Research on tire model parameter identification strategy based on CDTire/3D

F L Gao¹,*, N Zhan¹, X B Bu¹, X R Li¹ and Y Wu¹
¹CAE Performance Division, Vehicle Crash Testing and Research Department, CATARC Automotive Test Center (Tianjin) Co., Ltd, Tianjin, 300300, China
*gaofengling@catarc.ac.cn

Abstract. High accuracy tire modeling is essential to study the automotive fatigue-durability, handling-stability, and NVH performance in the virtual proving ground. Compared with other tire models, CDTire/3D can be directly used in multi-body dynamics simulation, and its linearized version can be adopted in road noise analysis. In consideration of its high generality for cost saving, CDTire/3D has an extensive engineering application prospective in the automotive industry. It is the critical technique to accomplish high-efficiency and high-precision CDTire/3D modeling by investigating the mechanical mechanism of tire and the influence of parameters on all test conditions, based on which a parameter identification strategy is conducted in this paper. The effectiveness of the strategy is verified by a tire modeling case.

1. Introduction
Tire model is the crucial input of automotive virtual proving ground (VPG) technique, which directly influences the simulation accuracy and engineering practicability. According to the different modeling methods, tire models can be divided into empirical formula model, finite element model and physical model [1]. The empirical tire model (such as Magic formula model and PAC model) has the highest simulation efficiency and sufficient accuracy in vehicle handling-stability analysis. However, it is not appropriate in fatigue-durability analysis and road noise analysis due to its simulation frequency limitation [2-4]. Modal tire models based on the FE method have been practically used in road noise analysis, but their modeling processes are complex. In the meanwhile, owing to the incompletely accurate definition of each layer of tire, the entire simulation accuracy is difficult to control [5, 6]. The physical model is to substitute the tire structure with physical description according to mechanical characteristics of tires. Ftire and CDTire/3D are the typical models constructed by flexible rings. At present, Ftire has been adopted in suspension K&C analysis and vehicle fatigue-durability analysis [7, 8]. The application of Ftire in NVH is rarely reported. CDTire/3D was developed later, which considered tire geometry information to increase the overall modeling accuracy. In addition, the influence of the cavity is taken into account as well, whereby high frequency simulation accuracy (over 180 Hz) is improved remarkably. The direct CDTire/3D model has been applied in 3D VPG simulation (handling-stability analysis and fatigue-durability analysis), while the linearized model can be utilized for 2D VPG simulation (NVH simulation) [9]. In view of the outstanding generality of CDTire/3D, it has a broad engineering application prospect.

The CDTire/3D modeling process is to identify tire parameters by matching the measurement curves and simulation curves. Dr. Gallrein et al studied the parameter identification for LMS CDTire, which is an older version of CDTire/3D model more than 10 years ago [10]. However, there are more
than 100 parameters in current CDTire/3D, and most of which have different effects on all test conditions. This makes CDTire/3D modeling much more complex. Consequently, an effective parameter identification strategy for CDTire/3D is necessary to be investigated for improving both of the modeling accuracy and efficiency, which will be conducted in this paper.

2. Tire modeling by CDTire/3D
CDTire/3D is a flexible rings based tire model which contains not only the physical information but also the geometry information. Based on a series of tests on tires, CDTire/3D model can be established after parameter identification (PI). The flowchart of CDTire/3D modeling is shown in Figure 1. Note that the CDT50 file in the final delivery is namely the CDTire/3D model.

3. CDTire/3D model test conditions and parameters to be identified
Standard CDTire/3D model test conditions mainly include static measurements (vertical stiffness, lateral stiffness, longitudinal stiffness, torsional stiffness and footprint), steady state measurements (pure longitudinal slip and pure lateral slip) and dynamic measurements (45° and 90° cleat runs, dynamic cornering stiffness and dynamic vertical stiffness). The sinusoidal driver as described in equation (1) is adopted here in steady state test simulation.

\[
\kappa(t) = \kappa_{\text{max}} \sin\left(\frac{2\pi}{T_{\text{sim}}} t\right)
\]

In order to ensure the tire model has enough simulation accuracy in a wide range of applications, each type of test is usually conducted several groups according to different type and position of cleat, inflation pressure, preload, velocity, and camber angle.

