

Programmed Load Spectrum for Fatigue Bench Test of a Vehicle Body

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ABSTRACT

A compiled method of the programmed load spectrum, which can simplify and accelerate the fatigue bench test of a car body, is proposed and its effectiveness is checked by the fatigue simulation. By using the multi-body dynamics model with a satisfactory accuracy, the virtual iteration is applied to cascade body loads from the wheel hubs. Based on the rain-flow counting method and statistics theory, the distributions of the body loads are analyzed, and then the programmed load spectrum is compiled and simplified. Through comparative study, the simulation results of random and programmed load spectrum are found to agree well with each other in terms of the damage distribution and fatigue life, which demonstrates the effectiveness of the presented method.

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1. INTRODUCTION

Durability is one of the most important performances that affect the safety and life of a vehicle directly. As a key in the vehicle design process, the fatigue life of the vehicle should be predicted at the design stage and the bench test should be conducted while the physical prototype of the vehicle body is available. It is very significant to conduct both the simulation and the bench test to obtain the body loads accurately at the early design stage [1,2,3,4].

It's common practice to cascade body loads through the multi-body dynamic model when the physical prototype is unavailable. The well-developed multi-body dynamic model is the premise to obtain the cascade body loads from the wheel hubs. For example, Gao et al. established a vehicle multi-body dynamics model to analyze the fatigue life of fuel cell bus body [5]. Guo et al. reviewed four prediction methods of fatigue load spectrum, i.e. free displacement loading method, the displacement reverse loading method, the free load loading method and the constrained load loading method [6]. Kim et al. developed a rigid-flexible coupling model to analysis the durability of bus body [7].

Programmed load spectrum has been widely used for the bench test for its simplicity and low-cost. Kobayashi et al. found that a programmed fatigue test can simulate the endurance test on the proving ground well [8]. Dini et al. compared the procedures for experimental and theoretical durability of a truck axle [9].

In this paper, multi-body dynamic model was first established to obtain the random load spectrum by using virtual iteration. Then, rain-flow counting method is implemented to attain the programmed load spectrum. In order to verify the effectiveness of the programmed load spectrum, the simulation results of random and programmed load spectrum are compared.

2. ACQUISITION OF THE BODY FATIGUE LOAD SPECTRUM

2.1. Establishment of the Multi-Body Dynamics Model

Based on the chassis parameters, the point coordinates of the suspension, the sprung mass with its center and inertia parameters, the stiffness of the suspension spring, the elastic stiffness of the damper, the damping curve of the shock absorber and the information of the stiffness of the rubber bushing, the multi-body dynamic modal is established using MSC.ADAMS, as shown in [Figure 1](#).

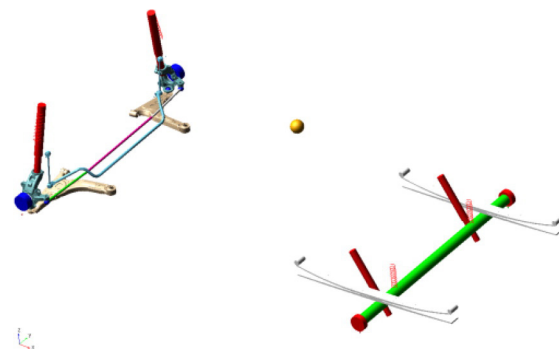


Figure.1. The vehicle multi-body dynamic model

2.2. Virtual Iteration

The virtual iteration is an inverse problem of solving the nonlinear systems, which means that given the output (response) of the system the external load input should be determined. The external load input can be force or displacement, and the system response can be acceleration, velocity, displacement or the stress and strain of the flexible components. It is similar to physical iteration, the virtual iteration process include two stages: system identification and the iteration of the target signal.

2.2.1. System Identification

- A reasonable identification signal is generated, and the white noise is commonly used;
- The generated identification signal is input to simulate the model, the system response of target location is obtained;
- According to the output and identification signal of the model, the frequency response function matrix is obtained. The transfer function $H(j\omega)$ of the system can be calculated as following:

$$H(j\omega) = \frac{G_{xy}(j\omega)}{G_{xx}(j\omega)} \quad (1)$$

where $G_{xy}(j\omega)$ is the cross spectral density function of the input and output signals; $G_{xx}(j\omega)$ is the auto-power spectral density function of the input signal.

2.2.2. Reproduction of the Target Signal

Generally, the driving signal is obtained by target signal and frequency response function. For the nonlinear of the system, the error between the response of the model and the tested value of target signal should be reduced through the iteration of the driving signal..

