The Crew Seat Vibration Test and Analysis to a Special Vehicle

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Abstract This paper tested and analyzed the vibration of a special vehicle's crew seat, collected the vehicle cabin vibration signal under different road environment, and at certain speed, it studied the effect of vehicle vibration on crew, and as the basis of vehicle seat retrofit design. The analysis results show that the maximum vibration acceleration value was on the longitudinal of the driver and other crew's position, and in the later, design improvements should mainly focus on the longitudinal vibration reduction. At the same time in the process of vehicle test under different grade road crew's comfort, all performed well; this shows that design in a certain velocity of anti-vibration meets the requirements of ergonomics. This paper provides suitable personnel vibration fatigue monitoring test method for special vehicle crew; the data obtained from this method are significant and can be effectively applied to the practical test, and it has important reference value on the seat of the vehicle vibration reduction design and the crew comfort evaluation.

Keywords Special vehicle · Seat · Vibration · Collect and analyze · Comfort evaluation

1 Introduction

The safe and comfortable working environment can guarantee the special vehicle crew's work efficiency and the effective displaying of the equipment performance. As required by mission, besides working on the roads of low grade and even in the severe environment, the special vehicle also needs to do some special work [1], and cabin vibration environment generated during work severely influences the crew's work efficiency. The comfortability in the vehicle can be assessed by collecting and analyzing the cabin vibration signals. Based on the influence and assessment of the

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vibration environment of the vehicle cabin and its influence on the crew's work efficiency, basis can be provided for controlling the vibration of the vehicle cabin and the crew's individual protection, which is significant for ensuring the crew's work efficiency, increasing the crew's work ability, and displaying the technical performance of the equipment of the special vehicle [2]. The paper collects and analyzes the vibration signals of the cabin seat of a special vehicle and mainly collects the relevant information about the influence of the vehicle vibration on the crew and is significant for improving the driving environment of the vehicle.

2 Analysis of Vibration Characteristics of Vehicle Cabin

The vibration characteristics can be summarized as the direction, strength, and frequency of the vibration. The vibration of the cabin of the special vehicle is the whole-body vibration in three axial directions which are respectively in the *X*-axis (from back to chest), *Y*-axis (from right side to left side), and *Z*-axis (from foot or hip to head). The excitation of the body caused by road unevenness is the main reason causing the vibration of the cabin of the special vehicle. Most of the vibration of the vehicle cabin is the low-frequency great-amplitude vibration, and the vibration strength in the *Z* direction is commonly larger than those of *X* and *Y* and is the main factor influencing the crew's work efficiency. Also, there are test results that show the spectrum range at the driver position is wide, and many signals have the uneven energy distribution at the range of 1–80 Hz to which the human body is most sensitive, and also the low-frequency ingredients are rich while the vibration frequency range of most crew positions is relatively narrow and is mainly distributed at 20–50 Hz [3]. Because the driver position is close to the engine compartment, and also the space of the driving cabin is narrow, the driver's seat is designed to be different from the passenger's seat in structure, size, and vibration reduction, which causes the comfortability of the driver's seat not as good as the passenger's seat while the vibration strength is higher than the that of the passenger's position. Thus, the low-frequency vibration in the *Z*-axis direction of the driver is the key point for the vibration control and protection design of the special vehicle.

3 Vibration Test

3.1 Test Scheme

The test is carried out strictly according to GJB59.15 field vibration test regulations [4]. Three sampling points together are set as follows: the first sampling point is set inside the driving cabin and near the driver's seat so as to collect the vibration signals in three directions of the driver's seat, whereas in the *X*-axis direction, it points from back to chest; in the *Y*-axis direction, it points from the left side to the right side; and in the longitudinal direction of *Z*-axis, it points from foot to head. The influence of vehicle vibration on the driver is obtained by analyzing the 3D vibration signals at the seat of the driving cabin. The second sampling point is set at the copilot site to collect the vibration signals of the copilot site when the vehicle runs, and the influence of vehicle vibration on the copilot is obtained by analyzing the 3D vibration signals at the copilot seat of the driving cabin. The three sampling point is set at the back passenger site to collect the vibration signals of the passenger site when the vehicle runs, and the influence of vehicle vibration on the back passenger is obtained by analyzing the 3D vibration signals at the back passenger seat of the passenger cabin.

The cement road, gravel road, and rough road are used for the test, and two times of test are respectively carried out to each type of road. The speeds for each test on the cement and gravel roads are all 40 km/h, and the speed on the rough road is 30 km/h.

3.2 Test System

The test system comprises the following parts as shown in Fig. 1. The acceleration sensor, the charge amplifier, and the portable data collector form the system for collecting the vibration signals. According to the test regulations, the acceleration sensor and charge amplifier from the PCB company are used for the test. The portable data collector comprises of a signal processor and some peripheral components.

