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Ride Comfort Analysis of Sedan Car using Quarter Car Suspension System Modelling and Simulation

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ABSTRACT:

With the application of high-tech technology in automobile industry, more attention is given to the ride performance which will directly affect the comfort and safety of the passenger/driver. This paper is focused on the study of vehicle ride performance using vehicle simulation model. Two degrees of freedom quarter car model of vehicle with Macpherson front suspension from Santana 2000Gsi saloon car is established. The parameters of the simulation model include the suspension stiffness, damping coefficient of shock absorber and the road excitation. The road surface excitation is gained by using white noise integral method. By inputting the calculated basic parameters into suspension simulation model, the ride performance can be evaluated. The parameters can be adjusted such that the vibration characteristics to be more intuitive, which further laid the basis for accurate vibration control.

KEYWORDS:

Ride performance; Quarter car model; Simulation model; Road excitation; Macpherson front suspension

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1. Introduction

Along with the development of economy, the automotive industry also showed a rapid development momentum. As one of the main transport tools, cars have entered innumerable families. Since the year of 2009, the whole sale of cars ranked among the highest for five consecutive years and even reached twenty million in 2013. Although the total number has ranked at the top, statistics show that household car ownership per capita in China at present reached 45 vehicles per one thousand people, which is under the world average level. Therefore, the automobile industry in China has great potential for development. In order to seize the great period of development and make differences, we have to pay more attention on developing our own brands by resorting to strong technology support to improve the performance and quality of the car, strengthening the industry of independent automobile brand [1].

When car ownership increases sharply, the car mileage or car driving time is increasingly longer. Gradually, people's corresponding requirements on the performance of car become higher. When improving the performance of car, we cast more attention on car ride performance [2]. In the process of driving, the car affected by road roughness will produce vibration which may also be caused by the car itself. The faster the speed is, the greater of the vibration will become. While the vibration can not only accelerate the degradation of auto parts, but also create harmful influence to the driver, for example, physiological reactions will bring danger to the driving. If we choose to slow down to relieve the vibration, not only will reduce the transportation, but also will improve the efficiency, influencing the discharge of cars.

Therefore, the study of ride performance is of great significance in developing the cars. The improvement of vehicle ride performance can improve ride comfort, reduces the wastage of the auto parts in the case of a high speed and makes driving safer thereby achieving good fuel economy at the same time [3]. According to the above, many automobile research and development departments nowadays take drive comfort as an important subject.

2. Vehicle ride performance

Vehicle ride performance mainly studies two aspects: influence of pavement roughness on passenger comfort and vibration influence on the car itself. When the car runs over random input and pulse input road surfaces, each way can cause vehicle vibration by the influence of pavement roughness. It will be passed into the body of the car through the tire, suspension and felt by the occupant, causing physiological reactions from passengers such as un-comfort or fatigue [4]. According to the degree of such un-comfort, the driver can adjust the speed to reduce the vibration. In a practical sense, the study of car ride performance equals to the study of road-car-people system which is dynamic. Fig. 1 is the representation of the vibration system. The system is composed of vehicle system input, vibration system, vehicle system output and result evaluation index [5]. The study not only has to achieve the purpose of improving comfort, but also ensures the stability and security of the driving car.

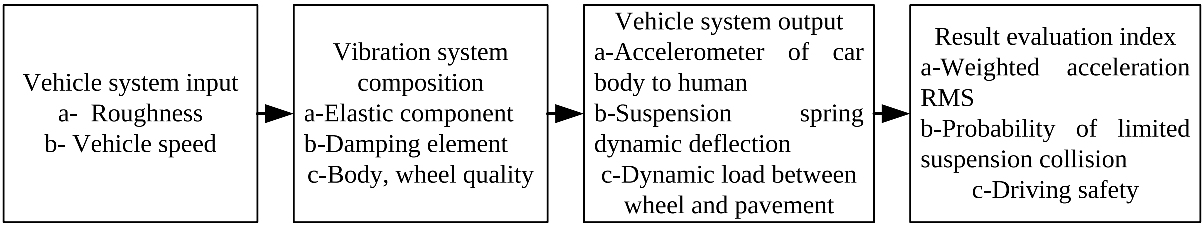

Fig. 1: Road-vehicle-people vibration system

In the automotive industry, in order to meet the growing number of new requirements for vehicle operation, high-tech technology with technical content has gradually been applied. A lot of research achievement has been made on the ride performance [6]. Currently, the main methods on vehicle ride performance are experimental methods and theoretical methods. Experiment research methods need real models to participate using vehicles for various tests. Theoretical approach is based on computer technology and relied on the mathematical modeling. According to the multi-body dynamics, virtual simulation model can be built to simulate the road excitation signal, after obtaining the experimental data through corresponding road tests. Then researchers can analyze the evaluation index to make relevant analysis. The vehicle ride performance research methods are shown diagrammatically in Fig. 2.

