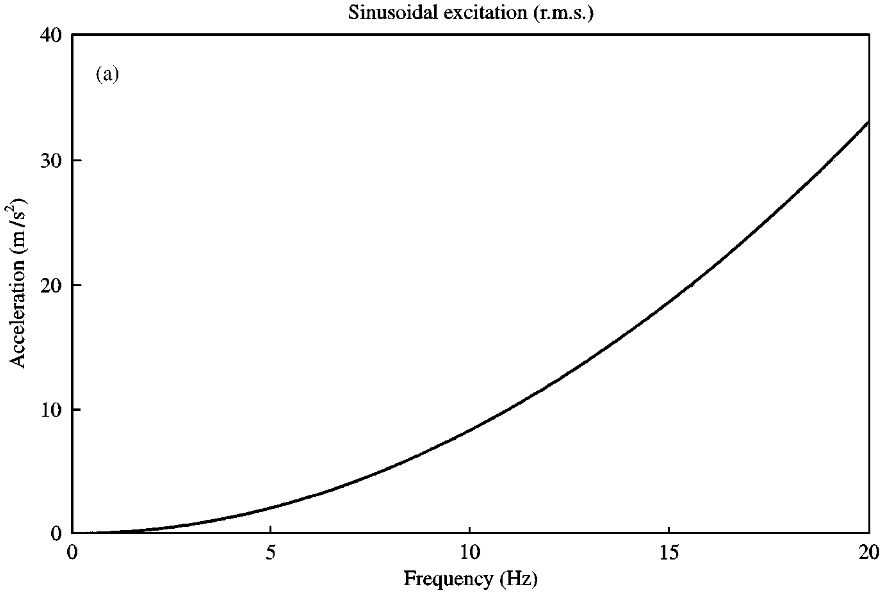
The vibration input is measured only in the vertical direction. In ride comfort, vertical vibration is more important than that in the longitudinal of lateral directions. In the frequency response, the sine wave was done using the logarithmic sweep. The sweep time was 90 s in the frequency range 2–20 Hz in this research.

Figure 7 shows the vibration magnitude used as the input signal. Figure 7(a) indicates sinusoidal excitation, and Figure 7(b) indicates random excitation. The random excitation was a vertical acceleration, which was recorded on the floor of a sedan-type car. The car was driven by a driver who had many years of driving experience at a speed of 60 km/h on a real road (the 188th national road line). Acceleration transducers were placed on the floor of the driving cabin, recording acceleration in the z direction. The vertical component of the recorded vibration was used to drive the baseplate of the servo-hydraulic pump in the research.

2.4. SUBJECTS

The subjects were chosen in consideration of the Japanese 50-percentile value [11] of a person of modern times and typical driving career. Geometrical characteristics of the subjects such as sex, age, stature, and weight are shown in Table 2.

The vibration examination was conducted on 11 subjects. Nine male and two female subjects volunteered for the study. Their mean age was 35·1 years (24–54), mean height 167·8 cm (161–178) and mean weight 63·9 kg (46–78). There is much variability and little repeatability in the vibration characteristics of the human body. To analyze the experimental results statistically, more than 10 subjects with different sex, age, stature, and weight were used to investigate the effect of arm angle on the affect of human dynamic behavior.



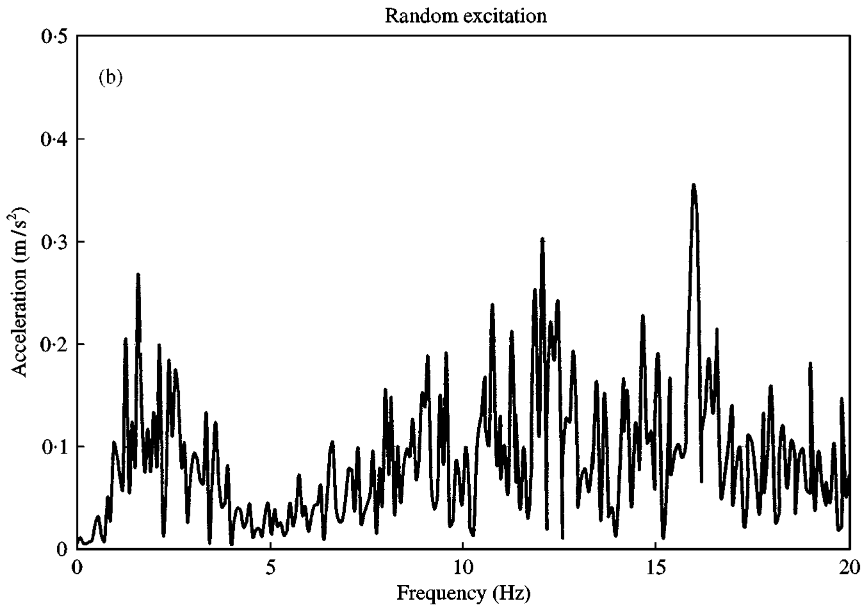


Figure 7. Vibration magnitude (a) Sinusoidal excitation; (b) Random excitation.

2.5. EXPERIMENTAL METHOD

The acoustic noise level at the position of subject's head was 56 dB(A) and was not significantly correlated with the vibration signals. The noise was mainly caused by the vibrator-cooling fan and did not vary. Figure 8 shows the measurement points and the direction of the acceleration of the body parts measured. As for the head, the position of the accelerometer was on the top. The center of gravity was measured for the chest, the thigh, the shin, the upper arm, and the lower arm. Vertical acceleration between hip and seat was

TABLE 2

Characteristics of the 11 *subjects*

Subject no.	Sex	Age (y)	Height (cm)	Weight (kg)
1	Male	32	178	78
2	Male	26	163	59
3	Male	25	171	67
4	Male	34	162	68
5	Male	51	164	75
6	Male	29	175	58
7	Female	31	154	47
8	Female	24	161	46
9	Male	48	174	67
10	Male	54	166	60
11	Male	32	178	78
Mean		35·09	167·82	63·91

