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Simulation of biaxial wheel test and fatigue life estimation considering the influence of tire and wheel camber

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ABSTRACT

The traditional fatigue test of wheel comprising the radial and cornering fatigue tests cannot simulate the real stress state of wheel well. Biaxial wheel fatigue test combining these two traditional tests has become an internationally recognized method that can reproduce the real loading condition of the wheel in service. Since the test is time- and cost-consuming, developing the simulation method on biaxial wheel fatigue test is urgently necessary. In this paper, a new method is proposed to evaluate the fatigue life of commercial vehicle wheel, in which the finite element model of biaxial wheel fatigue test rig is established based on the standards of EUWA ES 3.23 and SAE J2562, and the simulation of biaxial wheel test and fatigue life estimation considering the effects of tire and wheel camber is performed by applying the whole load spectrum specified in ES 3.23 to the wheel. The radial and cornering fatigue tests are also simulated, and the results are compared with ones of the biaxial fatigue test. The research shows that the proposed method provides an efficient tool for predicting the fatigue life of the wheel in the biaxial fatigue test.

1. Introduction

As one of the most important safety components in vehicle, wheel plays a significant role on driving safety, handing stability and riding comfort. Since the working conditions are random and complex, it is essential to guarantee the required durability of wheel during service life. Currently, the fatigue life of wheel is tested by radial and cornering fatigue tests in the lab. Because of the independence of these two tests, the real stress state of wheel cannot be well reproduced. Biaxial wheel fatigue test evaluates the durability of wheel under combined variable radial and lateral loads, which is demanded by many Original Equipment Manufacturers (OEMs) especially in European market in recent years. Moreover, the complexity of tire-wheel assembly cyclic loading distribution and wheel road conditions are considered synthetically in the test. Therefore, the fatigue safety of the wheel can be tested and evaluated comprehensively by the biaxial wheel fatigue test [1–3]. Since the test is time- and cost-consuming, the development of simulation method on biaxial wheel fatigue test is necessary and meaningful.

The two standards: ES 3.23 issued by Association of European Wheel Manufacturers [4] and SAE J2562 issued by Society of Automotive Engineers [5] promote the advancement of the wheel industry and show the great significance of biaxial wheel fatigue test in development cycle of “Design–Evaluate–Improve”. Studies on cornering fatigue test [6,7] and radial fatigue test [8–10] have been conducted extensively, mainly focusing on the life evaluation of wheel under a certain uniaxial load, which cannot reflect the real working life of wheel directly. Few researches were made to investigate the Virtual Experimental Method (VEM) of wheel biaxial fatigue test. Wang [11] applied finite element analysis to calculate the damage of a steel wheel in the biaxial fatigue test, but the effects of wheel camber and the contact property between wheel and driving drum of test bench were not considered. Firat et al. [12–15] had performed a series of research on multi-axial fatigue damage and proposed a prediction method of wheel fatigue life based on local strain-life applied to estimate the fatigue life of an aluminum wheel. However, their work only focused on fatigue damage of wheel under one certain load condition, without considering the load sequence prescribed in the standard ES 3.23. To the best of authors' knowledge, the research on practical and exact VEM of wheel biaxial fatigue test is limited.

To bridge these gaps, a simulation method is proposed for evaluation of biaxial fatigue life of commercial vehicle wheel based on EUWA standard ES 3.23 in this paper. The proposed technique involves the effects of tire model and wheel camber. The camber angles of wheel under biaxial loads are firstly calculated through camber analysis, which is addressed in the next section. In Section 3,

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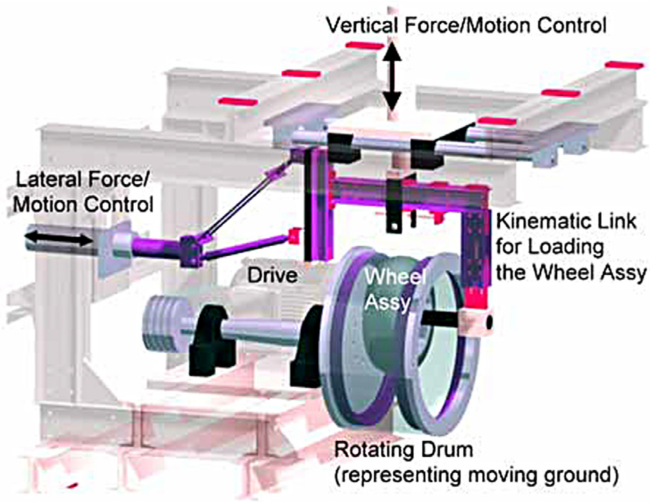

Fig. 1. Biaxial wheel fatigue test machine [16].

the strength analysis of the wheel under biaxial loads is conducted. The fatigue life of the wheel is evaluated based on the stress life (S-N) method in Section 4. The conclusions can be found in Section 5. The proposed simulation method provides an efficient tool for predicting the fatigue life of the wheel in the biaxial fatigue test.

