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RESEARCH ARTICLE

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The prediction technology study of fatigue life for key parts of a tracked vehicle's suspension system

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Abstract In allusion to fatigue life of a tracked vehicle torsion bar, a virtual prototype model of the tracked vehicle suspension system including a flexible torsion bar was built based on dynamic simulation software—ADAMS. Node force and stress results of the torsion bar from last step simulation were acquired; taking into account the material characteristics and influential factors, fatigue life of the flexible body of the torsion bar was predicted. Engineering results can be acquired through the contrast of the result of virtual test and statistical fatigue.

Keywords fatigue life, prediction technique, torsion bar, tracked vehicle

1 Introduction

Fatigue life of key parts of a tracked vehicle suspension system has a direct influence on the accomplishment of a vehicle's mission. As a rule, the traditional fatigue life prediction of a suspension system, especially torsion bars, was tested by means of abundant twist fatigue experiments after the production of torsion bars, which makes the development and study periods longer and the costs for testing higher. Fatigue life of a prototype system can be predicted during the design process of its suspension system by way of virtual emulation technique, and its development efficiency can be improved. This paper describes the prediction technology of fatigue life for key parts based on the virtual prototype technique.

2 Multibody dynamic model of a tracked vehicle suspension system

2.1 Multibody model of a suspension system

This paper studies the solid model of a suspension system that was constructed and imported into multibody dynamic simulation software—MSC.ADAMS in Parasolid format. Geometric relations and force constraints were added to the model. The model, which was composed of torsion bars, balance arms, road wheels, force constraints and joint constraints, is shown in Fig. 1.

2.2 Finite element model of the torsion bar

The torsion bar acts as the elastic component in a tracked vehicle suspension system. Elastic distortion deformation generated in the process of twisting can absorb energy, relieve impact and shock, and ensure stability and crew comfort when driving on rough roads with high speed.

The torsion bar is a key part of a suspension system, the fatigue life of which decides the fatigue life of the whole suspension system. Dynamic stress and load distribution in different types of load cases are needed to predict the fatigue life of the torsion bar. In recent years, finite element analysis has been the most convenient means to evaluate dynamic stress and load distribution of different parts. In this study, finite element software NASTRAN was adopted to mesh the torsion bar, and automatic and manual mesh methods were applied together to meet analysis precision of fatigue life. The meshing property is shown in Table 1.

2.3 Flexible-body modeling of the torsion bar

Finite element software NASTRAN can automatically fulfill bidirectional communication with multibody dynamic software ADAMS by a product called ADAMS/Flex. The flexible body could be introduced in an alternative modal flexibility method in ADAMS/Flex.

The discreteness of a flexible component into a finite element model represents the infinite number of degrees of

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Fig. 1 Solid model of suspension system

Table 1 Meshing property and mode number of torsion bar

Mesh type	Mesh number	Node number	Mode number
Tet4	47 091	71 086	24

freedom (DOF) with a very large number of finite elements or DOF. The linear deformations of the nodes of this finite element mode can be approximated as a linear combination of a smaller number of shape vectors (or mode shapes). The basic premise of modal superposition is that the deformation behavior of a component with a very large number of nodal DOF can be captured with a much smaller number of modal DOF [1].

The first 24 orders of inherent frequencies and mode shapes could be acquired based on normal mode analysis in finite element software—NASTRAN. The first-order mode shapes and second-order mode shapes of the torsion bar are shown in Fig. 2.

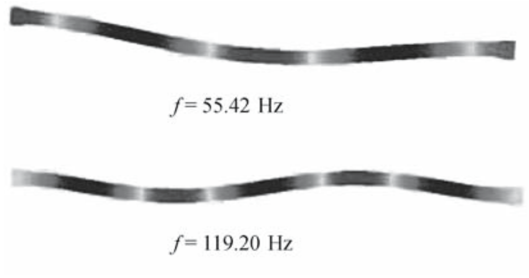

Fig. 2 The 1, 2 order mode for torsion bar

2.4 Rigid/flexible components coupled with modeling of tracked vehicle suspension system

The whole tracked vehicle model was established based on the tracked vehicle's special module ADAMS/ATV, which was composed of hull, two track systems on both sides and the pavement. The track system was composed of idler wheel, sprocket wheel, six road wheels, three support wheels and 98 blocks of track belts. The time history of dynamic displacements and loads on road wheels' spindle in the vertical direction of different types of load cases can be attained through dynamical analyses of the tracked vehicle [2].