There are more than 100 parameters in CDTire/3D model coupling together to decide the comprehensive performance of tire. It can be roughly divided into 5 categories, namely, static parameters (carcass layer stiffness, bandage layer stiffness…and their distribution along the tire section), slip related parameters (tread stiffness, friction coefficient and etc.), dynamic parameters (tire mass distribution, damp of each layer and etc.), calculating parameters, fundamental constants (no need for identification, such as the sound velocity) and the switch options (such as the acoustic cavity model).

4. CDTire/3D parameter identification strategy
Based on the research of Dr. Gallrein et al [10], considering the contribution of each parameter to different test conditions derived both from tire modeling mechanism and practical modeling experience, the CDTire/3D parameter identification strategy is present as illustrated in Figure 2.
As shown in Figure 2, due to tire longitudinal stiffness influenced greatly by the rubber mechanical properties, this part of work is arranged in the first step of parameter identification. In the second step, the test conditions of vertical stiffness and lateral stiffness are mainly benchmarked to search the appropriate carcass layer stiffness and bandage layer stiffness. Inflated contour needs to be considered in this step if the vertical and lateral stiffness tests are difficult to match. Compared with identifying parameters, Footprint condition is more appropriate for verification of identification effect. Note that the operation of this step will affect the results of the previous step to a certain extent. It should return to the first step to adjust related parameters until satisfied. In the third step, it is focused on the friction coefficient and the stiffness of the belt layer and the tread. Increasing the simulation time will effectively reduce the oscillation of the slip curve thus to reduce the error. In the last step of cleat run condition, the difference between simulation and test curves is compared from frequency and amplitude in time domain. Based on equation (2), mass has a direct impact on frequency in a vibration system.

$$\frac{1}{2\pi}\sqrt{\frac{K}{m}}$$

Therefore, the mass distribution on the tire should be taken into consideration in frequency adjustment. To change the amplitude of simulation curve, damp of each layer are required to be identified. From the first step to the last step is an iteration cycle, which practically needs several cycles to obtain the final satisfied result.

5. Tire modeling results and analysis

A CDTire/3D model of tire 245/45R19 is constructed based on the above mentioned parameter identification strategy. Comparisons between test and simulation curves under some working conditions are given in Figure 3, which demonstrates the PI results are reliable. In addition, the total error of simulation and test computed by equation (3) is 0.18, meeting the requirement of CDTire/3D modeling (less than 0.2).

$$\text{error}(f, g) = L_p(f, g) = \frac{\|f - g\|}{\|f\|}$$

with $$\|f\|_p = \left(\sum |f|^p\right)^{\frac{1}{p}}$$

here, $f$ and $g$ respect the response values on test curve and simulation curve, respectively.
Figure 3. Comparisons between test and simulation curves under some working conditions: (a) vertical stiffness, (b) lateral stiffness, (c) longitudinal stiffness, (d) torsional stiffness, (e) longitudinal slip, (f) lateral slip, (g) 90° cleat run, (h) 45° cleat run.
6. Conclusion
High accuracy tire model is the key to develop VPG technique. CDTire/3D model is very popular due to its excellent generality in vehicle fatigue-durability analysis, handling-stability analysis, and NVH analysis (after linearization). In order to ensure the accuracy of CDTire/3D model as well as to improve the modeling efficiency as much as possible, this paper established a parameter identification strategy. The effectiveness of the strategy was verified by an engineering example.

Acknowledgments
This research was financially supported by the research project on common basic technology of CATARC Automotive Test Center (Tianjin) Co., Ltd (NO. TJKY1920010), and CATARC cultivation research project (NO. 19201225).

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