The measurement of the vibration signals at the seat position belongs to the low-frequency vibration measurement, and also the seat surface is uneven when it is used by the passenger and cannot be drilled, either; thus, the best installing way is installed in the cushion.

Because the responses of all points of the vibration structure are greatly different, the proper position for installing the sensor is very important. Generally, the sensor shall not be installed on the node or nodal line of the structure vibration but the position with high structure response signals so as to increase the signal-to-noise ratio as well as the test precision. The seat test aims to monitor the vibration source of the seat structure, and the position for installing the sensor shall be as close as to the direct transmission path of the vibration source, and the installing direction must reflect the vibration direction of the vibration source.

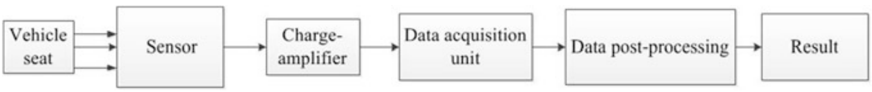

Fig. 1 Diagram of vibration test experiment system

4 Processing and Analysis of Test Data

4.1 Processing Method for Vibration Data

The key point for processing the test data is to confirm the driver's allowable exposure time according to the limit curve of work efficiency reduced by fatigue, which is given by *X*-, *Y*-, and *Z*-axis according to the regulations of the vibration test, so as to confirm the driver's safe driving hours, and also the total assessment for the driver's comfortability is qualitatively given according to ISO2631 [1]. At first, spectral value of one-third of octave of the corresponding vibration signals of each coordinate axis is calculated out at first, and then, the corresponding weighting acceleration root-mean-square (RMS) value can be confirmed according to the spectral value of one-third of octave. The formula is as follows:

$$a_{wj} = a_j \times w_j \tag{1}$$

wherein: a_j is 1/3 of the central frequency f_j and the spectral values of octave are $j = 1, 2, \ldots 20$, and w_j is the weighing factors relevant to the vibration direction and central frequencies. Then, the maximum value of a_{wj} is used for finding out the allowable exposure time according to the limit of the work efficiency reduced by fatigue in the corresponding direction in Table 2. At last, the minimum allowable exposure times in the *X*-, *Y*-, and *Z*-axis are used for confirming the driver's allowable exposure time.

4.2 Analysis of 3D Vibration Data at the Crew's Seats

The weighting acceleration root-mean-square values corresponding to each axis of each crew is calculated out as shown in Figs. 2, 3, and 4 according to Formula (1):

According to the analysis based on the calculation results, the weighing acceleration root-mean-square value in the transverse *Y* direction of the driver's position is minimum. According to Table 1 fatigue-work efficiency exposure time, it can be obtained that the allowable exposure times of the driver's position on three types of road are respectively as follows: On the cement road when the speed is 40 km/h, it is 16 h; on the gravel road when the speed is 40 km/h, it is 7.8 h; and on the rough road when the speed is 30 km/h, it is 19.6 h, and so on. The allowable exposure times of the copilot and back passenger positions under the three types of roads are shown in Table 2.

Indicated by Figs. 2, 3, and 4, the longitudinal weighing acceleration root-mean-square values of the three positions are maximum, and generate the highest influences on the crew, which will cause the crew to feel uncomfortable, wherein the uncomfortable seats play 80% influence on the crew's comfortability [5]. After comprehensively analyzing the 3D vibration test data of the seats, when

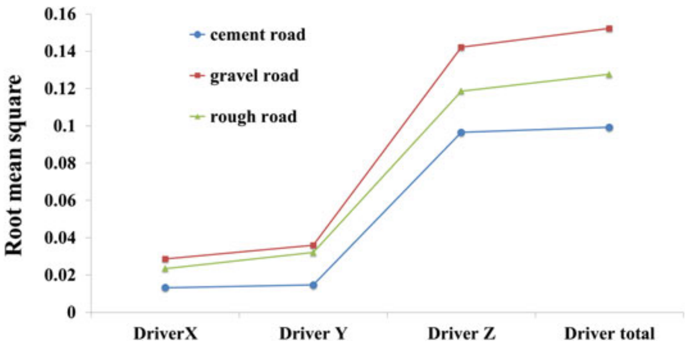

Fig. 2 The root-mean-square value of the driver's *X*, *Y*, *Z* directions and total weighted acceleration