2. Camber status analysis of wheel under biaxial loads

The biaxial wheel test machine for commercial vehicle is illustrated in Fig. 1 [16]. It consists of the wheel assembly, driving drum, radial/lateral load actuators, kinematic links, main frame, servo motor and so on. The drum is driven by the servo motor, and two inside curbs of the drum are designed to contact with the tire sidewall for reaction of lateral load. The wheel assembly is installed on a dummy vehicle axle inside the driving drum and is rotated by the drum while loaded by the actuators through kinematic links. The LBF load program (Eurocycle) [3,4,16], including 98 loading events describing radial load, lateral load and wheel revolutions, running in a computer is repeated until test termination as specified in the standard ES 3.23.

2.1. Camber analysis of the wheel under biaxial loads

The camber of the wheel assembly occurs when the radial and lateral loads are simultaneously applied in the test. The direction of the wheel camber depends on the direction of the lateral force as demonstrated in Fig. 2. In the coordinate system of Fig. 2, negative lateral load results in positive wheel camber (denoted as $+\theta$), while positive lateral force leads to negative wheel camber (denoted as $-\theta$). When the wheel camber is positive, the bending moments acting on spoke respectively generated by lateral force and radial force are in the opposite direction. Conversely, the two bending moments are in the same direction when the wheel camber is negative. This indicates that wheel camber has a significant effect on stress magnitude and distribution region on the wheel, which will be further discussed in this paper. Therefore, the strength analysis and fatigue estimation of the wheel under biaxial loads should involve the effect of the wheel camber. However, the previous literatures [11–15] on the simulation of wheel biaxial fatigue test did not consider this factor, which leads to inevitable errors.

The simulation of biaxial wheel test using finite element method can be performed nominally by directly applying the biaxial loads to the wheel. However, because of the occurrence of wheel camber, the simulation involves strong nonlinear problems including large displacement of the wheel, contact nonlinearity between the tire and drum, and tire material nonlinearity which may lead to divergence of the simulation. On the other hand, the load program (Eurocycle) described in standard ES 3.23 only includes the lateral forces and radial forces, but not wheel camber angles generated automatically during the test and determined by the lateral force, radial force, wheel structure, loading structure and tire properties. To guarantee the efficiency and precision of the simulation, the analysis will be divided into two stages. The first stage is to calculate the camber angle for each load condition through camber analysis of the wheel and test system based on the rigid model. Then the strength analysis is implemented based on the finite element model with wheel camber angles obtained in first stage.

2.2. The calculation on camber angles of wheel under biaxial loads

According to EUWA standard ES 3.23, a simplified but full scale three-dimensional model of the biaxial wheel test machine for commercial vehicle is established using the software SolidWorks, which consists of a rotating drum, loading frame, flange, tire and wheel, as

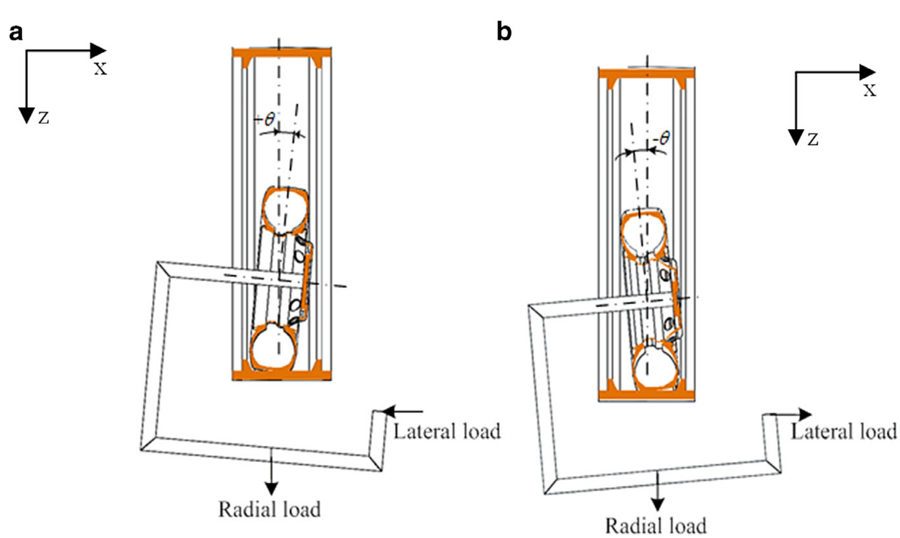

Fig. 2. Wheel camber under biaxial loads: (a) positive wheel camber; (b) negative wheel camber.