Research Article
Research on Damping Characteristics of Shock Absorber for Heavy Vehicle

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Abstract: The damping characteristic of shock absorber has an important influence on its design and overall performance of vehicle system. Firstly, the structural features and working principle of hydraulic shock absorber are introduced. Then the detail testing scheme of the shock absorber is proposed and the damping characteristics are tested under both sinusoidal and random displacement excitation (HT-911 dynamic material test platform). The testing data under different excitation frequency and amplitude are analyzed, respectively. The tested results show that the shock absorber has the typical features of non-linearity, non-symmetry and hysteresis. In order to satisfy the vehicle dynamics simulation, the Besinger model is chosen to describe shock absorb nonlinear characteristics. The LSM (Least Squares Method) is utilized to identify seven parameters of Besinger model based on experiment results. Finally, a nonlinear virtual prototype model of heavy duty vehicle is built to prove the fitted shock absorber model effectively.

Keywords: Damping characteristics, heavy-duty vehicle, hydraulic shock absorber, nonlinear modeling

INTRODUCTION

The road early damage is mainly caused by heavy load, which reduces the road service life and the vehicle performances (OECD, 1998; Yang *et al*., 2009). As a major damping component of the heavy vehicle, the dynamics characteristics not only affect the vehicle ride comfort and handling stability, but also directly decide the dynamic load between the vehicle and road (Adrian, 2002). At present there are many mathematical models to express shock absorbers damping characteristics (Lu and Li, 2002). A complex non-linear shock absorber model was proposed by Lang (1977), which includes 83 parameters depending on physical feature. Although the Lang's model is good at describing the distortion problem at the high frequency, it has some limitations in practical applications due to so many parameters. Karadayi and Masada (1989) established a kind of simple and clear model for describing the hysteresis characteristics of shock absorber, but it is only suitable for working condition in the low-frequency. Besinger and Cole proposed a nonlinear model including seven parameters. They applied Besinger model in the modeling for heavy-duty vehicle suspension shock absorber and its simulation results is better in accord with the experiment when frequency is less than 10 Hz and the speed is <1 m/s.

The working principle of the hydraulic shock absorber could be briefly summarized. When a piston is moving back and forth in the cylinder tube, the oil in the shell of shock absorber repeatedly flows from one cavity into other cavity through some narrow gaps. As a result, the damping force is produced because of the friction among oil molecules. In theory, a greater damping force attenuates vehicle suspension vibration faster. However, the damping force is always designed larger in the tension stage than in the compression stage. The purpose is to make shock absorber improve the vehicle dynamic behaviors. A bidirectional hydraulic shock absorber is studied in this study, which could attenuate the vibration in both tension and compression stage and reflects the obvious nonlinear hysteretic characteristics. The shock absorber is a typical nonlinear system and its damping force modeling has become a research highlight. The nonlinear modeling methods consist of: parametric model and non-parametric model. Parametric model accounts for the shock absorbers internal fluid flow and the real structure of throttle, while non-parametric model is mainly based on actual measurement ignoring its inner structure. So as to obtain the damping coefficient of the shock absorber and its motion regularity correctly, it is necessary to do actual measurement about the damping characteristics. Then non-parametric method is adapted to research nonlinear damping characteristics of the hydraulic shock absorber in this study.

In this study, the shock absorber damping characteristics of a heavy vehicle (DFL1250A9) are tested under the sinusoidal and random steady-state displacement excitation, respectively, with the material test platform (HT-911). The damping characteristic

curves are obtained under different frequencies and different amplitude. The seven nonlinear parameters of Besinger model are identified depending on the tested results. A case of virtual heavy vehicle is proposed to put the fitted shock absorber model into action.

