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Dynamics Simulation and Optimization of Ride Comfort for Car on Random Road

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Abstract: To ensure the safety, high efficiency and comfort of traffic and transportation, the research of automotive ride comfort is getting more and more important. Vehicle ride comfort is one of the most important performances of vehicle. At first, the subsystems dynamics analysis models were separately established, such as front suspension, rear suspension, person-chair system, steer system, tire and transmission subsystems in this paper, then these subsystems assembled an vehicle dynamics analysis model with the car body and frame by used the software-ADAMS. Where after validated the correctness of the model by the experiment results of sample vehicle. Secondly, the vehicle ride comfort on random road was analyzed by the weighting acceleration root-mean-square value. Finally, the paper had studied influence of the spring stiffness, the shock absorber damping and the tire stiffness on vehicle ride comfort, based on simulation and analysis, The study proposed the optimization plan.

Key words: Ride comfort, simulation, optimization, random road

INTRODUCTION

Smoothness is called the riding comfortableness. It is the main performance of the modern automobile with high speed and high efficiency. The target quality of the smoothness affects directly the performance display, the travel system's life as well as human's working efficiency and health. So how to guarantee the automobile has good smoothness has already attracts designers' attention. In recent years, with development of the computer technology, the theory of random vibration, the testing method as well as the systems dynamics, Simulation of vehicle ride comfort is to be more comprehensive and much closely approach to the fact.

Based on above purpose, this article used the software ADAMS, which developed with multi-bod system dynamics to establish the dynamics simulatio model of the full vehicle and has made the simulation and analysis of ride performance. Then it gives the appraisal to the A vehicle through the ISO 2631-1997 principle.

MODEL ESTABLISHMENT OF ENTIRE VEHICLE DYNAMICS SIMULATION

When we discuss the ride comfort: We mainly consider the vibration caused by the road surface roughness. The road input passes to the human body through the tire, suspension, the seat cushion that is elastic damping part. These constitute the automobile vertical vibration system interacted. In order to improve computing speed of the model, we can simplify secondary influence factors to ride comfort under the condition in which the model is accurate (Yu, 2006).

Front and rear suspension system: The front suspension of the vehicle is the double wishbone independent suspension. It mainly contains the up-down cross arm, shock absorber, helical spring and stabilizer bar. The rear suspension is the type of multi-link independent suspension which mainly contains the helical spring, the shock absorber, the longitudinal propelling rod, stabilizer bar and so on. Front end of the longitudinal propelling rod is connected with the automobile body and rear end is connected with the suspension. This is used to transmit the traction and braking effort.

The front and rear shock absorbers are displaced by restrains (DAMPER). Because the shock absorber damping is a non-linearity, we need to load damping characteristics of an damping shock absorber into DAMPER property file by the SPLINE curve. Similarly, we load the helical spring elastic characteristic into SPRING property file by the SPLINE curve. These could guarantee the precise of the model.

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Steering system: The steering system of the vehicle is the rack and pinion steering system and mainly includes the steering wheel, steering axle, steering column, drive shaft, steering tie rod, gear rack diverter and the boost steering system.

According to the corresponding connection relations, we can add on the corresponding restraint to constitute the steering system in ADAMS/CAR (Hu *et al*., 2012). The assist characteristic of the assist steering system can be indicated with property file which is possible to use similar method with the damping characteristic curve. This may the accurate simulate force outputs of the steering system during its steering.

Human-chair system: Simplify the human-chair system model. The human body quality is 75 kg, the chair elastic characteristic and damping characteristics realizes with the rubber bush, of which the elastic characteristic and damping characteristics may use property file to realize. Using the rubber bush is possible reasonable to simulate force that person receives sitting in the chair from each direction movement.

Because the automobile body physique has no influence to the simulation result in the simulation of the vehicle comfort, we can simplify the automobile body to the spheroid which contains all physical property parameter of the automobile body.

