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Research on Ride Comfort of Diminutive Forest Fire-fighting Vehicles

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Abstract: To improve the efficiency of forest fire fighting, ride comfort is very important for firemen to maintain good physical condition. Firstly, a whole vehicle model was established with the ADAMS/view(Automatic Dynamic Analysis of Mechanical Systems) software. Next, test and simulation were performed to verify the three-dimensional model. Finally, the comparison of real vehicle test and ride comfort simulation results show that the vibration and ride comfort performance have been improved. The total root mean square (rms) of weighted acceleration at the car seat position on Class A road has been reduced by about 15.1%. The proposed approach has saved much time and money cost for a forest fire-fighting vehicle's ride comfort optimization.

Keywords: ADAMS, forest fire-fighting vehicle, ride comfort, vibration.

1. INTRODUCTION

Generally, the forest road condition is poor, and the forest fire fighting rescue mission is emergent. So not only strong power and high-speed stability, but also certain comfort ride is required for fire-fighting vehicles.

ADAMS/CAR has been used in many optimization research areas, since the use of FBG (Flexible Body Generator) in ADAMS/CAR environment is faster and user friendlier than other FEM programs [1]. Magic Formula tire Modeling (MF-tire is a part of ADAMS/Tire) allows an accurate and efficient description of tire-road interaction forces required for any usual vehicle [2]. So it's a trend to apply them to the research of forest fire-fighting vehicles. In aspect of trafficability improvement, many advanced techniques have been used, and the suspension optimization method is various and sophisticated [3, 4]. However, there is still much space to study in the aspect of ride comfort. European countries have introduced advanced automobile theories of NVH, handling stability and ride comfort which are considered in passenger cars research and development into the design of the special vehicle, such as forest fire-fighting vehicles [5]. For example, The Seat Effective Amplitude Transmissibility (SEAT) values have been widely used to determine the vibration isolation efficiency of a seat and simplified ADAMS/car model is continuously emerging [6, 7].

Currently, previous researches of fire-fighting vehicles' ride performance based on real vehicle test are unable to meet the requirements. The rapid spread of advanced computer simulation technology in the passenger car area can provides technical support to fire-fighting vehicles' research. The assessment method and technique mentioned above should be fully applied in the forest fire-fighting vehicles to improve the economical and research development efficiency.

2. THREE-DIMENSIONAL MODELING AND SIMULATION OF VEHICLE RIDE COMFORT

2.1. Modeling

The multi-body dynamics vehicle model of BJ5030XZH27 is established in ADAMS/car module. As shown in Fig. (**1**), it includes six main subsystems, each subsystem is simplified reasonably to establish a parameterized system model according to actual needs. And the vehicle model of ride comfort is assembled by simulation test bench model and each subsystem. The model's reliability is validated by vehicle dynamics simulation debugging.

2.2. Offset Frequency Test and Simulation Analysis of Vehicle Suspension

The correctness of the vehicle model is verified through real vehicle test and simulation of suspension offset frequency. Then the impact of suspension system performance to the vehicle vibration and ride comfort is analyzed.

When look at the free damping vibration curve of carframe and axle after the vehicle model passing the bump, the peak of the frequency spectrum graph is the natural frequency of the bodywork and the axle vibration, and it can be read out directly through the spectrum graph, as shown in Fig. (**2**). The natural frequency of the bodywork and the axle is 3.0Hz and 14.5Hz respectively.

To verify the validity of the simulation model, the natural frequency, damping ratio of the bodywork and the axle are compared and analyzed in Table **1**. Then the simulation model was adjusted to get closer to the vehicle ride comfort model based on the real vehicle test results.