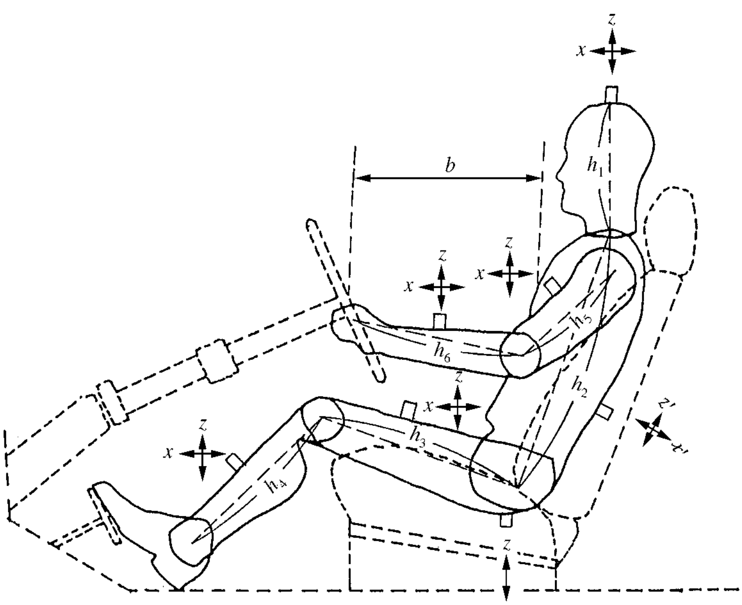


Figure 8. Measurement points and its directions.

measured for the hip. The seven parts of body were measured in the experiments. Measurements were made in the vertical and longitudinal directions for the head, the thigh, the shin, the upper arm, and the lower arm. The chest part was measured by the directions perpendicular (x') and parallel (z') to the chest. The hip was moved only in a vertical direction. The seatpan accelerometer was located between the seatpan and the subject's buttocks. Measurement points were located on the surface of human body part. The seat–steering–pedals system device was set-up on the vibration platform. The angle of the seat squab was set at 19·5° on the floor side, and the angle of the backrest was set at 110°. The subjects sat in an inclined seat squab and backrest of 110° from the horizontal. To reproduce the phenomenon in a real car as much as possible, only the seat position moved

TABLE 3

Dimensionless mean length of body parts and seat position

h_1/h	h_2/h	h_3/h	h_4/h	h_5/h	h_6/h	b_{180}/h	b_{150}/h	b_{120}/h	b_{90}/h
0·16468	0·34452	0·27464	0·25830	0·17659	0·19176	0·27275	0·24360	0·20558	0·16766

In the table h_1: length of head and h_2: chest, h_3: thigh, h_4: shin, h_5: upper arm, h_6: lower arm, and h: height, b_{180}: space between steering wheel and body at arm angle 180°, b_{150}: at arm angle 150°, b_{120}: at arm angle 120°, b_{90}: at arm angle 90°.

back and forth. The arm angle of a driver was determined from the difference between the steering wheel and the human body.

Table 3 shows the average value concerning 11 subject's geometrical characteristics, and difference between human body and the steering wheel at each arm angle.

Knees were kept apart and separated by the same distance as between the hands of each subject. The angle of the thigh had been adjusted so that the thigh might bind to the whole area between thigh and seat. Both feet were placed on the pedal applying the heel to the floor. Both hands lightly grasped the horizontal parts of the steering wheel. The subjects were instructed to look at a stationary cross on the wall approximately 4·1 m away during exposure.

The temperature in the laboratory ranged from 20 to 25°C over the period of the experiment. The head was vertically maintained to watch a stationary cross. The subject sat down on the seat in a relaxed muscular and comfortable posture. The frequency response experiments were done for the arm angle, which was set at 180, 150, 120, and 90°, continuously. Then random excitation was conducted when the arm angle was 90, 120, 150, 180°. In this way, eight kinds of tests were run for each subject. Two kinds of vibration input and four types of arm angles were run. The input channels were calibrated before the vibration signal was recorded. Only seat position could be adjusted for each subject in this research.

3. RESULTS

3.1. DATA ANALYSIS

There is great variability and little repeatability in measurements concerning the vibration characteristics of the human body. Therefore, the average of 11 subjects' measurement data was calculated in this research. The measurement data has values at 401 points in the frequency range from 0 to 20 Hz. Effective data were assumed to be in the range between 2 and 20 Hz from the performance of the vibrator. The average value was calculated and the response characteristic for each arm angle was examined.

3.2. SINUSOIDAL EXCITATION

Figure 9 shows the vibration characteristics for the head calculated from the average value when 11 subjects' arm angles were 90, 120, 150, 180°. The horizontal axis shows the frequency. The vertical axis indicates acceleration ratio between vibration platform and head. Physical properties of the horizontal and vertical axes are the same in Figures 9–15. The influence which the arm angle exerted on the vibration acceleration ratio of the head

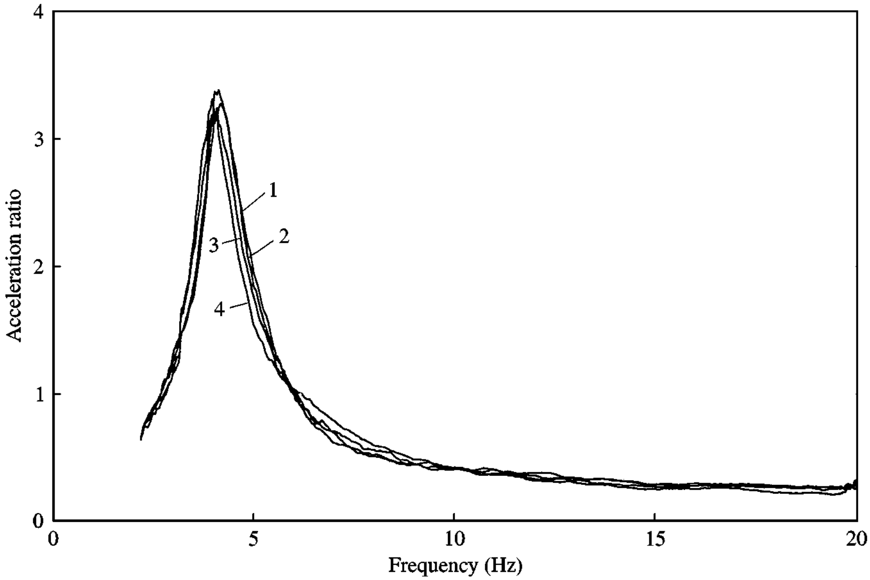


Figure 9. Mean acceleration ratio at the head for each arm angle. (1): arm angle 90°; (2): arm angle 120°; (3): arm angle 150°; (4): arm angle 180°.