Entire vehicle model establishment: Entire vehicle model like Fig. 1.

We establish the subsystem model assembled with ADAMS/CAR and then we guarantee the model movement to be normal through the suitable debugging (Hu *et al*., 2012).

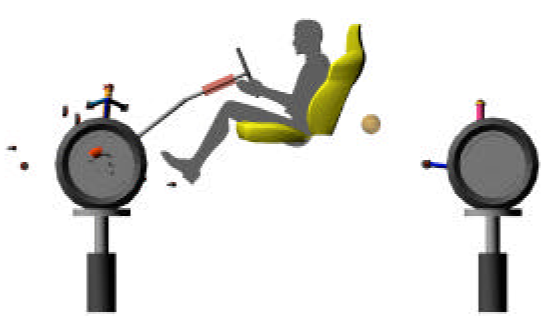

Fig. 1: Entire vehicle model

SIMULATION ANALYSIS OF ENTIRE VEHICLE MODEL

Establishment of tire model: The ADAMS software has provided 4 kinds of tire models, which are named the Fiala model, UA (university of Arizona) model, Smithers model and DELET model. In addition the user also may define the model. After we evaluate characteristic of these 4 kind of tire models and consider this topic need, so we use the DELET model. The DELET model data file In the ADAMS software is composed by eleven together, each one has the independence data unit which may simulate the tire separately the different operating mode and has the high precision (Kui *et al*., 2006), Also this kind of tire model also has the good toughness.

Road surface productions: The road surface structure needs to satisfy certain random distribution rule and it also conform to the road surface which the ADAMS tire model requests. This is the main point and difficulty to establish model. According to National Standards GB/T4970, 2009. "Method of running test-Automotive ride comfort", the road surface undulation displacement power spectral density fitting expression uses the equation below:

$$Gd\ (n) = Gd\ (n0) \left(\frac{n}{n_0}\right)^{-w} \quad n>0$$

Here: n_0-Reference frequency, n_0 = 0.1 m^{-1}; G_d (n_0)-Road surface undulation coefficient, m^2 m^{-1}; G_d (n)-Road surface undulation, m^2 m^{-1}; w-Frequency index, Empirical value w = 2. According to the spatial frequency and the temporal frequency relations, its expression is:

$$f = v\times n \tag{2}$$

Here, f is temporal frequency; n is vehicle speed expression of G_q (f) is:

$$G_q(f) = \frac{G_q(n)}{y} \tag{3}$$

Here, G_q (f)-Road surface time displacement power spectral density.

Through the research of the r power spectral density of road roughness, time and the inverse transformation function in the ADAMS software, we develop the visual software with VC++ to generate the road surface which is the B level road surface this article needs.

RANDOM ROAD SURFACE SMOOTHNESS ANALYSIS

To simulate ride comfort experiment of the entire vehicle in full load operating mode according to the ride comfort random input travel testing of our country (Crolla and Yu, 2004). In this article the automobile uses the speed of 70 km h^{-1} commonly used to travel with the uniform speed in the B level road surface that the random road surface input travel testing method stipulated. In the survey of ride comfort to the automobile, ISO 2631-1:1997 defines the sitting posture of man model inspired (Crolla and Yu, 2004). When we make comfortable evaluation, we not only considerate line vibrations in 3 direction on chair area of bearing place but also consider angular oscillations of 3 directions as well as line vibrations in 3 direction on the chair seat back cushion and foot area of bearing two entrance point. Altogether there are 3 entrance points 12 axial vibrations. This standard is that the human body has different sensitivity to the different frequency vibration. It gives each axial 0.5~80 Hz frequency weighting function (asymptote), we consider the different point and axial vibrations which affected to the human body and also give longitudinal vibration axis weighting factor k. Table 1 has given 3 entrance points and 12 axial that select frequency weight function and corresponding axis weighting coefficient k separately (Xun and Deng, 2005).