(a). The initial input signal for iteration is obtained according to the test value of the target signal and the multi-body dynamic model; (b). The error between the output of the model and the tested value of the target signal is occurred due to the nonlinear system; (c). The input signal is updated based on the error as:

$$U_{k+1}(j\omega) = U_k(j\omega) + \gamma \hat{H}^{-1}(j\omega) e_k(j\omega) \quad (2)$$

where $U_{k+1}(j\omega)$ is the driving signal of the $(k+1)$ th iteration; $U_k(j\omega)$ is the driving signal of the k th iteration; γ is the drive gain; $\hat{H}(j\omega)$ is the system model that is identified previously; $e_k(j\omega)$ is the error of the k th times iteration.

2.2.3. Convergence Criterion

Generally, the trend and the amplitude of the target signal and the monitoring signal should be compared with the tested value both in time domain and frequency domain during the iteration process. The target signal should be close to the tested value. At the same time, as the target signal of the iteration is applied to the prediction of the fatigue life, the convergence of the target signal should be evaluated from the point of the fatigue damage. Combined with the material SN curves, the relative damage is generally employed. The relative damage is defined as followed:

$$\mu = \frac{D_{iteration}}{D_{target}} \quad (3)$$

where μ is relative damage; $D_{iteration}$, D_{target} are the pseudo damage of the iteration signal and the tested value respectively[10,11].

The quality of the iteration is evaluated by the value of the relative damage. The ideal value of the relative damage is 1, and the iteration is judged successful if the value is between 0.5 and 2[12]. Taking the Belgium road as an example, it takes 6 iterations to reach the

convergence, and the relative damage process is shown in Figure 2. The results of the iteration are shown in Table 1 and Figures 3 and 4. The iteration value and the tested value of the target signal match each other very well both in time and frequency domain. The monitoring signals also have a good agreement in terms of the trends, amplitudes as well as the pseudo damage. The results of the iteration show that the multi-body dynamic modal has a high accuracy that could be used in the following analyses.

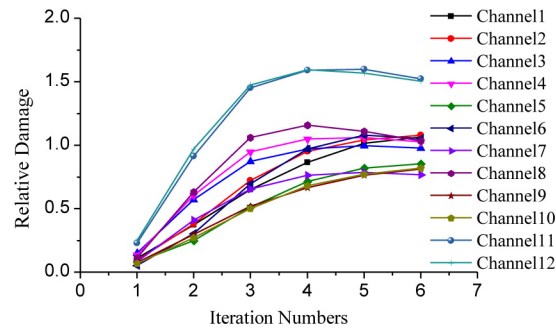
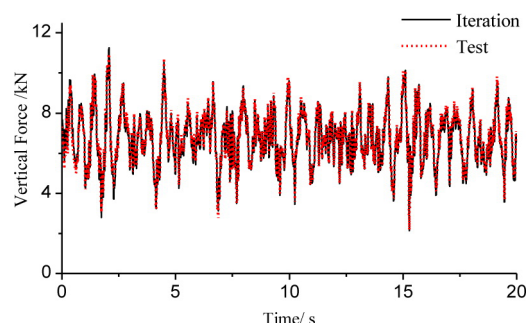


Figure 2. The iteration process of relative damage

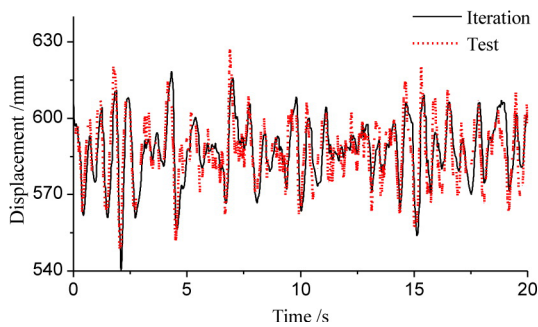
Table 1. The Iteration results (Relative damage)

Signal	Channel Number	Location	Relative Damage
The vertical force of the wheel hubs	1	Left front	1.06
	2	Right front	1.08
	3	Left rear	0.98
	4	Right rear	1.03
The displacements of the body	5	Left front	0.85
	6	Right front	1.05
	7	Left rear	0.77
	8	Right rear	1.03
The accelerations of the body	9	Left front	0.81
	10	Right front	0.82
	11	Left rear	1.52
	12	Right rear	1.50

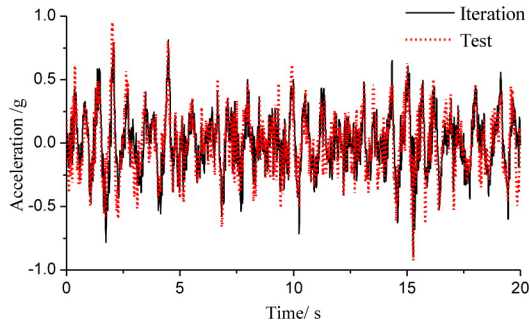


a. The vertical force of left front wheel hub

Figure 3. The Iteration results (Time domain)