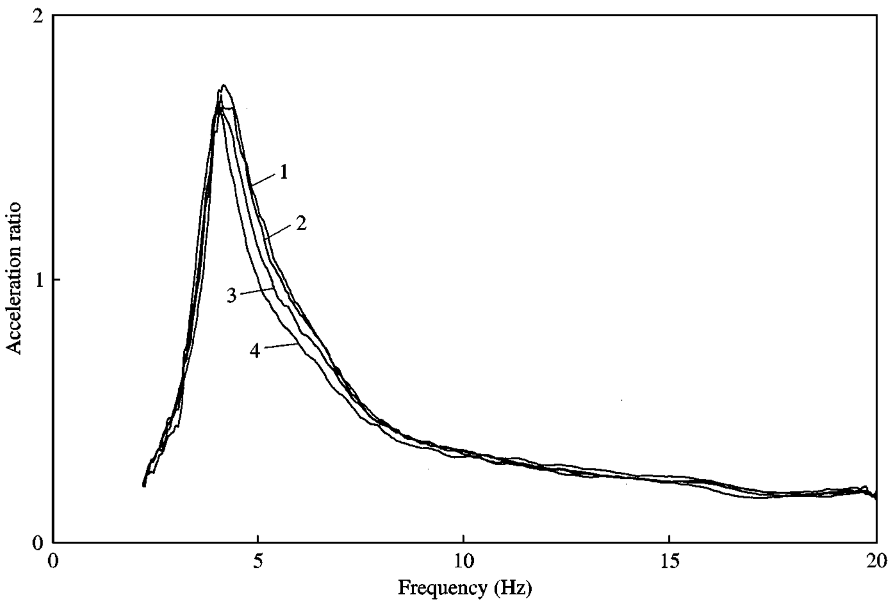


Figure 10. Mean acceleration ratio at the chest for each arm angle. (1): arm angle 90°; (2): arm angle 120°; (3): arm angle 150°; (4): arm angle 180°.

was small. The resonance frequency existed in the vicinity of 4 Hz, and the acceleration ratio was observed to be in the range of 3·3–3·4 for each arm angle. The transmissibility became less than one at very low frequencies. The human body is a complicated multi-degree-of-freedom system. Therefore, it is thought that damping characteristics of human body will ease vibration transfer.

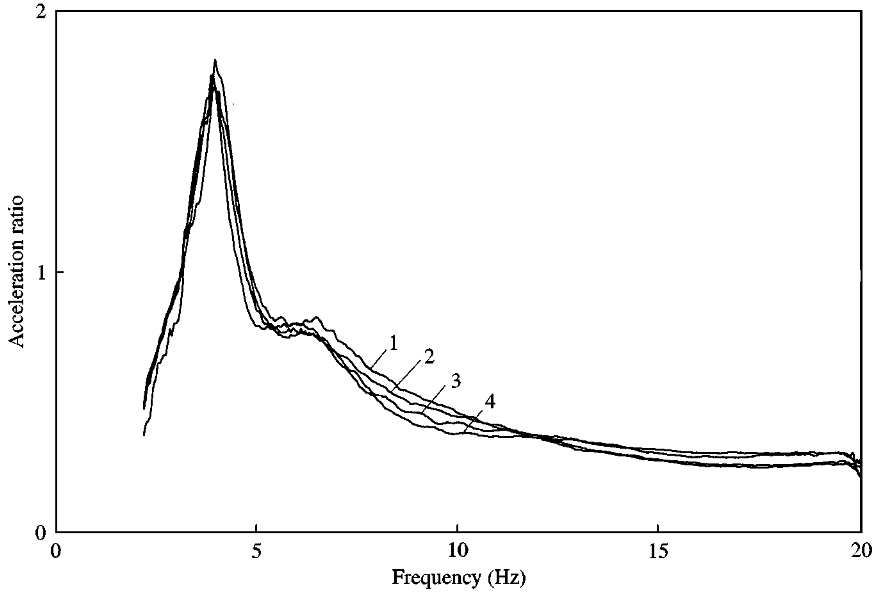


Figure 11. Mean acceleration ratio at the hip for each arm angle. (1): arm angle 90°; (2): arm angle 120°; (3): arm angle 150°; (4): arm angle 180°.