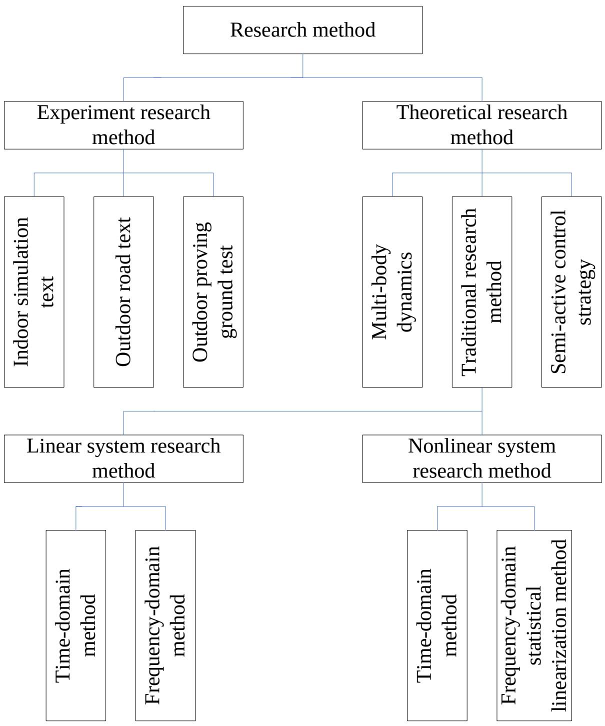

Fig. 2: Vehicle ride performance research methods diagram

There are three test methods in experiment research methods, including outdoor road test, proving ground test and indoor simulation test. At present, experiment research methods are used widely in foreign countries. In China, only some of the larger auto manufacturing companies and research institutions were conditioned. Since the experiment research methods have restrictions for testing equipment, grounds and vehicles, it also limits the research on ride performance by testing methods. On the other hand, theoretical research methods have widespread applications both in China and foreign countries; especially in the last decade, research achievements on ride performance in China are relatively rich and developing fast [7]. Compared to experiment research methods, this method has lower cost and much quicker to perform.

3. Simulation model

3.1. Construction of simulation model

Vehicle ride performance can be evaluated by the research on vibration performance of the suspension system. The direct influencing factors include structural parameters of road roughness, speed and suspension. Fourier analysis methods are commonly used in the former research on vehicle ride performance. When using this method, the first thing is to deduce the vehicle vibration system and frequency response characteristic of vibration response. The second thing is to calculate weighted root mean square (RMS) acceleration, including all three coordinate axes. This study only analyzed the weighted RMS acceleration of vertical direction, using simulation model to analyze the vehicle ride performance. The internal and external parameters are independent and can be independently adjusted simply and quickly, to obtain reliable results. This study has selected 2000Gsi Santana Sedan for analysing the vibration characteristics of suspension and its related parameters are given in Table 1.

Table 1: Main suspension parameters of Santana 2000Gsi Sedan

Description	Value
Axle load of full-load aft shaft	810kg
Total mass of suspensions in front axle	84kg
Front wheel quality	18.5kg
Tire stiffness k_1	194kN.m^{-1}
Spring stiffness k_3	22.68kN.m^{-1}

3.2. Model principles and parameters

In the mechanical model, spring indicating the relationship between force and displacement is often seen as having linear elasticity but with no quality. Damper representing the relationship between force and velocity is seen as having linear damping coefficient and no quality. Quality representing the relationship between force and acceleration is usually seen as absolutely rigid body. According to the above description, front wheel vibration system in one side of vehicle can be simplified as shown in Fig. 3. In the suspension system, the influencing parameters describing vibration frequency response characteristic include suspension stiffness and damping coefficient of shock absorber. Damping coefficient of suspension stiffness and shock absorbers can be calculated from the empirical formula. According to these two parameters obtained from calculation, vibration characteristics of the suspension can be simulated roughly to obtain the result from the preliminary analysis.

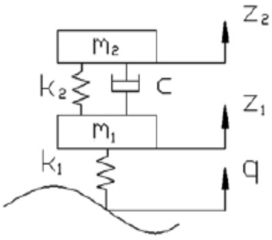

Fig. 3: Vehicle unilateral front wheel vibration system

3.3. Suspension vibration simulation model

To analyze the dynamic characteristics of the suspension in the time domain, the performance of pavement roughness in frequency domain needs to be transformed into the time series in the time domain. The theory that finite bandwidth white noise produces excitation signal can be used to describe the driving pavement situation. These two have similarity. Therefore the input resource of simulation model can select finite bandwidth white noise to simulate the pavement driving by integrating the input resource. In this study, MATLAB software is used to construct white noise road excitation model. SIMULINK toolbox in this software can be used to build the system dynamics model. The quarter car system model diagram is shown in Fig. 4. The established model can input the road excitation information produced by simulation in the suspension vibration system.

