

Simulation Modeling on Dynamic Stiffness of Leaf Spring Based on Three-link Model

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ABSTRACT

The leaf spring has significant hysteresis characteristics due to the interleaf friction. The traditional three-link model could not simulate the hysteresis characteristics at all. According to the dynamic load test results one can find that the dynamic stiffness of leaf spring has a nonlinear relationship with the travel distance and the load frequency has a tiny influence on it. Based on the traditional three-link model, this paper proposed a simulation modeling method by introducing torsional friction on the revolute joints. The key parameters including torsional spring stiffness, friction torque preload, stiction transition velocity and max stiction deformation are optimized by combining the ADAMS and OPTIMUS. The comparison analysis between the simulation and test results of front and rear leaf springs have revealed that the maximum average errors are 4.84% and 6.41%, respectively. The proposed simulation modeling method of leaf spring lays a foundation for the high efficiency and precision modeling of vehicles on ride comfort.

Keywords: leaf spring, hysteresis characteristics, three-link model, stick friction, optimization

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INTRODUCTION

The leaf spring has been widely used in commercial vehicles at present, its vertical stiffness has direct influence on the ride comfort [1]. Thus, an appropriate vertical stiffness is very important during design. Due to the interleaf friction, the leaf spring has significant hysteresis characteristics and its dynamic stiffness is changing along with the deformation [2, 3], which might be much larger than the static stiffness. The difference between dynamic stiffness and static stiffness will lead to a variation of ride comfort.

At present, there are four kinds of simulation methods of leaf springs, namely three-link model[4], Beam model[5], finite model[6] and Fancher model[7,8]. Traditional three-link model has advantages in simplicity and high efficiency[4]. However, it is unable to simulate the hysteresis characteristics of leaf spring. Although the Beam model and finite model could express the hysteresis characteristics, they are too complex to full vehicle simulation [9]. The Fancher model is not suitable for the dynamic software such as ADAMS.

In order to satisfy the demand of high precision and efficiency of full vehicle modeling, a modeling method of leaf spring based on the three-link model is proposed in this paper.

DYNAMIC STIFFNESS TEST AND ANALYSIS

Dynamic Stiffness Test

The middle of leaf spring is mounted with the hydraulic actuator through U-bolt and the spring eyes are supported by revolute joints which is shown in Figure 1. The hydraulic actuator is supported by a vertical linear guideway which makes load force is always vertically. Similarly, the spring eyes could travel along the horizontal linear guideway.

During the test, the vertical travel distance of leaf spring Δs is changing along with the vertical load force F . The periodic motion of hydraulic actuator is set as 0.5 Hz, 1Hz, 2Hz and 3Hz frequencies.

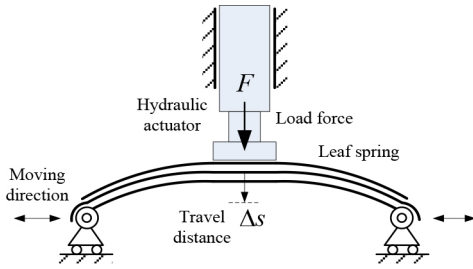


Figure 1. Test principle of leaf spring

Dynamic Stiffness Analysis

Figure 2 shows the test results of a leaf spring, in which the travel distances respectively are 1mm, 3mm, 5mm, 10mm and 20mm. According to Figure 2(a), one can find that the leaf spring has significant hysteresis characteristics. Figure 2(b) revealed that the loading and unloading results are not superposition, the slope of the line segmentation denotes the static stiffness, while the curve segmentation is result from the interleaf friction. In addition, the loading frequency has a tiny influence on the test results when it is not larger than 3Hz.

The dynamic stiffness of leaf spring is represented by the slope of one periodic motion curve[9]. The dynamic stiffness of the test leaf spring with respect to different travel distances is shown in Figure 3, in which the blue solid line denotes the test result and the red dot line indicates the fitting results. As a result, the dynamic stiffness has a nonlinear relationship with the travel distance, and the smaller travel distance is the larger dynamic stiffness is. The dynamic stiffness corresponding to 0mm is 3.6 time larger than those of 20mm. As a result, the actual ride comfort of a vehicle is different from that design one due to the difference of static stiffness and dynamic stiffness. The simulation modeling method is necessary and very important during engineering design.

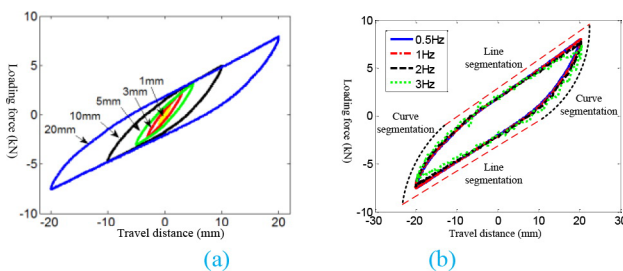


Figure 2. Test results of a leaf spring

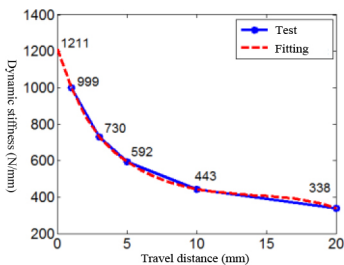


Figure 3. Dynamic stiffness of a leaf spring

SIMULATION MODELING METHOD

Vertical Static Stiffness Modeling

From the test principle on can find that the load and deformation are symmetric about the axle line of hydraulic actuator. Accordingly, a symmetric three-link model is established and shown in Figure 4, where joints A and D are composite joints with revolute and sliding, B and C are revolute joints. Assuming the lengths of link AB and CD both are a , the length of BC is b , the subtended angle between link AB or CD and BC is θ . The torsional torques exerted by torsional springs on joints B and C are T_1 and T_2 , the support force on joints A and D are F_{zA} and F_{zD} . The lengths a and b are determined by the leaf spring[4]. According to the force analysis shown in Figure 5, there will be

$$\begin{cases} F_{zA} = F_{zD} = F/2 \\ T_1 = T_2 = \frac{Fa \cos \theta}{2} \end{cases} \quad (1)$$

As Figure 6 shown, assuming the torsional stiffness is K_θ . The tiny vertical deformation under force ΔF is Δs .

$$\begin{cases} T_1 = K_\theta \Delta \theta = \frac{\Delta Fa \cos(\theta + \Delta \theta)}{2} \\ \Delta s = a [\sin \theta - \sin(\theta + \Delta \theta)] \end{cases} \quad (2)$$

Simplifying equation (2) yields

$$\Delta s = a [\sin \theta - \sin \theta \cos \Delta \theta - \cos \theta \sin \Delta \theta] \approx -a \Delta \theta \cos \theta \quad (3)$$

Then,

$$\frac{\Delta F}{\Delta s} = K_F = -\frac{2K_\theta}{a^2 \cos \theta \cos(\theta + \Delta \theta)} \approx -\frac{2K_\theta}{a^2 \cos^2 \theta} \quad (4)$$

where K_F denotes the vertical static stiffness.

The torsional stiffness also can be expressed as

$$K_\theta = -\frac{K_F a^2 \cos^2 \theta}{2} \quad (5)$$

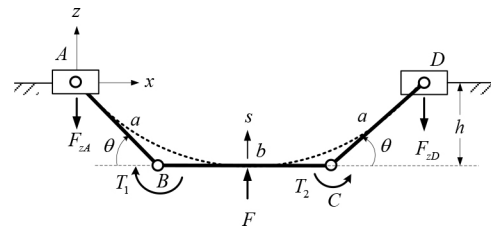


Figure 4. Geometric model of three-link model