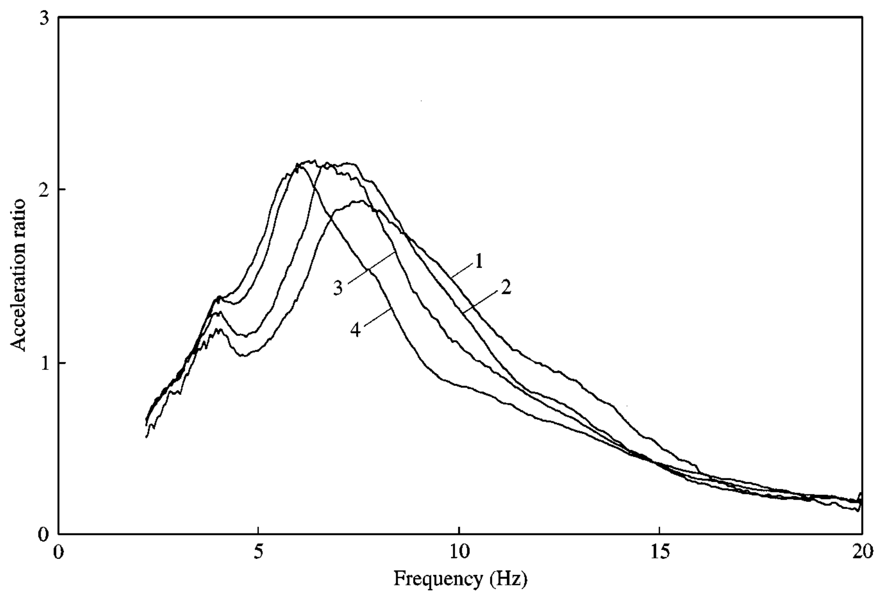


Figure 12. Mean acceleration ratio at the thigh for each arm angle. (1): arm angle 90°; (2): arm angle 120°; (3): arm angle 150°; (4): arm angle 180°.

Figure 10 shows the acceleration ratio of the chest. The peak value was noted in the vicinity of 4 Hz for each arm angle. The curve became sharp as the arm angle increased. The acceleration ratios ranged from 1·6 to 1·7.

Figure 11 shows the acceleration ratio for the hip. The peak value was observed in the vicinity of 4 Hz for each arm angle. The peak values ranged from 1·7 to 1·8. The acceleration

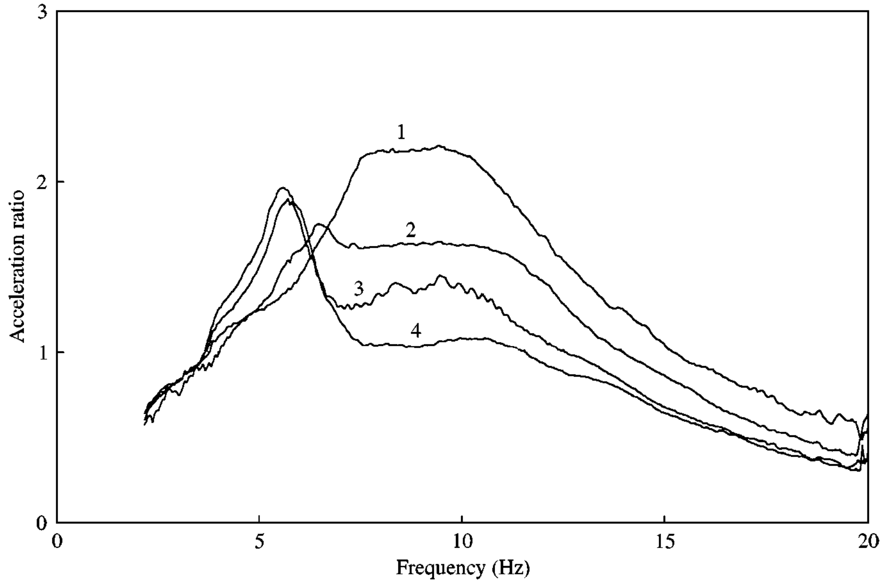


Figure 13. Mean acceleration ratio at the shin for each arm angle. (1): arm angle 90°; (2): arm angle 120°; (3): arm angle 150°; (4): arm angle 180°.

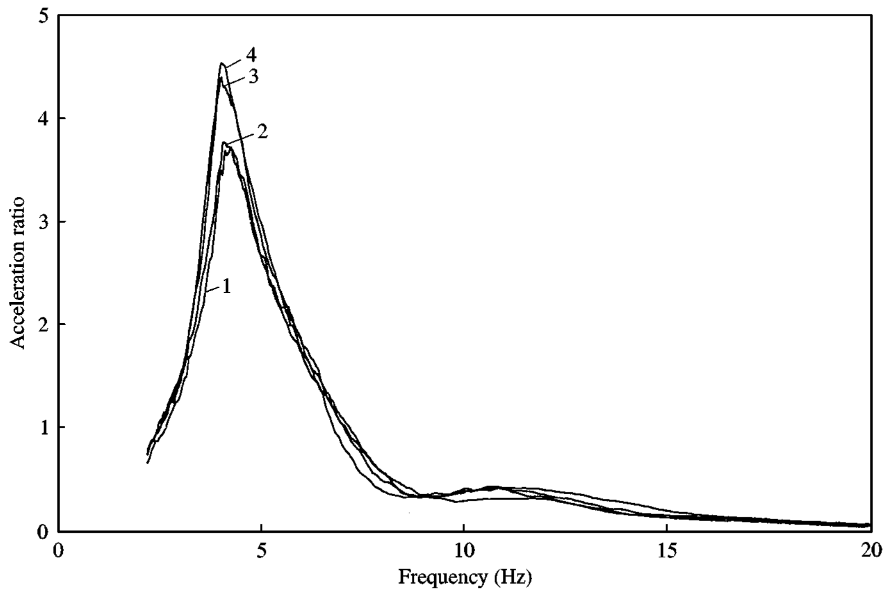


Figure 14. Mean acceleration ratio at the upper arm. (1): arm angle 90°; (2): arm angle 120°; (3): arm angle 150°; (4): arm angle 180°.

ratio decreased when the frequency increased from the peak. A small peak was seen again in the vicinity of 6 Hz. The curve decreased with an increase in the frequency thereafter. No noticeable tendency was seen for the influence of the arm angle.