TESTING FOR DAMPING CHARACTERISTICS

Testing system and scheme: In this study, the dynamic materials testing system (Hongda HT-911) is chosen to test the damping characteristics of the shock absorber. The test system contains servo control system, signal acquisition system, function generator, security monitoring system, digital A/D interface system, servo-valve driver and the twin-tube hydraulic shock absorber and so on. The specific scheme of the testing is designed, as follows:

- **Clamping the shock absorber:** The lower end of a shock absorber is vertically fixed to the hydraulic servo-platform and the upper end is fastened to the rigid beam equipped with a force sensor. The shock absorber is adjusted along the vertical direction to ensure that piston does not produce eccentric wear during the loading process. Then the initial position of the servo-console should be also adjusted to ensure the piston locate in the middle of the effective stroke.
- **Loading the shock absorber:** The excitation frequency, amplitude and sampling frequency are all typed into the computer. The driving signal of sinusoidal displacement is produced through a function generator. The signal is amplified by the digital A/D interface to make servo platform excite the shock absorber according with the pre-input frequency and amplitude.
- **Collecting the data:** Because the excitation method is displacement driving, the displacement signal of the shock absorber piston can be directly obtained by the pre-input signal. And the damping force can be recorded through the force sensor on the rigid beam. The actual photo and testing scene of the shock absorb are shown in Fig. 1 and 2, respectively.

Testing results for damping characteristics: For the purpose of obtaining the nonlinear damping characteristics of the shock absorber, it is needed to do some excitation tests at different excitation frequencies and different amplitudes. The steady-state excitation to the shock absorber is made according to the standard QC/T 545-1999. The exciting frequency IES were

Fig. 1: Shock absorb of DFL1250

Fig. 2: Experimental setup for testing damping characteristics
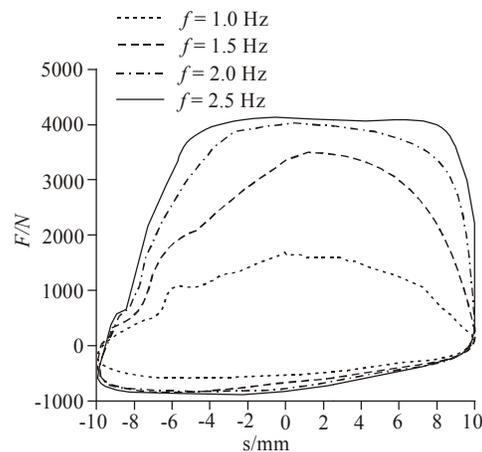

Fig. 3: Force displacement curve under different frequency

chosen as 1.0, 1.5, 2.0 and 2.5 Hz, the excitation amplitude of the piston were chosen as 5, 10, 15 and 20 mm, respectively.

Because the shock absorber is excited by sinusoidal displacement, the piston motion is given as:

$$S = S_0 \sin(2\pi\omega t) \tag{1}$$

where,
S_0 : The largest amplitude of the piston movement
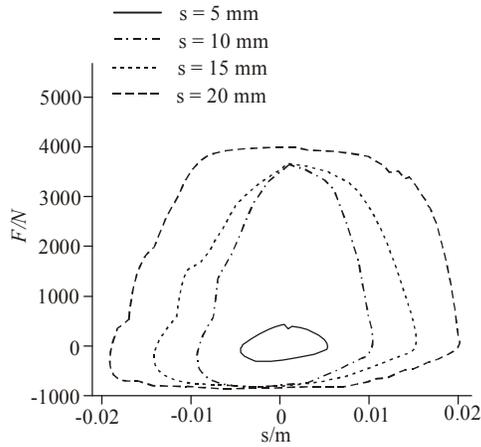ω : The movement angular frequency

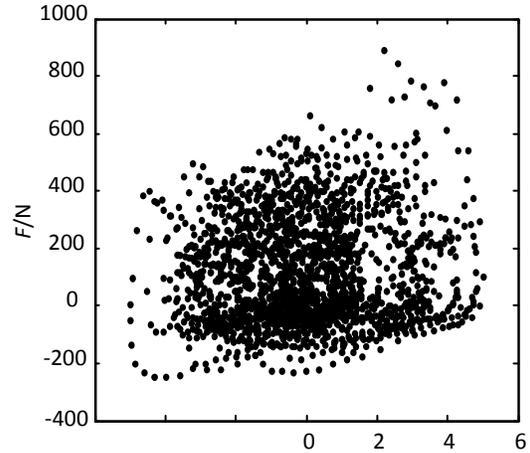Fig. 4: Force displacement curve under different amplitude

