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Abstract. In this paper, we conduct a vibration simulation analysis of the suspension system in the cab of a heavy truck in ADAMS. Through establishing the parametric vibration mechanics model of suspension system and using the vibration signal as the excitation signal in the simulation, and regarding rms value of the weighted acceleration as the evaluation indicators, we optimize and match the parameters of the suspension system.

Keywords: cab suspension, vibration analysis, parameters optimization

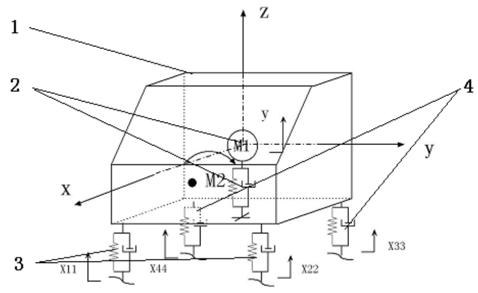
1 Introduction

Heavy trucks need to work under bad conditions of the road, so in order to ensure the comfort of the cab, researchers should improve the vibration isolation performance of suspension system. Establishing accurate virtual prototype model combining with multi-body dynamics is the key to analyze the performance of avoiding vibration of the suspension system in the cab. The suspension system is a vibration system of many degrees of freedom by connecting the vehicle frame, the suspension elements with the cab. The main element of reducing vibration in the suspension of the cab is springs and dampers. Without changing the structure and position of the suspension system, the main parameters of influencing the elements of reducing vibration are the damping and stiffness of the vibration absorber. Therefore, the optimization and matching of the parameters of the stiffness and damping of the front and rear suspension systems is the main way to improve the vibration performance of the suspension system. In terms of the stiffness and damping of the suspension system in the cab of one heavy vehicle, we perform a parameter optimization and matching of the suspension system to reduce vibration with applying the theory of multi-body dynamics and the function of Design of Experiments, DOE in ADAMS.

2 Parametric Modeling of Virtual Prototype

2.1 The Establishment of Mechanical Model

Excitation, quality, elasticity and damping are main factors which influence the vibration of the mechanical system. Therefore, if we get the four elements accurately, we can reflect the mechanical model of the physical process in a right way from the complex machine. For the scattering of the quality and elasticity of the actual vehicle system, we can’t succeed in analyzing the continuous system in the analytic method, but change the scattering of the continuous system to several concentrated quality and then analyze with the springs and dampers connected[1]. This paper regards the suspension system in the cab as the research subject as a whole, the mechanical model of the spatial vibration equivalent system in the spatial coordinate is shown in Fig. 1.



1.Cab 2.People- seat system
3.The front suspension system 4.The rear suspension system
Fig.1. The mechanic model of the suspension system in the cab

Before establishing the dynamics model of the suspension system in the cab, we should acquire the geometric model parameters, quality parameters, mechanic parameters to ensure the correctness of the model and the accuracy of the simulation. All the main parameters are provided by the manufacturers and furthered tested by the degree of freedom after establishing system model in ADAMS. The acquired 47 degrees of freedom of the system mainly include:

(1)The stabilizer bar freedom: with being changed into 8 flexible elements, connected by 2 fixed hinge with the lower bracket, 12 degrees of freedom constricted, the degree of freedom from the stabilizer bar is 8x6-2x6=36.

(2)The degree of freedom of the cab and the suspension elements: 6 degrees of freedom.

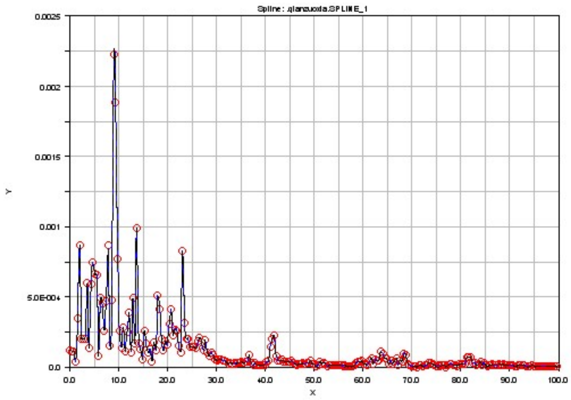
(3)The degree of freedom of the seat: with constricting the movement of the seats and the cab, only one degree of freedom of vertical movement according to the cab remains of the seats.