Figure 12 shows the acceleration ratio of the thigh. The acceleration ratios for different arm angles were almost the same within the range from 1·9 to 2·2. The resonant frequency,

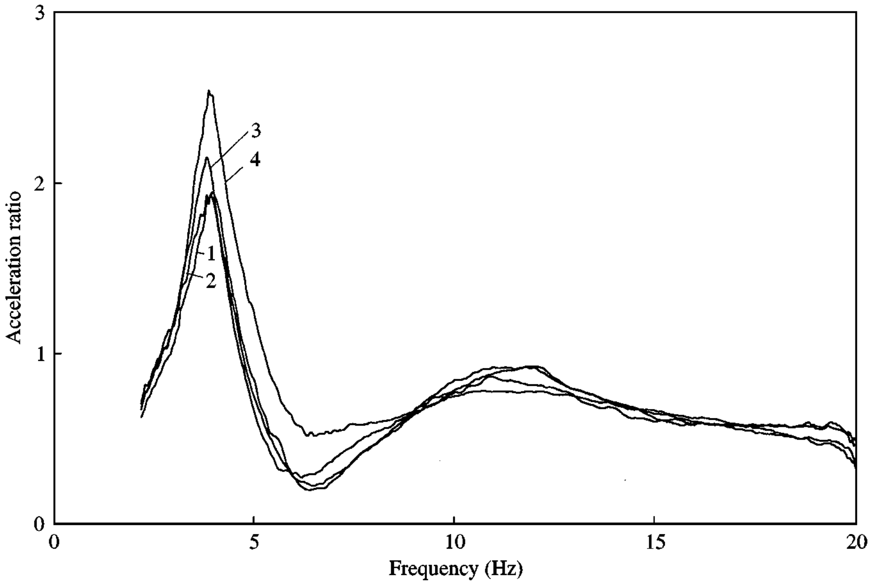


Figure 15. Mean acceleration ratio at the lower arm. (1): arm angle 90°; (2): arm angle 120°; (3): arm angle 150°; (4): arm angle 180°.

which produced the peak, was influenced by the arm angle. The resonance frequency was 7·6 Hz at 90°, 6·7 Hz at 120°, 6·4 Hz at 150° and 6 Hz at 180°. The resonance frequency thus decreased when the arm angle increased. The angle of the thigh based on the floor grew large when the arm angle become small. It seems that when the arm angle exerts an influence on the posture of the thigh, such a characteristic appears.

Figure 13 shows the acceleration ratio of the shin. The resonance frequency, which produced the peak, is influenced by the arm angle though the acceleration ratio is almost the same within the range from 1·9 to 2·2. The resonance frequency was 9·5 Hz at 90°, 6·5 Hz at 120°, 5·75 Hz at 150° and 5·65 Hz at 180° respectively. The resonance frequency decreased when the arm angle increased. The curve resembles the characteristic for the thigh. The thigh angle based on the floor grew when the arm angle became small. It seems that the arm angle exerts an influence on the posture of the shin, such a characteristic appears. The frequency characteristic becomes flat-topped for the 90 and 120° curves.

Figure 14 shows the acceleration ratio of the upper arm, ranging from 3·7 to 4·5 at resonance. The resonance frequency, around 4 Hz, was not influenced by the arm angle. When the arm angle increased, the acceleration ratio grew, becoming approximately the same at 90 and 120°. The acceleration ratio also became the same at 150 and 180°.

Figure 15 shows the acceleration ratio of the lower arm, ranging from 1·9 to 2·5 at resonance. The resonance frequency, which was little influenced by arm angle was close to 4 Hz. In addition, a small peak existed in the vicinity of 12 Hz. As for the peak value in the vicinity of 4 Hz, when the arm angle grew, the acceleration ratio became larger.

3.3. RANDOM EXCITATION

The experimental results with a random excitation were similar to those for sinusoidal excitations. The results of random excitation were used to provide additional data, but are not examined in detail.

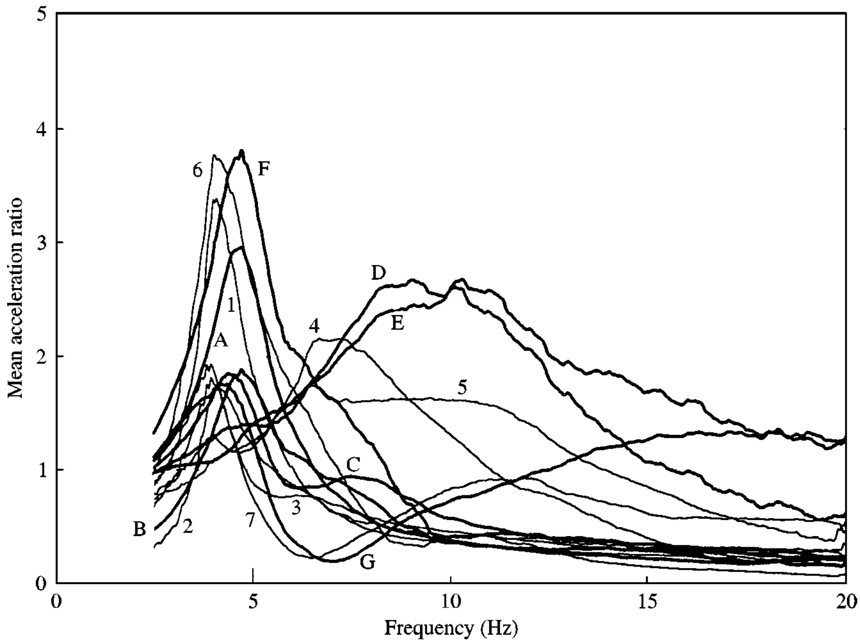


Figure 16. Comparison of mean acceleration ratio between sinusoidal and random excitation to arm angle 120°. Thin solid lines show the sinusoidal excitation and thick solid lines random excitation. (1): head; (2): chest; (3): hip; (4): thigh; (5): shin; (6): upper arm; (7): lower arm; (A): head; (B): chest; (C): hip; (D): thigh; (E): shin; (F): upper arm; (G): lower arm.

Figure 16 shows the mean acceleration ratio for 11 subjects, when the arm angle was 120°. The experimental results of sinusoidal excitations at arm angle 120° are repeated as thin solid lines. The human body parts had different resonance frequencies and different peak values. Random excitation showed the tendency that the peak value of acceleration ratio was larger and the resonance frequency became higher, as compared with the results of sinusoidal excitation.

4. DISCUSSION

4.1. EFFECTS OF BODY PARTS

The transmissibility and the resonance frequency vary with body parts. It is desirable to reduce the vibration experienced by arms and legs in order to operate the steering wheel and pedals. But, in ride comfort, the amount of vibration for the head, the chest, and the hip may be more important. It is therefore necessary to investigate the vibrational characteristics of various body parts.