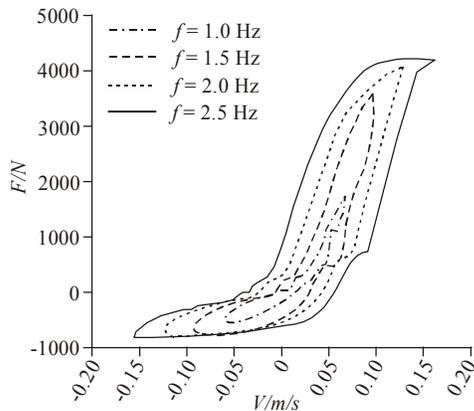Fig. 7: Force displacement curve under random excitation

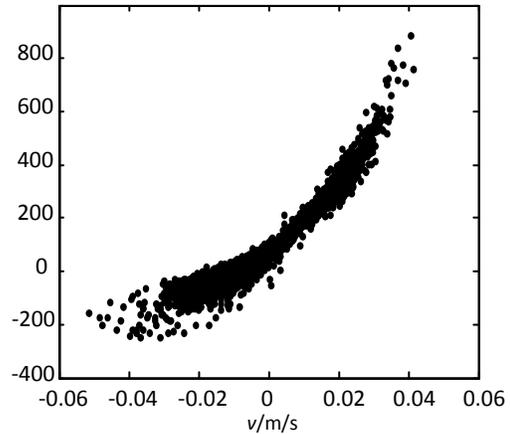Fig. 5: Force velocity curve under different frequency

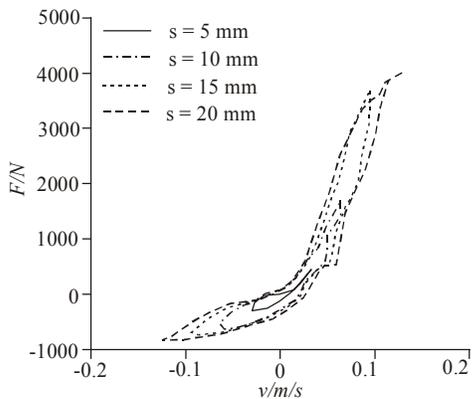Fig. 8: Force velocity curve under random excitation

$$V = 2\pi S_0 \omega \cos(2\pi\omega t) \qquad (2)$$

Through a series of experiments, the damping characteristic curves of the shock absorber are measured. Then the force-displacement curves under different frequency and amplitude are shown in Fig. 3 and 4, respectively.

Figure 5 and 6 show that the curves present obvious nonlinear characteristics during both the tension and the compression processes. Furth more, there also exits hysteresis phenomenon.

In order to further simulate the actual vibration of heavy vehicle travelling on uneven road, the random excitation test is also done for shock absorber. Figure 7 and 8 show the damping characteristics of shock absorber under the random excitation.

Some conclusions could be drawn from the Fig. 7 and 8, as follows:

Fig. 6: Force velocity curve under different amplitude

Then the relative velocity between the piston and cylinder tube can be deduced as:

- The working points have the feature of uneven distribution under the random excitation. But these points basically locate in an area within -6~6 mm amplitude, -0.06~0.06 m/s velocity.
- The force-displacement curve presents "Hamburger" shape and the left and right sides are not completely symmetrical. The damping characteristics curve presents "Banana" shape. These results once again prove that the shock absorb has indeed the feature of non-linearity and non-symmetry.