(4)4 degrees of freedom of the vibration table: vertical direction

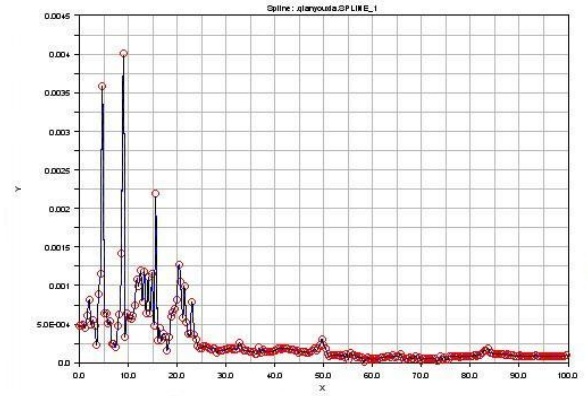
In ADAMS, we have to ensure the model is neither under under-constrained nor over-constrained. Under-constriction makes it hard for us to ensure the correctness of the simulation; a warning will be given in the simulation under over-constriction and the simulation cannot work normally. Through the verification of the degree of freedom and static equilibrium, the model is established accurately. Then we can conduct the following simulation.

2.2 The Establishment of Model Input Excitation

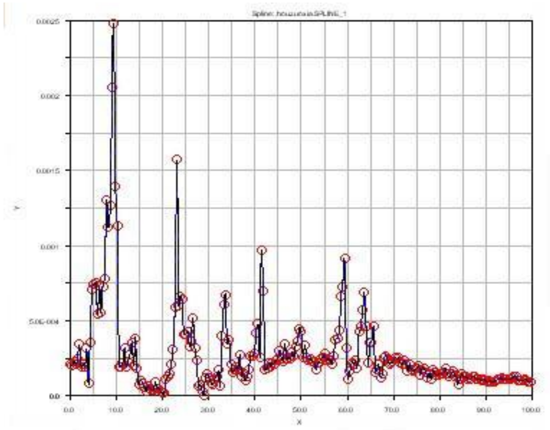
The excitation signal applies the vibration accelerating speed of the 4 test points under the suspension acquired from the road vibration test as the excitation input, as shown in Fig.2. For the actual test signals are combined from the road roughness incentives, engine vibration, frame bending vibration and torsional vibration transmission, so we apply the actual signals as the stimulation excitation sources, making the simulation closer to the actual situation. With establishing the multi-body dynamics model of the suspension system in the cab in the multi-body mechanic software ADAMS, regarding the weighted rms acceleration value of the cab's seat as the assessment target output, selecting the actual signal of the vehicle at the speed of 60km/h as the excitation source in the simulation, and separately entering them into the lower excitation model of the front and rear suspension system of the model, we conduct a vibration simulation analysis of the suspension system.



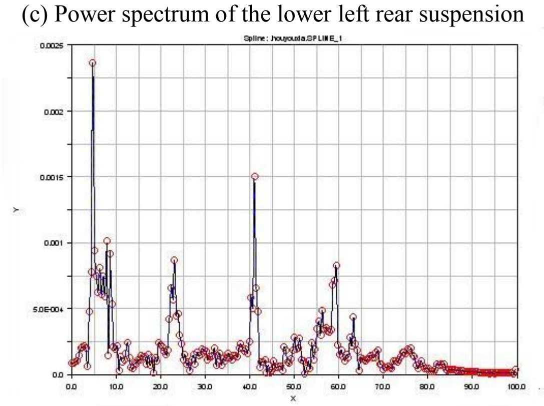
(a) Power spectrum of the lower left front suspension



(b)Power spectrum of the lower right front suspension



(c) Power spectrum of the lower left rear suspension



(d) Power spectrum of the lower right rear suspension

Fig.2. Model excitation signal

2.3 The Vibration Simulation Analysis

We confirm the excitation input of the suspension system model in the cab, conduct a vibration simulation of the model and then choose the forced damped vibration analysis. We get the power spectrum after the analysis, as shown in Figure 3. The measured signals in the same position are shown in Fig.4.

