Application of Fatigue Simulation Analysis Based on CDTire

YanTang1*, BuXiaobing1, GaoFengling1, YuBayi2, GengDongliang1, WuYuan1.
1.Vehicle crash testing and research department, CATARC Automotive Test Center (Tianjin) Co.,Ltd,Tianjin, China
2.Factory inspection department, China Quality Certification Center,Beijing, China
* Corresponding author: yantang@catarc.ac.cn

Abstract: In order to verify the fatigue-durability performance of chassis components, the simulation and analysis process is established in this paper based on CDTire model. High-accuracy tire model is constructed by CDTire modeling software according to the tire test data. The multi-body dynamics simulation is completed by combining the CDTire model with the vehicle model. The load of chassis components is extracted and imported into fatigue software. The swing arm is taken as an example for calculation. This analysis process can guide the analysis of chassis components and shorten the development cycle.

1. HEADING
In the traditional fatigue durability calculation process of automobile chassis components, it is necessary to collect the load data from vehicle test as input, and then use fatigue simulation software to calculate the fatigue life. This calculation process is limited by the production time of the test vehicle, and the fatigue calculation is relatively backward, which restricts the optimization space of components [1].

To deal with this problem, it is crucial to put the fatigue durability analysis in the front. Through the virtual proving ground technology, the multi-body dynamics analysis can be conducted by driving the vehicle model on the high reliability digital road and the virtual load spectrum will be extracted as the input for subsequent fatigue life calculation [2, 3]. The applicability and accuracy of tire model is the key to establish virtual proving ground. CDTire model is one of the physical tire models with mature application. Due to the consideration of tire section information, CDTire model has higher accuracy. The feature of wide coverage frequency enables it to meet the collaborative development of vehicle performance such as handling stability, durability and NVH, which can save costs for enterprises [4]. At present, CDTire model is widely used in foreign countries. Owing to the high requirements on tire testing and modeling, the domestic research on CDTire model is not enough, and the application of CDTire model in virtual proving ground simulation is relatively less.

In this paper, based on the multi-body dynamics, combined with CDTire model and high-accuracy 3D digital road, the virtual proving ground fatigue durability analysis process of automotive chassis components is realized.

2. CDTIIR MODEL
In addition to testing the basic parameters of tire such as mass and geometric size, CDTire model also needs to test its static, steady and dynamic conditions. In the process of tire modeling software, the tire simulation curve is compared with the test data, and the comparison error can meet the engineering
application by adjusting the parameter settings in the software. Finally, the tire file is generated. The application process of tire is shown in Figure 1.

This paper refers to 215/50 R17 tire selected for a certain vehicle. The tire mass is 11.6 kg, the standard tire pressure is 2.3 bar, and the standard load is 700 kg.

In the tire modeling software, CDTire model parameters include more than 100 parameters, such as mass, stiffness of each layer, damping, preload and its distribution weight along the geometric section. The comparison diagram of simulation curve and test curve of tire under different working conditions is as follows:
According to the theory of hierarchical structure error calculation, the comparison error between CDTire simulation curve and test curve is calculated. The total error of tire identification ($\text{Totalerr}$) is the weighted sum of all test conditions error, the calculation is as follows:

$$\text{Totalerr} = \sum \text{exp} \cdot \text{exp}$$

In the formula: $\text{exp}$ is the group error value of each identification work condition, $\text{exp}$ is the corresponding error weight factor. The calculated error of the CDTire model is 0.2147, which meets the engineering requirements.

3. VEHICLE MODELING

In this paper, the data parameters of a certain brand model are used as input to create the suspension system, steering system, power system, body system, tire system and so on. The important information in the whole vehicle model creation process includes: hard point parameters, mass, inertia, bushing performance, shock absorber and spring performance, etc[5].

In the process of multi-body dynamic analysis, due to the elastic deformation of parts, which affects the simulation accuracy of kinematic characteristics of the whole vehicle system, the front subframe, the front swing arm, the rear subframe and the rear stabilizer bar are discretized into flexible bodies. There are three methods to create flexible body files of multi-body dynamics: the first method is to create flexible body files directly through software multi-body software; the second method is to discrete beam function, which discretizes the bar components into many small rigid components, and the rigid components are connected by flexible elements to realize flexibility; the third
method is to divide the components into small units by using finite element software to generate MNF files.

In this paper, the third method is adopted. Firstly, the components are meshed to define the materials and properties of components. Then, rbe2 element is created by taking the hard point position of components as the main node and the nodes within the installation position or contact surface as the slave nodes. The flexible file is imported into the multi-body dynamics software. The communicator is established at the joint of rigid body and flexible body, and the corresponding output command is established at the load extraction position, which is convenient for the load output of multi-body dynamics simulation.

The parameters in the multi-body dynamics software model library were modified according to the vehicle parameter information, and the 215/50 R17 CDTire model was used for tire. Because the high frequency vibration of the engine and the shape of the body have little influence on the extraction of multi-body dynamic load, in order to simplify the model, the engine and body are replaced by mass points, and the whole vehicle model is as shown in the figure.