Vertical loads on road wheels in whole vehicle emulation were imported to the rigid/flexible body suspension system. Stress distribution of the flexible torsion bar under dynamic loads can be acquired by emulating suspension modeling in ADAMS/View environment. The stress distribution of the torsion bar is shown in Fig. 3.

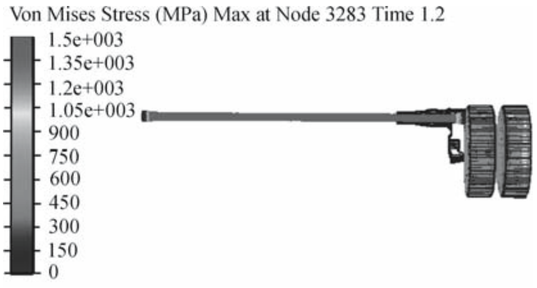

Fig. 3 Stress distributions of torsion bar

3 Fatigue life prediction of a suspension system

3.1 Flowchart of fatigue life prediction

After constructing the whole tracked vehicle parametric model by importing many types of road conditions, the responses of force and displacement exerted on the torsion bar can be obtained by kinematical and dynamical emulation of the whole vehicle. The displacement response was imported to the rigid/flexible suspension system for simulation, and node stresses were imported to FE-Fatigue software through ADAMS/Durability. Finally, fatigue life of torsion can be predicted through the combination of rain flow counting of dynamic load time histories and material *S-N* property of the torsion bar. The flowchart of fatigue life prediction is shown in Fig. 4.

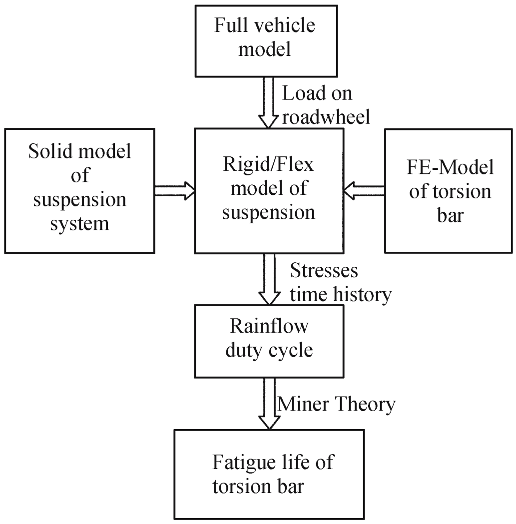

Fig. 4 Flow-chart for fatigue life prediction

3.2 Material property of the torsion bar

The torsion bar was subjected to single-direction alternating shear stress under single-direction twist fatigue loads. Usually the alternating shear stress S was less than the yield stress of the torsion bar, and the bar would not yield visible plastic deformation, but fatigue failure. It was called high cycle fatigue [3].

In the case of high cycle fatigue, the stress-life curve of the material can be described as two straight lines in a log–log coordinate system.

The equation of the first straight line is

$$\log(S) = \log(S1) + b_1 \log(N) \tag{1}$$

The equation of the second straight line is

$$\log(S) = \log(S2) + b_2 \log(N) \tag{2}$$

where S is the stress of maximal-experiment fatigue; $S1$ and $S2$ the intercepts of each curve, b_1 and b_2 the slopes of each curve, N cycle times.