The weighting acceleration root mean square value in x, y and z directions, can be obtained by integral equation of the auto power spectral density function which this longitudinal vibration acceleration function is:

$$a_{wi} = \left[\int_{80}^{0.5} W_i^2(f) G_{ai}(f) df\right]^{\frac{1}{2}} \tag{4}$$

Here, a_{wi}-weighting acceleration root mean square value in x, y and z directions, i = x, y, z

G_{at} (f)-weighting acceleration power spectral density function in x, y and z directions, i = x, y, z

w_t-frequency weighting function in x, y and z directions, i = x, y, z. Frequency weighting function w (f) (asymptote) may be expressed by following formula:

$$w_k(f) = \begin{cases} 0.5 & (0.5 < f < 2) \\ f/4 & (2 < f < 4) \\ 1 & (4 < f < 12.5) \\ 12.5/f & (12.5 < f < 80) \end{cases} \tag{5}$$

$$w_d(f) = \begin{cases} 1 & (0.5 < f < 2) \\ 2/f & (2 < f < 80) \end{cases} \tag{6}$$

$$w_c(f) = \begin{cases} 1 & (0.5 < f < 8) \\ 8/f & (8 < f < 80) \end{cases} \tag{7}$$

$$w_e(f) = \begin{cases} 1 & (0.5 < f < 1) \\ 1/f & (1 < f < 80) \end{cases} \tag{8}$$

The various pictures above express separately the acceleration and power spectral density curve of the 3 points measured. Figure 2 expresses the three direction line accelerations and angle acceleration on the chair bearing surface. Figure 3 expresses three direction line accelerations on the backrest bearing surface. Figure 4 expresses the three direction line accelerations on the foot bearing surface.

In the chart the upper part expressed the line acceleration in this direction, the lower part expresses the acceleration power spectral density curve in this direction.

Through computation, the weighting acceleration root mean square value and total weighting acceleration root mean square value of the vehicle at the speed of 70 km h^{-1} are followed in the Table 1.

Table 1: Each axial weighting acceleration and total weighting acceleration of the vehicle speed at 70 km h^{-1}

Position	Name of coordinate axis	Frequency weighting function	Axis weighting f coefficient k	Weighting acceleration (rms) a_w m sec^{-2}	Peak value coefficient k
Chair	xs	wd	1.00	0.0300	4.9
	ys	wd	1.00	0.0069	4.2
	zs	wk	1.00	0.3009	5.1
	rx	we	0.63	0.0092	4.3
	ry	we	0.40	0.0302	4.9
	rz	we	0.20	0.0028	4.1
Backrest	xb	wc	0.80	0.0514	4.2
	yb	wd	0.50	0.0029	4.1
	zb	wd	0.40	0.1477	4.7
Foot	xf	wk	0.25	0.0353	4.4
	yf	wk	0.25	0.0048	4.1
	zf	wk	0.40	0.1582	5.4
		$a_y = (\sum a_{yj}^2)^{\frac{1}{2}}$		0.3785	