Parameter identification of shock absorber: The experiment research is only the beginning to understand the shock absorbs characteristics visually. The parameter identification should be done to satisfy the vehicle dynamics research. There are two ways to accomplish the system parameters identification, as followers: in the time and in the frequency region. The LSM (Least Squares Method) is firstly proposed by Gauss, which is a basic and effective method to apply the identification theory into the static and dynamic system, or linear and nonlinear system etc. Thus the LSM is utilized to identify the shock absorber parameters based on experiment data. In this study, the Besinger model is chosen for identifying damping force. A nonlinear springs and damper are cascaded together in this model, shown as Fig. 9. The model has three features: nonlinear relationship between the tension and compression stages, hysteresis loop and saturation in high-speed stage during the tension stage.

In the Besinger model, the damping force F_v is defined as:

$$F_v = \begin{cases} C(v)v & v < v_{\lim} \\ C_e v_{open} + C_b (v - v_{open}) & v \geq v_{\lim} \end{cases} \quad (3)$$

where,

$C(v) = \dfrac{c_1 (v - \alpha)}{\alpha \sqrt{1 + (\frac{v - \alpha}{\alpha})^2}} + c_2$: A function of the piston velocity relative to cylinder tube

C_c : The damping coefficient of shock absorber in the compression stage

C_e : The damping coefficient at the low-speed stage of the tension stroke

C_b : The damping coefficient of shock absorber at the high-speed stage of the tension stage

$v_{\lim}$: The speed at the turning speed between high speed and low speed during the tesniling stroke

α : A transition parameter between compression and tension damping force and $C_1 = (C_e - C_c)/2$, $C_1 = (C_e + C_c)/2$

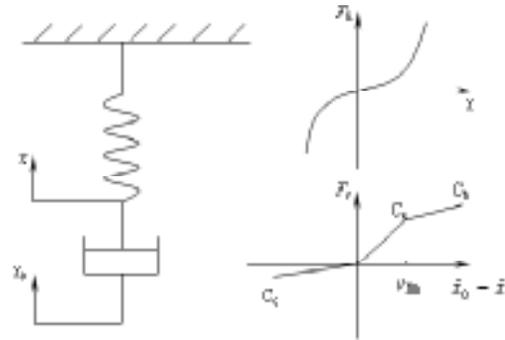According to the model Fig. 4, the damping force could be written as:

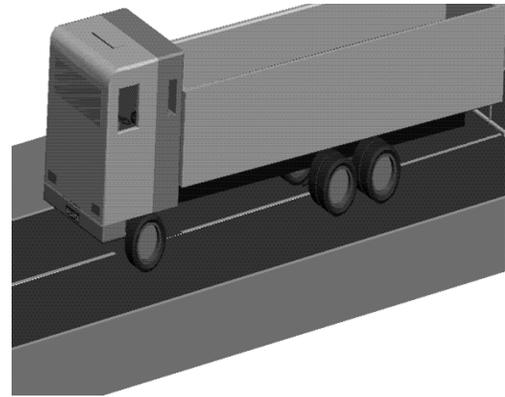Fig. 9: Besinger model of shock absorber

Fig. 10: Multi body heavy vehicle model

$$F_c = k_1 x + k_2 x^3 \quad (4)$$

where, k_1 and k_2 are the coefficients of the spring stiffness.

Based on the testing data (frequency 2 Hz, amplitude 10 mm), the LMS method is utilized to indentify the damping parameters of the shock absorber. The specific damping coefficient are: C_c = 14.4 Ns/mm, C_e = 15.6 Ns/mm, C_b = 3.6 Ns/mm, $v_{\lim}$ = 0.125 m/s, α = 0.7 m/s, k_1 = 150 N/mm, k_1 = 150 N/mm, k_2 = 0.12 N/mm^3.