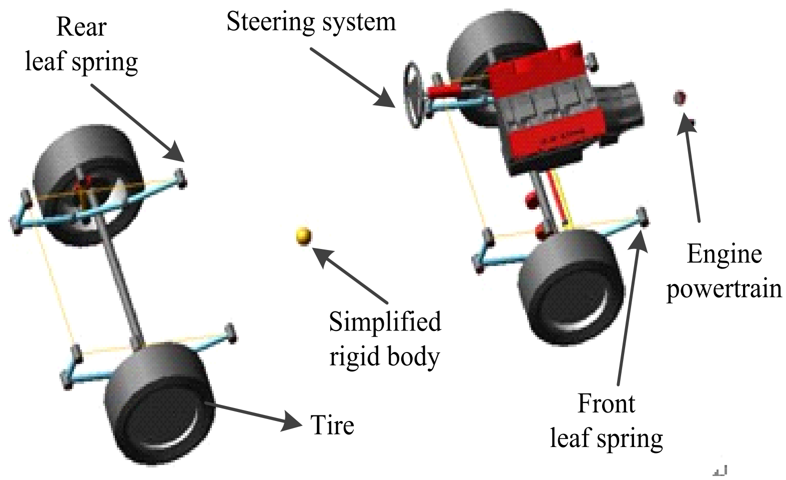

Fig. (1). Vehicle model.

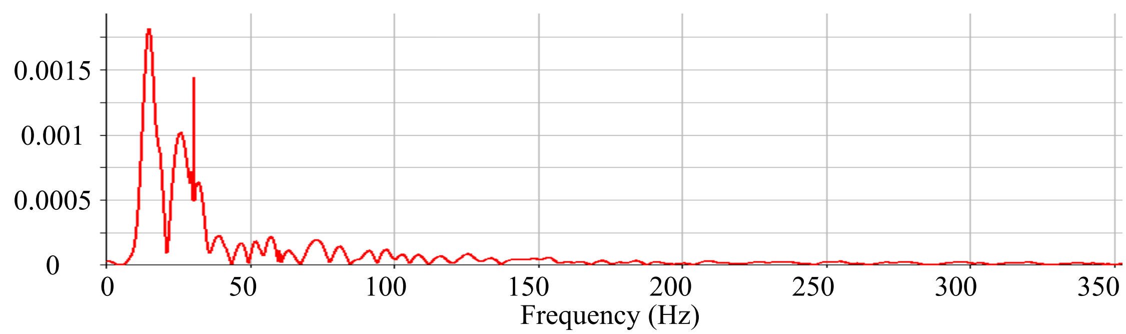

Fig. (2). The axle vibration damping power spectrum curve.

Table 1. Simulation and test results.

Natural Frequency	Test	Simulation	Deviation to Test
Axle	14.5	14.9	2.76%
Bodywork	2.5	2.65	6%

3. FOREST FIRE ENGINE VIBRATION AND RIDE COMFORT TEST

A diminutive forest fire-fighting vehicle BJ5030XZH27 is chosen as the test setup. Its front and rear suspensions are non-independent leaf spring suspensions. The vehicle has a spacious cabin equipped with plate seats transporting fire-fighters and a toolbox loading forest fire equipment. It is a typical diminutive forest fire-fighting vehicle.

3.1. Test Conditions and Equipment

The test road should be straight, dry and with a longitudinal gradient less than 1%, length of 100m, 30m-50m at both ends as the steady speed section. It is Class A road according to GB/T 7031 (Chinese Standard/Recommendation) regulations. Concrete pavement and unpaved road are selected as random input according to the requirements. 20km/h, 30km/h and 40km/h are selected as test speeds. Test equipment include three vibration acceleration sensors and one set of B&K (a Danish company) signal acquisition and analysis system.

3.2. Test Method

Firstly, three acceleration sensors are mounted on the cabin floor beneath the seat in the three directions (X, Y, Z), and the BK test system is connected to record the data. Then the fire engine is started and driven to the test road (flat concrete pavement and forest road, as shown in Fig. **3**).

Next, the vehicle runs 100m in straight line at a constant speed of 30km/h, 40km/h and 50km/h respectively. Record and save the test results.

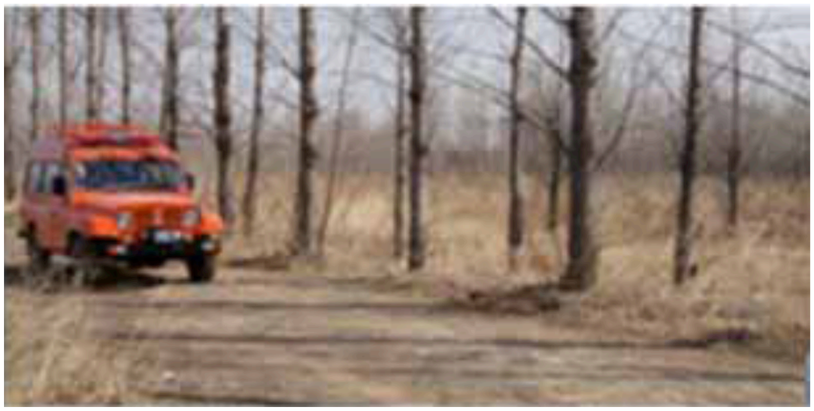

Fig. (3). Test on Class A cement pavement and forest road.

