Fatigue Analysis of Suspension Control Arm Based on Road Spectrum

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Abstract. Aiming at precisely predicting fatigue life for suspension control arm, a fatigue life analysis method is presented. First of all, 2D road spectrum is structured using Sayers. Then, a rigid-flexible coupling multi-body model is built for vehicle dynamics simulation based on ADAMS software. Automobile test is simulated and the time-load histories of each connecting point of the suspension control arm are obtained. By means of the rain flow counting method, fatigue analysis load spectrums are obtained. Finally, the fatigue life of the control arm is analyzed. The result of fatigue life analysis shows that the control arm is designed to meet the requirements of durability.

1. Introduction
Suspension system is an important part of automobile, whose performance is an important factor which affects the ride comfort, handling stability and speed of the vehicle. McPherson suspension has a simple structure and occupies a small space, so it has been widely used in the car. The control arm is an important part of the McPherson suspension, whose fatigue life has a great influence on the performance of the vehicle. At present, the fatigue life of the control arm has been studied extensively. The load spectrum of the control arm is obtained through road test and bench test [1-2]. The fatigue life of the control arm is analyzed by finite element method and multi-body dynamic analysis method. First, based on ISO/TC108/SC2N67, GB7031-86 and Sayers empirical model, two dimensional road spectral curves are constructed by applying Sayers theory. Then, the rigid flexible coupling multi-body dynamics simulation model is established in Adams. The motion of the vehicle in the road spectrum is simulated, and the time load history of each connection point of the suspension control arm is obtained. The load spectrum of fatigue analysis is obtained by rain flow counting method. Finally, the fatigue life of the control arm is analyzed.

2. Basic Theory
2.1. Power Spectrum Density of Road Surface
The expression of road power spectral density is recommended by ISO/TC108/SC2N67 and GB7031-86. As follows:
\[ G_q(n) = G_q(n_0)\left(\frac{n}{n_0}\right)^{-w} \]  

(1)

Where \( n \) is spatial frequency (m\(^{-1}\)); \( n_0 \) is reference spatial frequency, \( n_0 = 0.1 \) m\(^{-1}\); \( G_q(n) \) is power spectrum density of spatial frequency; \( G_q(n_0) \) is road roughness coefficient (m\(^3\)). According to the above two documents road roughness grading standards, at different levels, \( G_q(n_0) \) have different values; \( W \) is frequency index, \( W=2 \). \[3\]

Taking into account the speed, the spatial frequency power spectral density \( G_q(n) \) can be converted to the time frequency power spectral density \( G_q(f) \).

\[ G_q(f) = G_q(n_0)n_0^2 \frac{H}{f^2} \]  

(2)

2.2. Road Spectrum in Adams/Car

In Adams/Car, Sayers empirical model shows that there is a relationship between spatial power spectral density and spatial frequency of road profile:

\[ G_s(n) = G_s + \frac{G_a}{(2\pi)^2} + \frac{G_v}{(2\pi)^2} \]  

(3)

Where, \( n \) is spatial frequency, \( G_s \) is the amplitude of white noise of spatial power spectral density. \( G_v \) is the amplitude of white noise of velocity power spectrum density. \( G_a \) is the amplitude of white noise of acceleration power spectrum density.

The mean value of each white noise is 0, the standard deviation is

\[ \sigma = \sqrt{G/2\Delta} \]  

(4)

where \( G \) is \( G_s \), \( G_v \) or \( G_a \);

\( \Delta \) is sampling interval. \[4\]

Road of automobile reliability test include Smooth asphalt pavement, asphalt pavement, Rough asphalt pavement, Smooth cement pavement, cement pavement, Rough cement pavement and so on. Parameters of these road surfaces are shown in Table 1.

| Table 1. Parameters of sayers model |
|-----------------------------------|
| Type of road surface             | Ge   | Gs | Ga |
| Smooth asphalt pavement           | 0 6  | 0  |
| asphalt pavement                  | 0 12 | 0 17|
| Rough asphalt pavement            | 0.003 20 | 0.2 |
| Smooth cement pavement            | 0 1  | 0  |
| cement pavement                   | 0.1 20 | 0.25|
| Rough cement pavement             | 0.1 35 | 0.3 |

Based on Sayers methods, the model of 2D road roughness is built in Adams/Car. The result is shown in Figure 1.