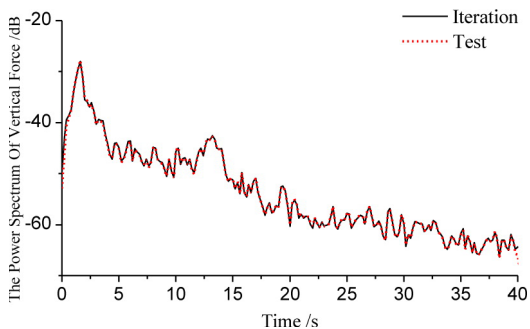


b. The relative displacement of the left front shock absorber

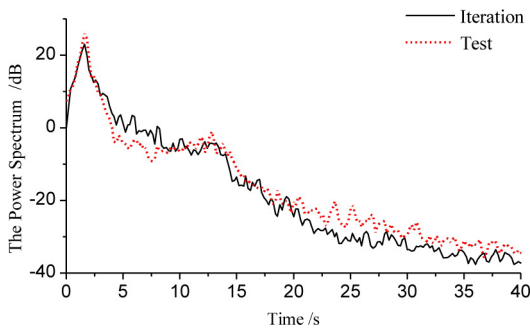


c. The acceleration of the left front body

Figure.3. (cont.) The Iteration results (Time domain)

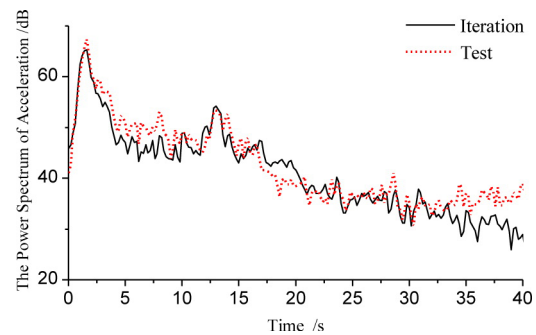


a. The vertical force of left front wheel hub



b. The relative displacement of the left front shock absorber

Figure.4.



c. The acceleration of the left front body

Figure.4. (cont.) The Iteration results (Frequency domain)

2.3. Decomposition of Body Loads Spectrum

The load spectrum for the predication of the body fatigue life can be obtained by applying the iterated signal on the multi-body dynamic modal. There are 18 suspension joint points on the body as shown in [Table 2](#), and the time series of the 6 direction force/moment of the front shock absorber joint point are shown in [Figure 5](#).

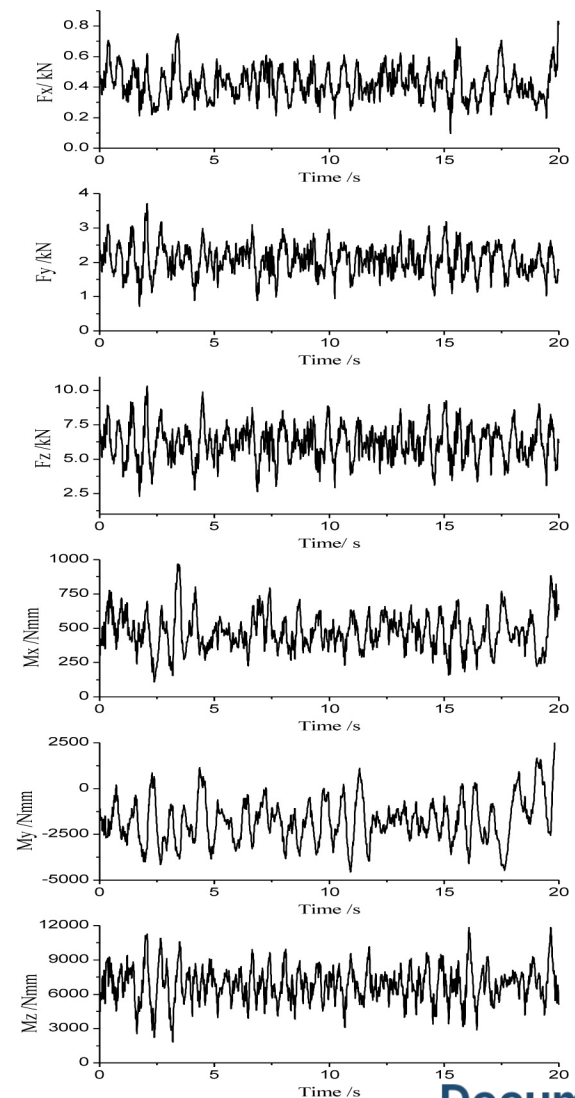


Figure.5. The force and moment of the front shock absorber