NUMERICAL RESULTS

Based on the above identified nonlinear damping force and the multi-body theory, a full heavy vehicle model is established in the multi-boby software. The vehicle model consist of the front and rear suspension, steering room, steering system, engine, tires and other subsystems models. After precise definition of the spatial locations for these subsystems, vehicle model is established through the input and the output communication device. The integrated model could

Table 1: Main parameters of suspension system

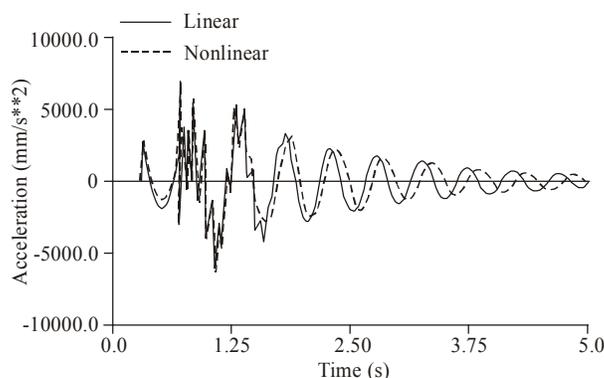| Camber angle	Kingpin inclination	Caster angle	Length/width/thickness of front leaf spring (mm)	Full load of front axle (kg)
1°	7°	1°52′	1600/90/13	6900
Length/width/thickness of rear leaf spring (mm)	Stiffness of front leaf spring (kN/m)	Stiffness of tandem leaf spring (kN/m)	Vertical stiffness of tire (kN/m)	Full load of tandem axle (kg)
1600/90/24	252	1195	1100	18000

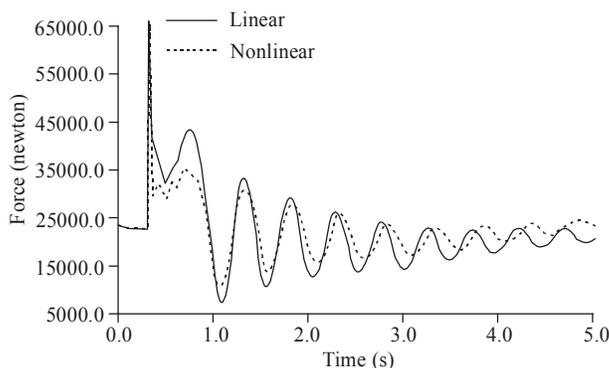Fig. 11: Compare of the vehicle body acceleration of vehicle

Fig. 12: Compare of the dynamic tire force

reflect the fine structure of vehicle systems more accurately and truly. Some quasi-static equilibrium simulations are implemented to check redundant constraint and make the virtual model valid. The whole 3D vehicle model is shown in Fig. 10.

Some main parameters of the vehicle model are shown in Table 1. And the nonlinear parameters of shock absorb according to the above experiment results.

The vehicle runs on the virtual road (taking a bump model as impulse excitation) at a constant speed of 40 km/h. The total simulation time and step size are 5 s and 0.005, respectively. The default Gear Stiff Integrator (GSTIFF) is adopted to solve coupled nonlinear Differential-Algebraic Equations (DAE). The vehicle body acceleration and tire dynamic force are simulated by comparing the linear damping and

nonlinear damping force. The results are illustrated in Fig. 11 and 12.

As can be seen from the Fig. 11 and 12, there exit differences for vehicle performance between the nonlinear and linear shock absorber model. The vehicle body acceleration is not sensitive to the effect of nonlinear shock absorb, but the dynamic tire force has obvious difference, which has an important meaning for researching the interaction between the vehicle and road.

CONCLUSION

- A detailed testing scheme for the damping characteristics of shock absorber is proposed. The damping characteristics are tested on dynamic

material platform under the sinusoidal and random excitation.

- The results show that the shock absorber has the features of non-linearity, non-symmetry and hysteresis.
- The Besinger nonlinear model is chosen to identify the damping force based experimental data. And a nonlinear virtual prototype model of heavy duty vehicle is modeled considering the above fitted shock absorber model. Thus it is an effective method to build nonlinear shock absorber model, which can be easy to be utilized in vehicle simulation.

ACKENOWLEDGMENT

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