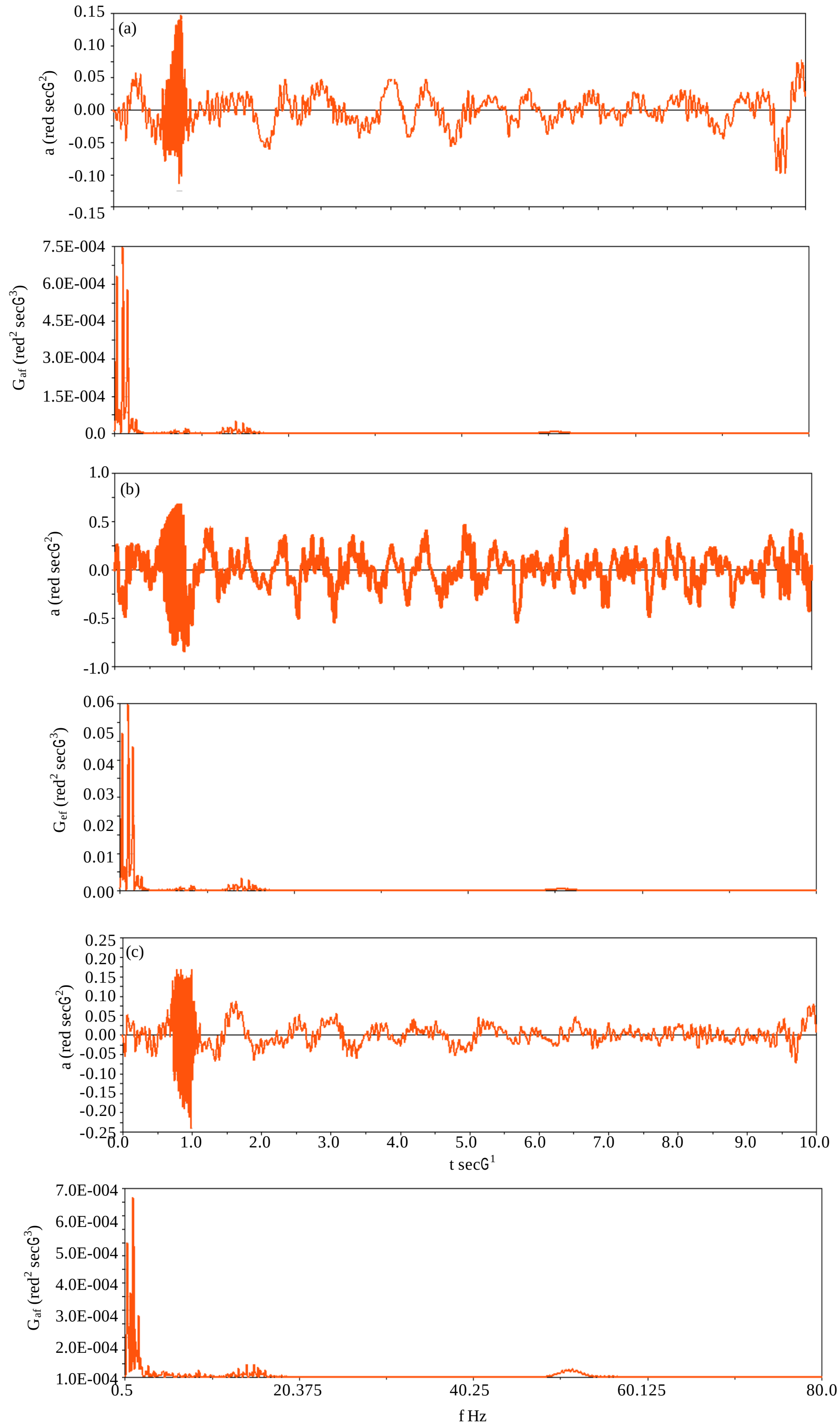

Fig. 2(a-c): Curve of the, (a) Rolling angle, (b) Pitch angle and (c) Yaw angle acceleration and acceleration power spectral density values in this direction on the chair