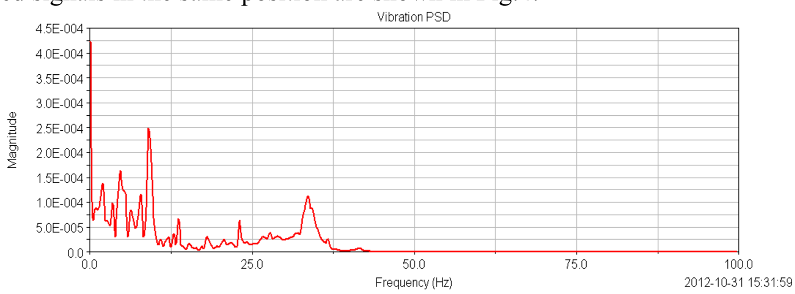


Fig.3. The power spectrum of the simulation test

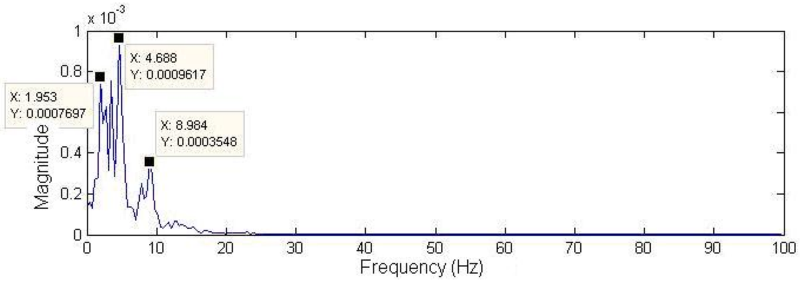


Fig.4. The power spectrum of the measured signal

The vibration peak frequencies of the power spectrum curve of the cab's seat acquired from the simulation are 0.1 Hz、0.1995 Hz、1.9907 Hz、4.7769 Hz、9.0558 Hz、33.6347Hz in turn. After comparing with the actual vibration peak frequencies of the power spectral curve of the cab's seat, as shown in table 1, we can know 1.953Hz, 4.688Hz and 8.984Hz are separately close to 1.9907Hz, 4.7769 Hz and 9.0558 Hz.

Table 1. The comparison of the main peak frequencies from simulation and the measured test

The main peak frequencies from simulation in ADAMS(Hz)	The main peak frequencies from measured test(Hz)
0.1995	—
1.9907	1.953
4.7769	4.688
9.0558	8.984
33.6347	—

Although the peak frequencies change a little in the result from the simulation, they are still the main peak frequencies of vibration. The corresponding frequencies are basically consistent with the peak frequencies of the actual signals, proving that the vibration state of the simulation model can simulate the vibration of the vehicle cab's actual state.

3 The Parameter Optimization of Vibration Based on DOE

Design of Experiments, DOE mainly does research in the influence of every design variable to performance of the prototype when several design variables change at the same time. It is a method to optimize the prototype model through tests. The design of experiments mainly includes the establishment of design matrix and the statistical analysis of test results[2].

The experiment scheme in the process of DOE is described by the test design matrix. The size of the test design matrix is related to the number of factors, the level of each factor and their way of arrangement and combination. Good test design can get enough test data from relatively less number of trials. Therefore, The construction of the design matrix of DOE is the key to the test design[3]. The method of DOE combines orthogonal experiment design. To conduct the construction of the test design matrix with the tool of the orthogonal experiment design— the orthogonal table, thus reducing large amount of test work. Arrange for tests with orthogonal tables, that is, randomly arranging the test factors to various columns on the orthogonal table (blank columns allowed), and arrange the levels of factors to various lines on the orthogonal table. The provided DOE technical tools in ADAMS can efficiently fulfill the analysis process[4].

3.1 Determine the Experiment Scheme

(1) Select experiment factor

Suspension system's stiffness, damping are main factors of influencing the comfort and smoothness of the cab. Therefore, we separately select the stiffness and damping parameters of the air spring damper of the front and rear suspension system in the cab as the experiment factors, they are separately front suspension stiffness Kf, damping Cf, rear suspension stiffness Kr and damping Cr.

The air spring damper of the suspension system in the cab is nonlinear damping elements. In order to simplify the operation, in the process of establishing dynamic model, the damper is regarded as the linear element. According to the document provided by the manufacturer, we select the front and rear suspension stiffness as 30N/mm, the damping as 1.8Ns/mm, as the initial values of the simulation models.