Figures 17–20 show the effect of arm angle on body parts vibration, for arm angles of 90, 120, 150 and 180° respectively.

4.2. EFFECTS OF ARM ANGLE ON PEAK VALUE AND RESONANCE FREQUENCY

The arm angle largely depends on the seat position. The transmissibility for the head has a sharp resonance response curve, and which is little influenced by arm angle. There was

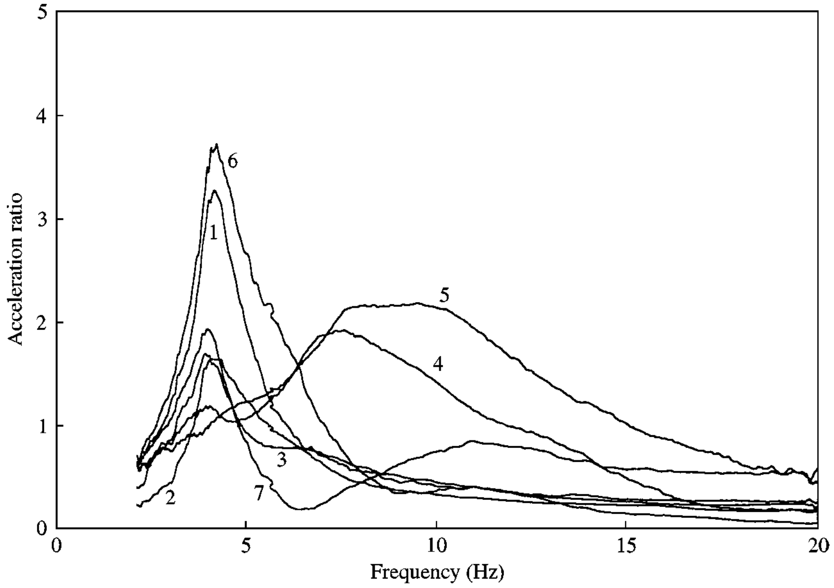


Figure 17. Body parts acceleration ratio for arm angle 90°. (1): head; (2): chest; (3): hip; (4): thigh; (5): shin; (6): upper arm; (7): lower arm.

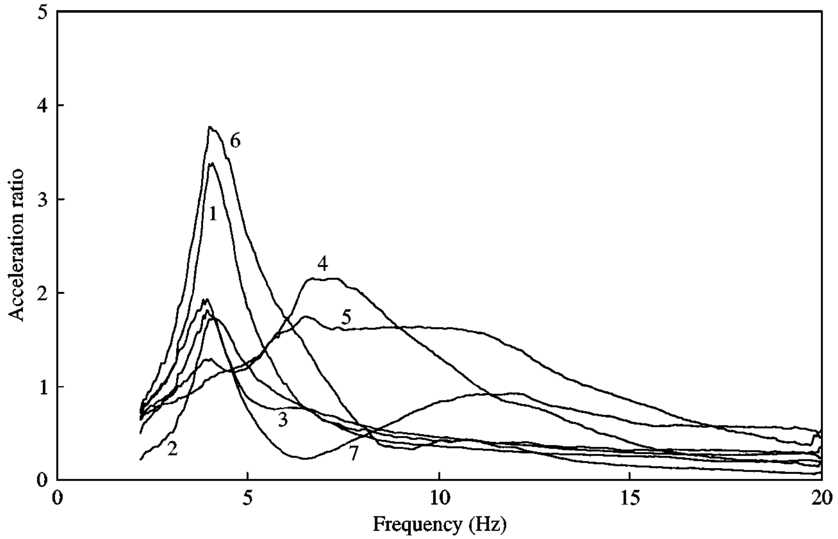


Figure 18. Body parts acceleration ratio for arm angle 120°. (1): head; (2): chest; (3): hip; (4): thigh; (5): shin; (6): upper arm; (7): lower arm.

a different characteristic at frequencies beyond resonance. The larger arm angles had large damping. There were two peaks for the hip, the first resonant frequency was around 4 Hz, and the second one was around 6 Hz. The peak value at the second resonance frequency was comparatively small. Transmissibility and the resonance frequency were significantly influenced by the arm angle for thigh vibrations. The angles of both thigh and shin were

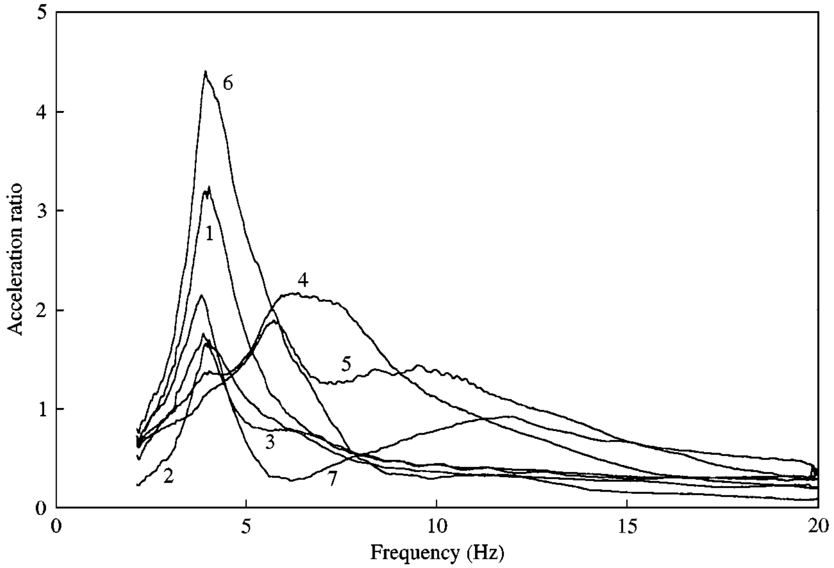


Figure 19. Body parts acceleration ratio for arm angle 150°. (1): head; (2): chest; (3): hip; (4): thigh; (5): shin; (6): upper arm; (7): lower arm.