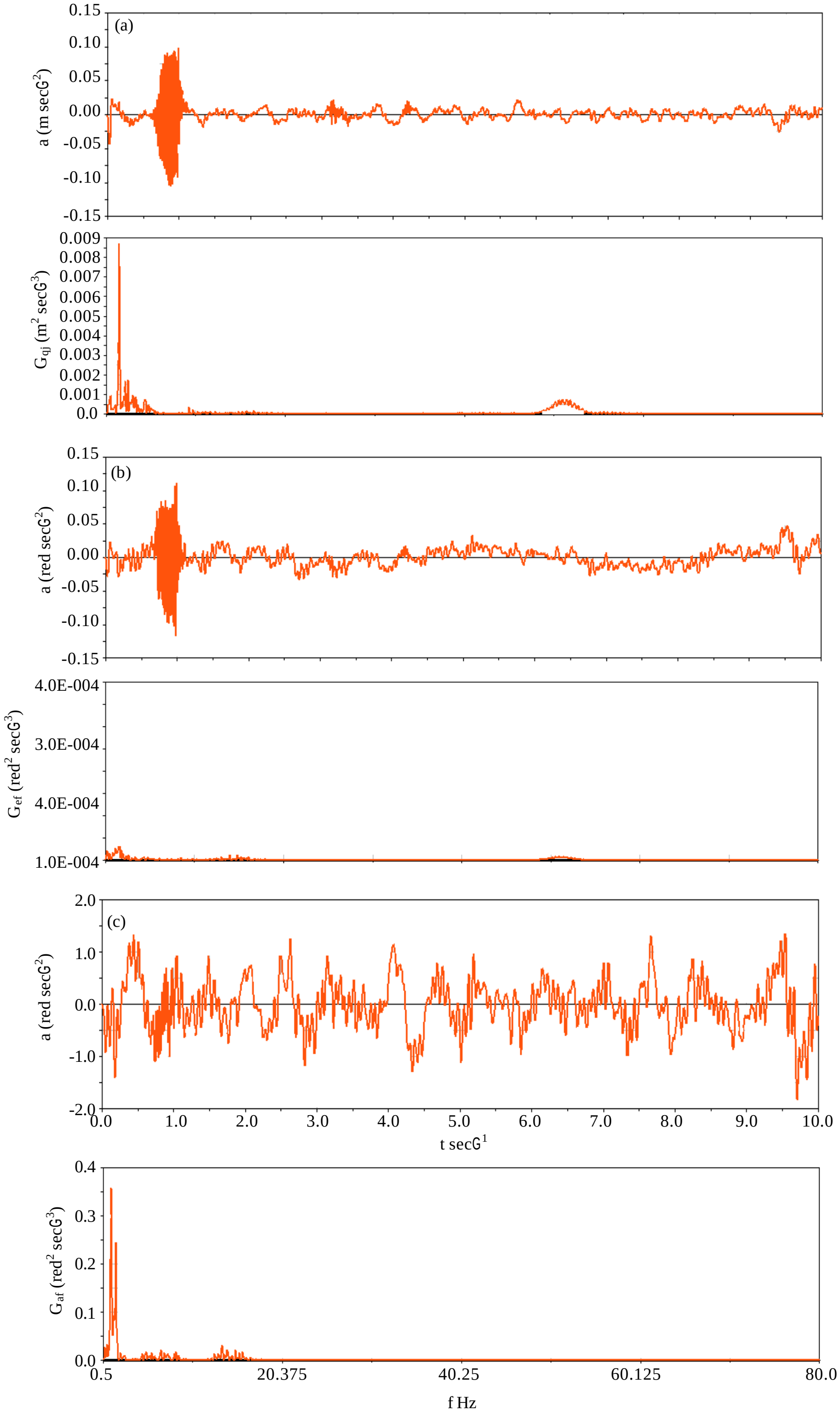

Fig. 3(a-c): Curve of the, (a) Longitudinal (b) Lateral and (c) Vertical acceleration and acceleration power spectral density values on the backrest