![Figure 1. 2D road roughness](image_url)
3. Multi-body Dynamics Simulation

3.1. Vehicle Road Coupling Model
The front suspension of the vehicle is Macpherson suspension, and the rear suspension is a multi-link suspension. In order to get high precision stress of Macpherson suspension control arm, Macpherson suspension rigid flexible coupling dynamic model is built by finite element method and multi-body dynamics method, in which the control arm is as flexible body. The control arm of the Macpherson suspension is connected to the steering knuckle by a ball joint and is connected to the body by front and rear rubber bushing. According to the coordinates of suspension hard points, a rigid flexible coupling Macpherson suspension model is built based on Adams. As shown in Figure 2.

![Figure 2. Macpherson front suspension model](image)

Other subsystems, including rear suspension, wheel, steering system, brake, power system, body, etc., are modeled separately and finally these systems are assembled. Simulate the movement of vehicles on the road on the four column test stand in Adams, and the simulate model is shown in Figure 3.

![Figure 3. Simulate model](image)

3.2. Multi-body Dynamics Simulation
The result is that the load spectrum of each connection point of the left control arm is obtained. The load spectrums of left control arm rear bushing are shown in Figure 4.

![Figure 4. Load spectrum](image)
4. Control Arm Fatigue Analysis

4.1. The Finite Element Model of the Control Arm

The CAD 3D model of the Macpherson suspension control arm is imported into the CAE software. At the same time, the control arm model geometry clean and proper simplification is carried out. Then, the control arm is meshed with tetrahedron elements as shown in Figure 5. The material of the control arm is 40cr, whose parameters are shown in Table 2. S-N curve of fatigue analysis can be obtained by Yield strength and Ultimate strength.

According to the traditional method, the static analysis of the control arm is carried out, the front and back bushes of the control arms are fully restrained to prevent rotation of the control arm. This is not in conformity with the actual movement of control arm, and causes the control arm stress is greater than the actual stress. The static analysis and fatigue analysis of the control arm are carried out by using the inertia release.

| material | Elastic modulus | Poisson’s ratio | Density | Yield strength | Ultimate strength |
|----------|-----------------|-----------------|---------|----------------|------------------|
| 40cr     | 2.06E5MPa       | 0.3             | 7.82E-9 t/mm3 | 780MPa         | 910MPa           |

Figure 4. Load spectrums of left control arm rear bushing

Figure 5. FEA model of control arm

Table 2. Physical property
4.2. Control Arm Fatigue Analysis
According to the results of the dynamic analysis, the load time history of each connection point of the control arm is obtained. These load time histories are simplified as a series of full or half cycles of different amplitudes, which is called the counting method. Rain flow counting method is the most widely used in the study of fatigue.
For the same stress amplitude, the higher the average stress, the shorter the fatigue life. Therefore, the mean stress must be corrected in fatigue analysis. Mean stress correction include Goodman and Gerber. Here, GERBER is used. Give the material S-N fatigue property, specify various parameters, and get the cumulative damage coefficient directly.
The fatigue life of the control arm is shown in Figure 6.

The results show that the minimum fatigue life of control arm is 41110 load cycle. The life of the control arm is 17 years, according to a vehicle running 8 hours a day and 300 days a year. In general, the service life of a vehicle is 15 years, so the control arm is designed to meet the requirements of durability.

5. Conclusion
(1) According to Sayers model, 2D road spectrum is structured. Then the road is structured in Adams, which is used as road model in the vehicle road coupling multi-body dynamic analysis.
(2) The vehicle dynamics model of rigid flexible coupling is constructed. The load time history of the connecting point of the control arm is obtained;
(3) The fatigue life of the control arm was predicted by the method of CAE fatigue analysis.
(4) The fatigue analysis process provides a reference for the fatigue analysis of other automobile parts.

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