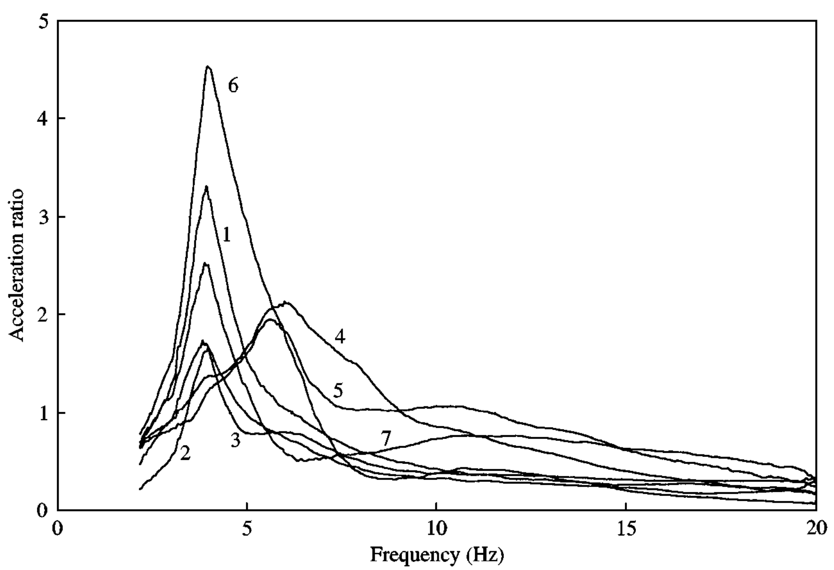


Figure 20. Body parts acceleration ratio for arm angle 180°. (1): head; (2): chest; (3): hip; (4): thigh; (5): shin; (6): upper arm; (7): lower arm.

changed accordingly as the seat position. As the seat is moved forward, the arm angle becomes small and angle of thigh and shin becomes large. Therefore, the transmissibility and the resonance frequency had different values.

As for the shin, similar characteristics to those of the thigh were evident for transmissibility and resonance frequency. The curve had a wide top in the vicinity of 10 Hz.

TABLE 4

Average value of peak acceleration ratio, resonance frequency, and those standard deviations

Positions	Parameters	Arm angle (deg) 90	120	150	180
Head	Peak acceleration ratio	3·29	3·39	3·25	3·32
	S. D. of peak acceleration ratio	0·377	0·338	0·452	0·491
	Resonance frequency	4·15	4·10	4·04	3·95
	S.D. of resonance frequency	0·107	0·161	0·159	0·123
Chest	Peak acceleration ratio	1·66	1·74	1·70	1·67
	S. D. of peak acceleration ratio	0·366	0·367	0·355	0·341
	Resonance frequency	4·10	4·10	4·05	4·00
	S.D. of resonance frequency	0·142	0·198	0·182	0·148
Hip	Peak acceleration ratio	1·71	1·82	1·76	1·75
	S. D. of peak acceleration ratio	0·207	0·202	0·245	0·203
	Resonance frequency	3·95	3·95	3·90	3·85
	S.D. of resonance frequency	0·164	0·154	0·158	0·127
Thigh	Peak acceleration ratio	1·94	2·16	2·17	2·15
	S. D. of peak acceleration ratio	0·396	0·439	0·436	0·448
	Resonance frequency	7·55	6·70	6·40	6·00
	S.D. of resonance frequency	1·229	0·909	0·778	0·824
Shin	Peak acceleration ratio	2·20	1·75	1·90	1·96
	S. D. of peak acceleration ratio	0·570	0·344	0·386	0·216
	Resonance frequency	9·50	6·50	5·75	5·65
	S.D. of resonance frequency	1·149	2·035	2·249	1·878
Upper arm	Peak acceleration ratio	3·73	3·77	4·41	4·54
	S. D. of peak acceleration ratio	0·680	0·766	1·042	0·990
	Resonance frequency	4·20	4·05	3·95	3·95
	S.D. of resonance frequency	0·180	0·251	0·164	0·158
Lower arm	Peak acceleration ratio	1·94	1·96	2·15	2·54
	S. D. of peak acceleration ratio	0·279	0·287	0·512	0·725
	Resonance frequency	4·00	3·95	3·85	3·90
	S.D. of resonance frequency	0·143	0·220	0·278	0·191

The resonance frequency decreased with increasing arm angle. There were two patterns for the upper arm. Resonance frequency was not significantly influenced by the arm angle. However, transmissibility was influenced. The peak values for 90 and 120, were smaller than those of 150 and 180. There are two peaks for the lower arm. The first resonance frequency is around 4 Hz, the second 12 Hz. The second transmissibility was smaller than that at around 4 Hz.

Table 4 shows the experimental results for 11 subjects. The numerical value shows the peak value of transmissibility and the resonance frequency at the peak. Standard deviations of peak acceleration ratio and resonance frequency are also shown in the table. This table shows mean values for 11 subjects.

Figure 21 is drawn based on the numerical values in Table 4. The influence of the arm angle on the vertical acceleration ratio for each human body part is shown. The only body parts which are significantly influenced by arm angle appear to be the upper and lower arms, for which accelerations increase with arm angle.

Figure 22 is also based on the data given in Table 4. The influence of the arm angle on the resonant frequency of human body parts is shown to be insignificant. However, the shin and thigh do exhibit a shift in resonant frequency to lower values as the arm angle is increased. As far as the authors know, this is the first experiment of its kind.