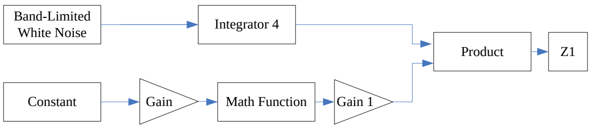

Fig. 4: Finite bandwidth white noise road excitation model

According to inspection standard of human body's bearing capacity on vibration and ride performance, the vehicle ride performance can be evaluated in three axes of the seat surface, respectively x, y, z direction. Normally, with the premise of not affecting precision, the description of ride performance in the vertical direction affects the comfort most. This study selected B-level road with the roughness coefficient of 64×10^{-6}, with speed limit of 80km/hr, from vibration of vehicle displacement in the vertical direction, vibration acceleration, displacement, acceleration, and acceleration RMS can be obtained after second derivative, as shown in Figs. 5-7. In the parameter setting of vehicle, the front wheel quality is 18.5kg. Unilateral suspension unit is set to 363kg. Tire stiffness and suspension rate are set to 194000 Nm and 22230Nm respectively. Reference spatial frequency is constant as 0.1. The damping coefficient of shock absorber is 1570. After the coefficient setting, the common pavement grade and common speed are selected for simulation. The acceleration RMS in vertical dimension for various speed and pavement conditions is shown in Table 2.

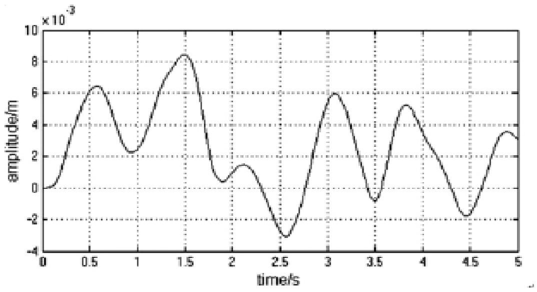

Fig. 5: Vehicle body displacements in vertical dimension

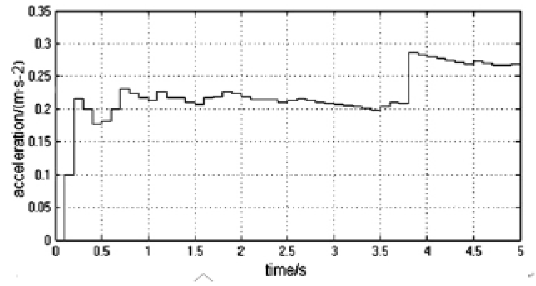

Fig. 6: Vibration acceleration in vertical dimension

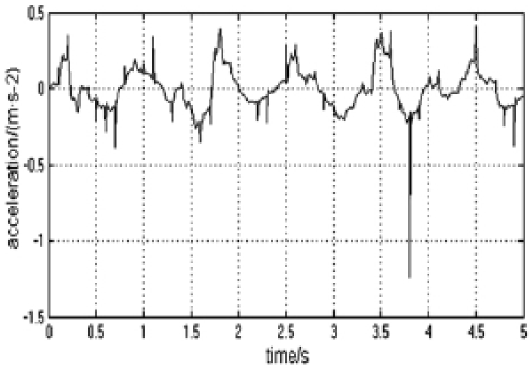

Fig. 7: Acceleration RMS in vertical dimension

Table 2: Common pavement grade and acceleration RMS in vertical dimension for various speeds

Speed (km/hr)	Acceleration RMS ($m.s^{-2}$)	
	B-level pavement	C-level pavement
20	0.1343	0.2657
40	0.1885	0.3742
60	0.2497	0.4567
80	0.2666	0.5260

4. Result analysis

Two degrees of freedom suspension vibration simulation model designed in this study is constructed using the MATLAB software. The SIMULINK toolbox in the software is capable for model framework. By simulating grade road and driving speed separately without priori information, we can achieve simulation results of ride performance. In the ride performance evaluation of simulation result, the adopted standard is ISO 2631-1. The evaluation result is shown in Table 3. Comparison of the data in Table 2 and Table 3 shows that, when Santana Sedan of the fixed model is driven in the common grade road at common speed, state of the occupant is mostly comfortable. Some passengers have found a little uncomfortable. These results can be obtained intuitively, which shows that the system model can basically meet the requirements of the human body in terms of ride comfort. Therefore this type of car suspension meets the ride performance requirements for the studied pavement conditions and vehicle speeds.

Table 3: Subjective feeling of passengers and acceleration RMS corresponding table

Acceleration RMS ($m.s^{-2}$)	Subjective feeling
<0.315	No uncomfortable
0.315-0.63	A little uncomfortable
0.5-1.0	Quite uncomfortable
0.8-1.6	Uncomfortable
1.25-2.5	Very uncomfortable
>2.0	Extremely uncomfortable

5. Conclusion

This article focused on the study of vehicle ride performance using a quarter car two degrees of freedom system simulation model with Santana 2000Gsi Sedan car suspension system. The basic parameters of the simulation model included suspension stiffness, damping coefficient of shock absorbers and road excitation. The first two parameters can be calculated, and road excitation is generated by the white noise integral method. Inputting these basic parameters to the simulation model of suspension vibration system, ride performance can be obtained from comparative study. On the premise that each parameter setting is invariant, ride comfort is evaluated by separately changing the pavement grade and vehicle speed. The simulation model parameters can be adjusted so that the image and data with vibration characteristics can be displayed more intuitively to further vibration control research.

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