(2) Determine the scope of factor levels

According to the test data of the air spring stiffness provided by the manufacturer, the stiffness in the DOE test ranges from 20 to 70 N/mm, and the damping ranges from 1.8~8Ns/mm.

(3) Construct experimental design matrix

The orthogonal table is used in experiment design, we divide the range scope of stiffness of damping 20~70N/mm and 1.8~8Ns/mm into 6 equal parts and get the medium date of every factor, as shown in the following table 2.

Table 2 . The level factor values of test factors

Level	Factors			
	$\mathrm{A}(\mathrm{K_f})$	$B(C_f)$	$C(K_r)$	$D(C_r)$
1	20	1.8	20	1.8
2	30	3.04	30	3.04
3	40	4.28	40	4.28
4	50	5.52	50	5.52

5	60	6.76	60	6.76
6	70	8	70	8

3.2 The Analysis of the Simulation and Optimization Results

With the minimum of the vibration power spectral peak of the seat as the optimized target, we conduct a DOE simulation calculation of the dynamics model in the suspension system. When the design variables are Kf=30N/mm，Cf=5.52Ns/mm，Kr=60N/mm，Cr=8.0Ns/mm, the optimized target value reaches the minimum. The group of optimized parameter is noted as scheme 1. Because the orthogonal test technology shrinks the test scale, so to avoid some schemes may be ignored, we conduct an range analysis of the data from the simulation[5]. The parameter data in the scheme 2 is shown in table 3.

Table 3. The comparison of the simulation optimization results

Scheme	$\mathrm{A}(\mathrm{K}_{\mathrm{f}})$	$B(C_f)$	$C(K_r)$	$D(C_r)$	Accelerated speed rms (m/s^2)	The reduced range of optimized results（%）
Original scheme	30	1.8	30	1.8	0.5477	—
Optimized scheme 1	30	5.52	60	8	0.4359	20.41
Optimized scheme 2	30	5.52	70	8	0.4358	20.43

Compared with the original scheme, the assessed target values in scheme 1 and scheme 2 reduce separately by 20.41% and 20.43%. The final scheme 2 is the best optimized parameter: the front suspension stiffness is 30N/mm; the front suspension damping is 5.52Ns /mm; the rear suspension stiffness is 70N/mm; the rear suspension damping is 8Ns /mm.

We change the design variables to the optimized stiffness and damping values in the model and analyze the vibration simulation once again. Then we get the output power spectral density of the cab’s seat and compare it with the original spectral. Fig. 5 is the curve before and after optimization, with the optimization fulfilling the target of avoiding vibration.

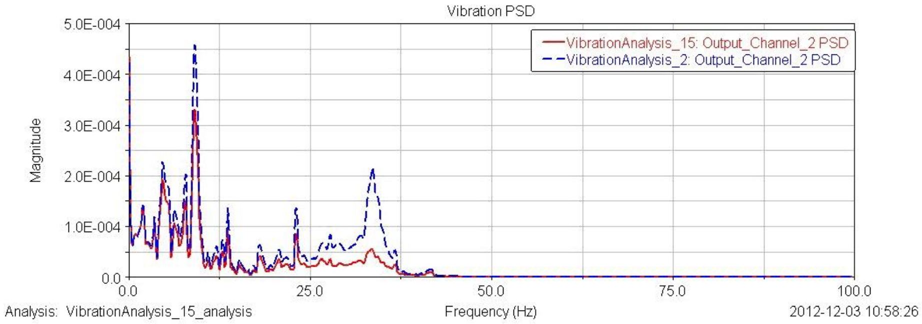


Fig.5. The comparison of simulation results

4 Conclusions

With applying the parameter match optimization method of the suspension system based on the dynamics modeling and vibration simulation, we succeed in reducing the vibration of the cab. With applying multi-body dynamics theory, we establish the dynamics model. Through the vibration simulation and parameter optimization of the suspension system in the cab, we get a group of optimized stiffness and damping values of the performance of avoiding vibration: the front suspension stiffness value is 30N/mm; the front suspension damping value is 5.52Ns /mm; the rear suspension stiffness value is 70N /mm; the rear suspension damping value is 8Ns /mm. The simulation results show that with the group of suspension parameter, the weighted acceleration RMS of the cab's seat is reduced by 20.43% compared with the original vehicle index, which improves the stability of the model vehicle and reduces the vibration.

Acknowledgment

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