Then close the car handbrake, keep the transmission in neutral gear, make the engine run at a stable idling mode when testing the effect of vehicle powertrain system on the entire automobile vibration then keep the engine at idle speed (850rpm), 2000rpm, and 3500rpm respectively in parking condition, measure the cabin floor vertical vibration acceleration beneath the seat and save the data.

3.3. Test Data Processing

The total rms of weighted acceleration of ride comfort evaluation index is used to evaluate the ride comfort. Based on the time domain graph of each axial direction acceleration measured in the test, each axial vibration acceleration frequency domain graph can be obtained through the fast Fourier transform, and then solving the total rms of weighted acceleration according to the provision of GB/T 4970-2009.

3.4. Ride Comfort Test Results

Due to the poor condition of bumpy forest roads, combined with the actual speed of the forest fire-fighting vehicle, the vibration situation on forest road is measured at the usual forest fire-fighting vehicle speed (30km/h). Ultimately, the total weighted rms acceleration values: 1.3740 m/s^2. At this point, the body's subjective feeling is very uncomfortable.

The calculation formula of total rms of weighted acceleration is as below:

$$a_w = [(1.4a_{xw})^2 + (1.4a_{yw})^2 + a_{zw}^{\ 2}]^{\frac{1}{2}} \tag{1}$$

Weighted vibration level：

$$L_{aw} = 20\lg(a_w / a_0) \tag{2}$$

Where, $a_{x\omega}$, $a_{y\omega}$ and $a_{z\omega}$ are the rms of weighted acceleration of X, Y and Z axis respectively. a_0 is rms of reference acceleration.

In conclusion, the overall performance parameters of the forest fire-fighting vehicle's ride comfort can be got after a real vehicle test, as shown in Table **2** below. A comprehensive comparison of vibration acceleration power spectral density at different speed level on Class A pavement shows that the low-frequency excitation from the cement pavement and the high-frequency excitation from the power assembly are main source of vibration excitation frequency of fire engine.

3.5. Test Results of Effect of Power Assembly to Vehicle Vibration

The vibration acceleration power spectral density curves at the location near the floor seat when the engine is idling, at 2000rpm and 3500rpm shows that the excitation frequencies distribute around 27.5Hz, 61Hz and 85Hz, so the power assembly is the source of high-frequency excitation of

Table 2. Ride comfort of forest fire-fighting vehicle.

Items	a_w	L	Subjective Feeling
Class A pavement [30km/h]	0.8-1.6	118-124	Uncomfortable
Class A pavement [40km/h]	0.315-0.63	110-116	Some uncomfortable
Class A pavement [50km/h]	0.8-1.6	118-124	Uncomfortable
Forest road [30km/h]	1.25-2.5	112-128	Very uncomfortable

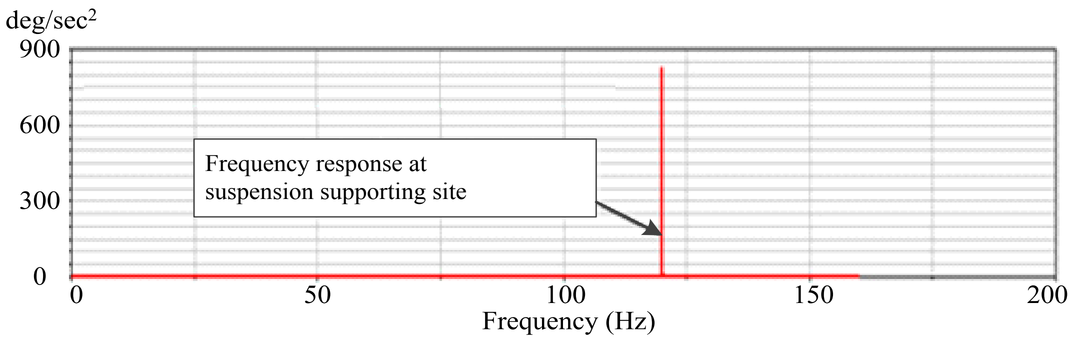

Fig. (4). Frequency domain graph of Z-direction vibration acceleration at the suspension supporting.

vehicle vibration, and as the engine speed increases, the vehicle vibration frequency increases.