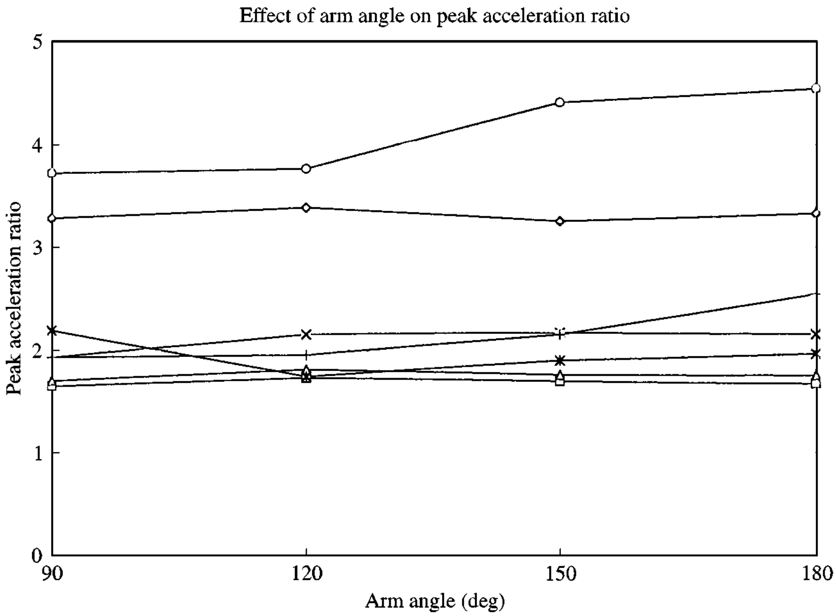


Figure 21. Effect of arm angle on peak acceleration ratio: (-◇-) head; (-□-) chest; (-△-) hip; (-✕-) thigh; (-✱-) shin; (-○-) upper arm; (+) lower arm.

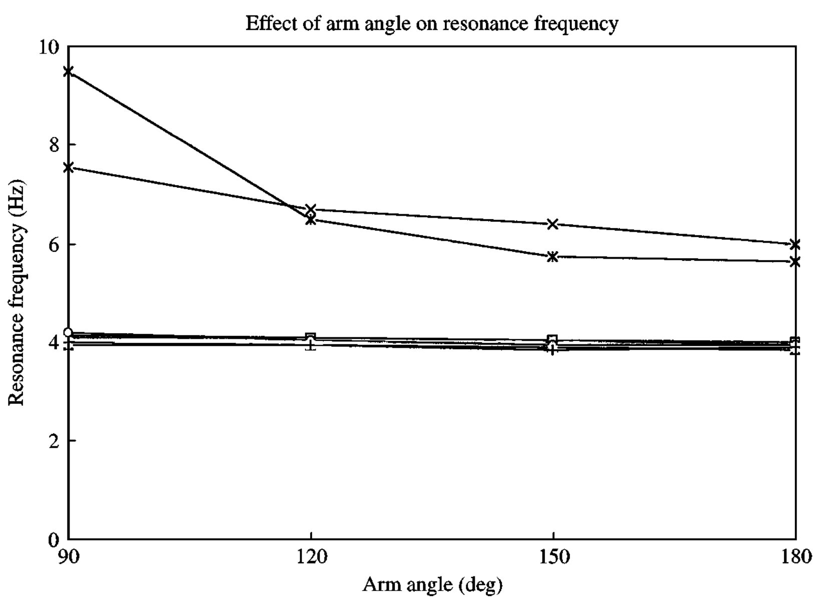


Figure 22. Effect of arm angle on resonance frequency: (-◇-) head; (-□-) chest; (-△-) hip; (-✕-) thigh; (-✱-) shin; (-○-) upper arm; (+) lower arm.

4.3. PREFERABLE ARM ANGLE AND PROBLEMS IN THE FUTURE

The parameters such as acceleration ratio and resonance frequency are very important in vibrational ride comfort. Judging from the effects of arm angle on acceleration ratio and resonance frequency, an arm angle of about 120° is preferred with respect to ride comfort and handling of the steering wheel and pedals.

A sensory evaluation from the subjects was not conducted during these experiments. A quantitative evaluation was attempted in this research, and priority was given to the acceleration measurement for a number of different human body parts. In this kind of vibration examination, it seems important to correlate a quantitative evaluation and the sensory evaluation of the subject. The vibration measurement of parts of the human body parts is not trivial, and in general the modeling of a simulation system is useful. The model for vibrational characteristics of the human body and the seat–steering wheel–pedals system, which can be used to examine vibrational characteristics in detail, has been shown here to provide a very useful simulation.

As instrumentation technology improves in the future, measurement of acceleration of each human body part by non-contact means may become possible. Hence, the repeatability of measurement increases and, in addition, more accurate and detailed measurements will become possible. Moreover, it is desirable to investigate the range of arm angles for a diversity of drives, to determine factors for a driving person, and to analyze the arm angle of the person driving the car, and to promote good driving posture from the viewpoint of ride comfort, maneuverability and safety.

5. CONCLUSIONS

The influence of seat position of a car driver on the vibrational characteristics of human body parts was examined for 11 subjects of different sex, age, and stature. We summarize the results of this study as follows.

(1) The device by which the relative position of the seat–steering–pedals system could reproduce a real car was developed. A quantitative evaluation of the vibrational characteristic of the human body parts became possible by using this realistic seat–steering–pedals driver system.
(2) A quantitative measurement of the vibrational characteristics of each human body part by using specially developed devices for acceleration sensor installation became possible.
(3) The arm angle was incrementally changed to clarify the influence of the seat position on the vibrational characteristics of each human body part. The variation of arm angle on the head, chest, and hip acceleration was not significant. However, the arm angle was observed to have a primary influence on the upper arm, the lower arm, the thigh, and the shin accelerations. It became clear that resonance frequency and peak value for body parts were different
(4) From the perspective of driving posture, an arm angle of about 120° is preferred with respect to ride comfort and handling of the steering wheel and pedals.
(5) The human body parts had different resonance frequencies and different peak values. Random excitation showed the tendency that the peak value of acceleration ratio was larger and the resonance frequency became higher when compared with the results of sinusoidal excitation.
(6) The standard deviations of both the peak acceleration ratio for upper arm and the resonance frequency for shin and thigh were large. The following can be said as a result: there is considerable variability concerning the vibration characteristics of upper arm, shin and thigh.

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