Important influential factors such as effective stress concentration coefficient K_τ, part size coefficient ξ_τ, and part surface status coefficient β should be taken into account when predicting fatigue life of the torsion bar [4]. Effective stress concentration coefficient is related to the configurations of parts, because the transitional zone of the torsion bar is so smooth that K_τ can be set to 1. According to the diameter of the torsion bar and the engineering handbook, ξ_τ can be set to 0.76. Taking into account the heat treatment, surface strengthening, and pre-twist treatment, part surface status coefficient β can be set to 1.05.

The stress-life curve for the torsion bar is shown in Fig. 5.

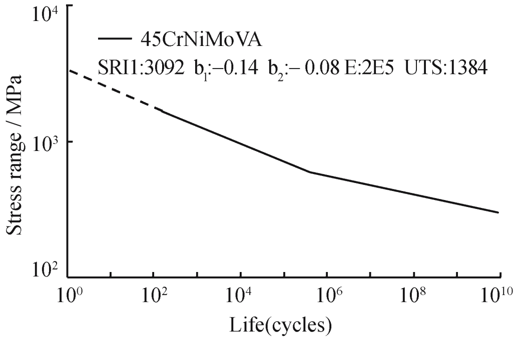

Fig. 5 Stress-life curve of torsion bar

3.3 Average stress correction and fatigue damage cumulative theory

When the torsion bar is subjected to unsymmetrical circular stress, the stress-life curve should be amended. Two types of average stress correction methods were introduced: the Goodman average stress correction theory and the Gerber average stress correction theory. The former was regarded as linear correction model and the latter was called parabolic model.

Miner theory was adopted in this paper to cumulate the damage of each cycle of stress level. The fatigue cumulative theory is supposed to be a linear formula. When the values of fatigue damage added up to a certain value, damage occurred and the torsion bar was destroyed. The basic premise of modal superposition is that if the damage value of n_i times of stress cycle in stress level S_i can be denoted as $D_i = n_i/N_i$, then the total damage value of n_i times of stress cycle in k scales of stress level S_i can be denoted as

$$D = \sum_i^k D_i = \sum n_i / N_i \quad (i = 1, 2, \ldots, k) \tag{3}$$

then the criterion of damage is

$$D = \sum n_i / N_i = 1 \tag{4}$$

where n_i is the times of cycles in S_i stress level; N_i damage life in S_i stress level which is based on $S-N$ curve.

4 Results

Two types of average stress correction means—Goodman and Gerber—at different stress scales can be used to calculate fatigue life of the torsion bar. The calculated fatigue life was compared with that of standard sample fatigue test under symmetrical circular stress levels. The contrasting results are shown in Table 2.

Table 2 Fatigue life contrasts of test and calculation

Stress level /MPa	Times of fatigue test	Goodman stress correction	Gerber stress correction
438.9	1.00×10^6	7.739×10^5	8.184×10^8
500	3.34×10^5	7.156×10^4	1.400×10^8
570	1.40×10^5	6.235×10^4	$1.438\,2 \times 10^7$
664	5.25×10^4	—	$7.911\,1 \times 10^5$
770	2.04×10^4	—	$1.308\,7 \times 10^5$

It can be seen from Table 2 that the results of calculation based on Goodman correction means are less than those of the test while the calculated results based on Gerber correction means are greater than those of the test. The contrasting results make it clear that linear correction means was conservative while Gerber correction means was dangerous. It can also be seen that results based on Goodman correction were much closer to test results at low stress level but on the contrary at high stress level.

5 Conclusions

A new method was brought forward for predicting fatigue life of the torsion bar of a tracked vehicle suspension system. This paper concentrates on the construction of a rigid/flexible model and on fatigue life prediction.

1) A technology for predicting fatigue life based on virtual prototype technique is presented. A theoretical basis for predicting fatigue life of components at an early stage of the design process and design scheme optimization is furnished.

2) The consistency of calculation results with test results via comparison of results proves that the way of modeling is correct and the simulation result is feasible.

3) The means fits mainly for early stage of design and development of mechanical components. The accuracy of the means should be studied in a further step.

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