Contrastive analysis of experimental and calculated data shows that, the vibration frequency of the bodywork and the excitation frequency of the engine are in good agreement when the engine is idling and at 2000rpm. Whereas, the vibration frequency of the bodywork is lower than the excitation frequency of the engine when its speed is at 3500rpm, this suggests that the suspension elements have certain vibration isolation efficiency, but it just has filtration function to high-frequency vibration excitation over 85Hz.

4. SIMULATION OPTIMIZATION OF RIDE COMFORT

4.1. System's Inherent Characteristics

The forest fire engine powertrain mass is 167Kg measured by the method of hanging, the center-of-mass coordinate G0 is (148.78, 28.09, 99.89). With this information and other given data, the system's natural frequencies and mode of vibration can be solved through ADAMS/Linear module, powertrain natural frequency of each order mode can also be obtained. It is found that the natural frequency of powertrain system in the θx direction is 25.26 Hz, much larger than 20.2Hz (the maximum natural frequency which meets the requirement of the vibration isolation theory), thus resulting in poor vibration isolation efficiency of forest fire engine suspension system.

4.2. Response Simulation of Suspension System Under Different Engine Conditions

Vibration response around the suspension system can be got through simulation of ADAMS/view. The results showed that three suspension vibration acceleration frequencies are mainly 27-29Hz. So the resonance frequency of the suspension is 28.33Hz. The simulation value and theoretical calculated value of powertrain excitation frequency are relatively consistent when the engine is idling. When the engine is at high speed of 3500rpm, the powertrain is not only affected by excitation from the second order torque around the X axis, but also the excitation frequency caused by the second order reciprocating mass and it is the major component of the excitation, then the powertrain vibrates mainly in the vertical direction. Put excitations into ADAMS to simulate the vibration response situation at the powertrain barycenter and suspension supporting site. The results showed that the Z-direction vibration acceleration frequency of three suspensions distributed mainly at about 120Hz (Fig. **4**). Its theoretical value is 117Hz. So the simulation value and theoretical calculated value of powertrain excitation frequency are relatively consistent when the engine is at high speed.

4.3. Optimization Analysis of Powertrain Suspension System

This article is aimed at improving the vibration isolation efficiency proceeding from the point of reasonable matching of system natural frequency through optimizing stiffness parameters of the suspension for the design variables when

Table 3. Ride comfort performance of forest fire engine.

Items	a_w (Before Optimization)	a_w (After Optimization)	Optimization Rate
Class A road [30km/h]	0.8538	0.7430	13.0%
Class A road [40km/h]	0.6842	0.5773	15.6%
Class A road [50km/h]	0.9048	0.7015	22.5%
Class F road [30km/h]	1.3740	1.2450	9.4%

the engine is idling. After calculation, it is known that the vibration transmissibility at θx direction is 84.2%, less than the original 114.3%, vibration isolation efficiency of the system is improved. Analysis to the results shows that the natural frequency at θx direction is reduced from 25.26Hz to 18.9Hz after optimization, thereby the vibration at θx direction of engine excitation is less transmitted to the bodywork, to some extent, vibration isolation efficiency is improved when the engine is idling.

4.4. Simulation and Optimization of Vehicle Riding Comfort

Simulation results show that the total rms of weighted acceleration values at the car seat position have a decline than test values, as shown in Table **3**. After comparing the results of optimized simulation and real vehicle test, it shows that the total rms of weighted acceleration values on Class A road and the weighted rms acceleration values of the fire engine on forest roads have all been reduced to some extent, so the ride comfort of fire engine has been improved to achieve the optimization purpose.

CONCLUSION

In this study, powertrain suspension system model and vehicle multi-body dynamics model are established through ADAMS/view and ADAMS/car module, and the rationality of the model is verified. Simulation analysis of the vibration and ride comfort performance is done, and the riding comfort of forest fire engine is improved through optimizing the parameters of front and rear suspension. The proposed approach has simplified the research process of a forest fire-fighting vehicle's ride comfort, and it can be applied in other special vehicles in forest.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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Declared none.

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