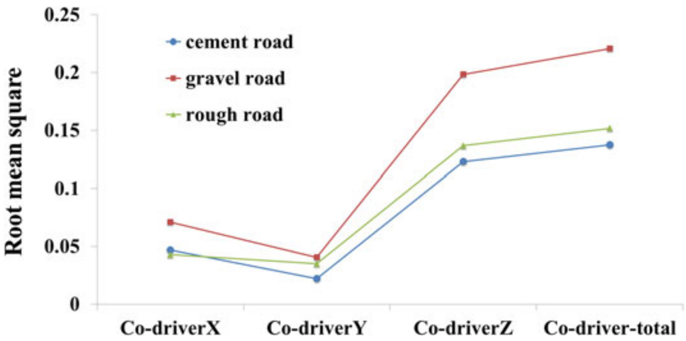

Fig. 3 The root-mean-square value of the co-driver's *X*, *Y*, *Z* directions and total weighted acceleration

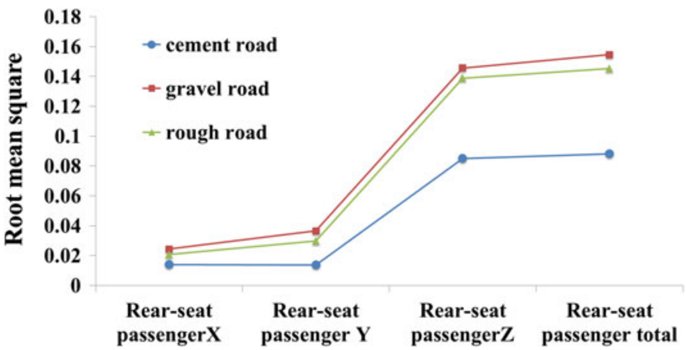

Fig. 4 The root-mean-square value of the rear-seat passenger's *X*, *Y*, *Z* directions and total weighted acceleration

Table 1 The corresponding acceleration-weighted root-mean-square value of allowed exposure time (m/s^2)

Time	24 h	16 h	8 h	4 h	2.5 h	1 h	25 min	16 min	1 min
The root-mean-square value of vertical weighted acceleration	0.14	0.212	0.32	0.53	0.7	1.18	1.8	2.12	2.8
The root-mean-square value of horizontal weighted acceleration	0.1	0.15	0.22	0.36	0.5	0.85	1.25	1.5	2

Table 2 The crew allowed exposure time (h)

The road level	Driver Y	Co-driver Y	The rear passenger Y
Cement road 40 km/h	16	15.7	24
Gravel road 40 km/h	7.8	17.7	14
Rough road 30 km/h	19.6	15.7	21.7

Table 3 The weighted acceleration value of all the crew in three kinds of road level (m/s^2)

The position	Driver	Co-driver	Rear-seat passenger
Cement road	0.09	0.14	0.09
Gravel road	0.15	0.22	0.15
Rough road	0.13	0.15	0.15

Table 4 The relationship between acceleration value and crew's subject feeling

The weighted acceleration value (m/s^2)	<0.315	0.315–0.63	0.5–1	0.8–1.6	1.25–2	>2
The evaluation of Crew's feeling	None	Little sense	Some feeling	Uncomfortable	Very uncomfortable	Terrible
	Good	Good	Good	Not good	Bad	Very bad

the vehicle runs at a certain speed on every type of the road, the comprehensive assessment of all positions of the passenger is obtained. Wherein, the weighting acceleration values of the three passengers on the three types of roads are shown in Table 3. Indicated by the relationship between the acceleration values and people's subjective feeling of Table 4, the vibration comfortability of the crew at the three positions is good.

5 Discussion and Conclusion

(1) The difference of the seat vibration system of each position after vibration reduction is mainly caused by the different structure design and layout of the whole body. The analysis of the vehicle vibration test is the important way for assessing the vehicle body vibration environment. The data obtained by measurement can be analyzed to provide data support for designing the seat and the whole vehicle vibration systems. The vibration reduction efficiency of the seat system can be improved for absorbing the vibration energy, wherein the vibration reduction material of the seat and the contact part of the seat and the vehicle body can be improved. Because the vibration conditions of different positions are different, the vibration reduction requirements on different positions cannot be satisfied if only one type of vibration reduction is used. Indicated by the test, the vibration statuses of the vehicle on different types of roads are not same, but in general, the longitudinal vibration acceleration value is the highest, and it shall focus on improving the design of the longitudinal vibration reduction. Also, it indicates the crew's comfortabilities on different types of roads in the test process are good, which means the vibration reduction design of the vehicle at a certain speed meets the requirement of work efficiency.

(2) Limited by the actual test field, the test does not cover all of the tests on all types of roads and at high speeds, and it will be supplemented and completed in future tests.

(3) The paper provides a test method applicable for the special vehicle crew's vibration fatigue monitoring. The data obtained by the method are significant, can be effectively applied to the actual field test, and play an important reference value for the vibration reduction design of the vehicle seat and the assessment of the crew's comfortability.

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