![Figure 6 Multi body dynamic model of vehicle](image)

The real-time motion state of the whole vehicle can be obtained by solving the differential equations of equation (2) - equation (4):

\[
\frac{m du_x}{dt} = (F_{x1} + F_{x2} - F_{y1} - F_{y2}) \cos \delta - (F_{x1} + F_{x2}) \sin \delta + F_{x3} + F_{x4} + m \omega u_y
\]  
\[ (2) \]

\[
\frac{m du_y}{dt} = (F_{y1} + F_{y2}) \sin \delta - (F_{y1} + F_{y2}) \cos \delta + F_{y3} + F_{y4} + m \omega u_x
\]  
\[ (3) \]

\[
\frac{dw}{dt} = \frac{1}{I_{zz}} \left[a(F_{x1} + F_{x2}) \sin \delta + a(F_{y1} + F_{y2}) \cos \delta - b(F_{y3} + F_{y4}) - \frac{L}{2} \right] (F_{x1} - F_{x2}) \cos \delta + \frac{L}{2} \left(F_{y1} - F_{y2}\right) \sin \delta - \frac{L}{2} \left(F_{x3} - F_{x4}\right)
\]  
\[ (4) \]

L is the track width (set the front and rear tracks are equal); \( F_{xi} \) is the longitudinal force of each wheel; \( F_{yi} \) is the lateral force of each wheel; \( u_x \) is the longitudinal speed of the vehicle; \( u_y \) is the lateral speed of the vehicle; \( \omega \) is the yaw rate of the vehicle; \( \delta \) is the front wheel angle; \( \alpha \) is the distance from the front axle to the center of mass; \( \beta \) is the distance from the rear axle to the center of mass; \( m \) is the total mass of the vehicle; \( I_{zz} \) is the moment of inertia of the body around the z-axis.
4. Fatigue Calculation of Swing Arm

After building the vehicle model and identifying the CDTire model, the model is imported into the Adams Car software, and the setup solver is set to GSTIFF, because of its better stability. The minimum step size of the solver is 0.001s.

According to the fatigue and durability simulation specification of the test site, the vehicle model simulation conditions are set, which including simulation speed\(^6\), road information, simulation time, sampling frequency. The setting of working conditions is shown in Table 1

| Number | Test pavement name      | Speed (km/h) |
|--------|-------------------------|--------------|
| 1      | Cobble Road             | 25           |
| 2      | Vibration Road          | 40           |
| 3      | Twisted Road            | 10           |
| 4      | Potholes Road           | 55           |
| 5      | Damaged Road            | 70           |
| 6      | Stone Road              | 60           |
| 7      | Bumpy road              | 15           |
| 8      | Ditch Road              | 15           |
| 9      | Curb                    | 55           |
| 10     | Railway Track           | 30           |
| 11     | Roadblocks              | 20           |

The load of each component's hard point is extracted from the results of multi-body dynamics simulation, and the load information of each hard point is composed of six components. According to miner's linear fatigue accumulation theory, the average damage value of parts under constant cyclic load is \( \frac{1}{N} \). \( N \) is the total number of load cycles, and the total damage of parts after \( n \) cycles is \( C = \frac{n}{N} \). When the component is subjected to irregular load, the total damage is the sum of the single load damage, and the formula is as follows:

\[
D = \sum_{i=1}^{l} \frac{n_i}{N_i} \quad (5)
\]

\( l \) represent the number of times the parts are subjected to different loads, \( n_i \) is the number of times of damage under the i-th load, \( N_i \) represents the total number of damage that can be sustained under the i-th load, and \( D \) represents the total damage value of the components. When \( D \geq 1 \), it is considered that the structural failure of the components is caused by fatigue damage.

In order to avoid stress concentration when the front swing arm generates flexible body file, quadrilateral element is used for welding element and its connecting element\(^7\). The average unit size is 4mm, and the number of cells is 10292.
Based on the principle of inertia release, the unit force and torque in XYZ direction are applied to the three mounting points of the swing arm, and the stress state under the action of unit force and unit torque is obtained. The stress calculation file of the front swing arm and the extracted 18 channel loads spectrum are imported into the fatigue calculation software Ncode, and then calculated according to miner fatigue linear superposition theory.

The damage nephogram of the front swing arm is shown in the figure, and the maximum damage value is 0.1826, which is far less than 1, and the risk of structural failure is low. It can be judged that the fatigue life of the front swing arm meets the design requirements.

5. SUMMARY
In this paper, the CDTire model is established based on the test data. Combined with the multi-body dynamic model, the complete fatigue durability simulation process of chassis components is established, and the fatigue analysis of the front swing arm is completed. The effective implementation of the technical route can realize the analysis of fatigue durability analysis, shorten the research and development cycle, and reduce the cost of enterprise research and development.

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