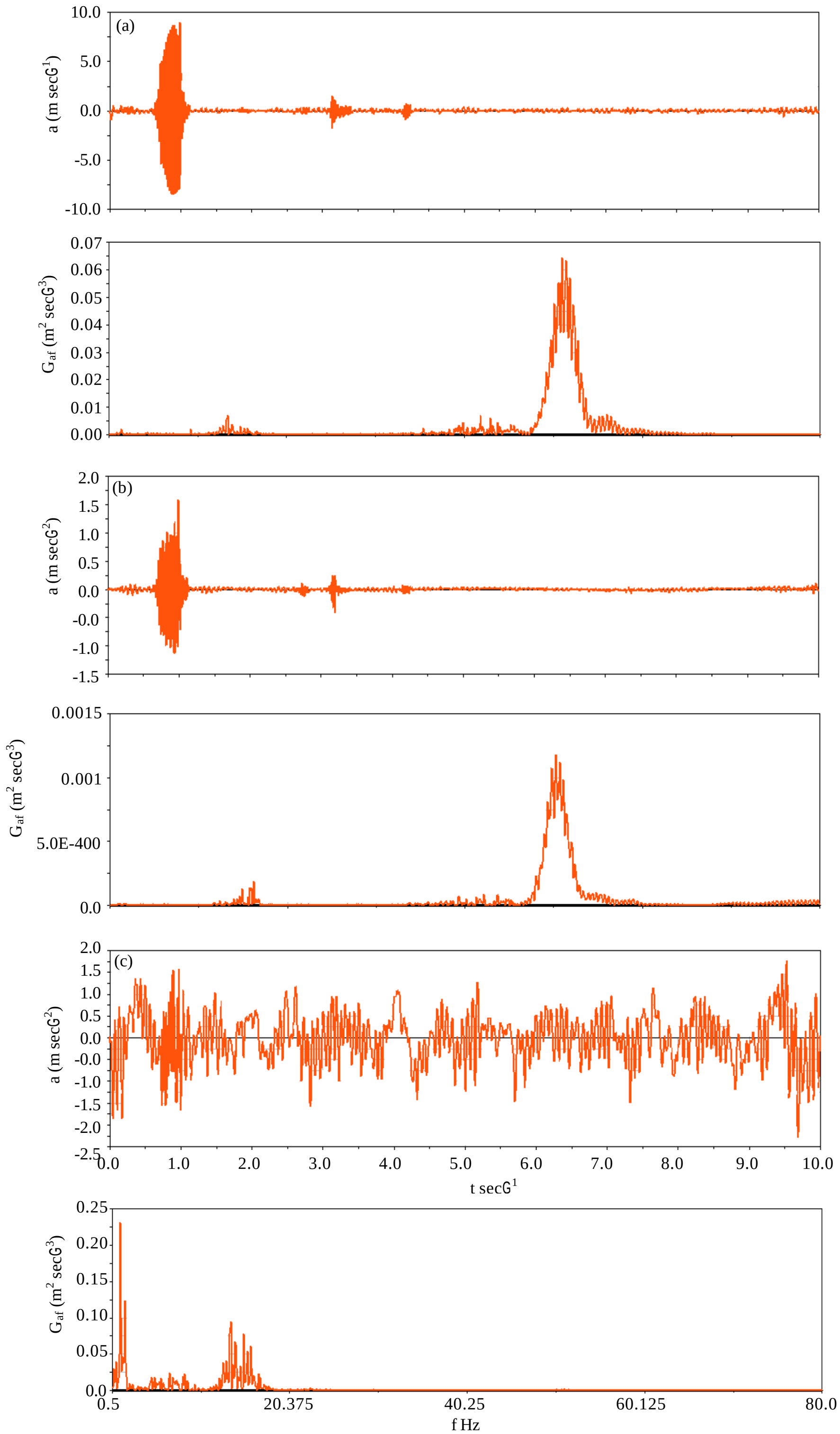

Fig. 4(a-c): Curve of the, (a) Longitudinal (b) Lateral and (c) Vertical acceleration and acceleration power spectral density values on the foot

CONCLUSION

Through the survey and evaluation method in international standard ISO 2631-1:1997, considering the influence of the different position as well as the different direction vibration to the human body, we may reflect comprehensive and accurately how comfortable the person feels riding this vehicle. After above simulation analysis we may know that when the automobile goes on the B level road surface at the speed of 70 km h^{-1}, its total weighting acceleration root-mean-square value is small, this shows its smoothness is good and it reflects this vehicle has good ride comfort. Also computed result above may provide the instruction to optimize this vehicle smoothness further.

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