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Property Modelling

Prediction of tread pattern block deformation in contact with road

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ABSTRACT

Tire tread patterns re arrangements of grooves, blocks, sipes, and channels, which effects on the performance of the tire, such as braking, turning, noise and side slip properties. For analyzing the performance in static and dynamic conditions, deformation behavior of the tread block was investigated under the on-road condition. A new tread pattern block deformation test device has been developed for measuring the forces and deformation. A modified analytical model of the tread block was developed, which considered the influence of the compression on the deformation under sliding conditions. Finite element models of six different typical tread pattern blocks of TBR tires have been developed by ABAQUS for analyzing the dynamic stiffness and contact pressure. Results indicated that the predicted stiffness of the tread blocks was in good agreement with the experimental data.

1. Introduction

Tires are indispensable components of automotive vehicles. In tire rolling contact, the continuous stiction to sliding transition in the contact area contributes significantly to the maximum achievable force level. As a result of the evolution of the deformation during contact, the rubber is later detached to sliding [1]. Thus, tread friction and deformation are very important criteria for tire design, which is composed of many grooves and blocks in complex pattern for the sake of major tire running performances such as traction, braking, riding comfort and hydroplaning [2]. The service life of the tire is primarily affected by the treads, a careful study of the tread contact problem is of great practical importance in improving tire performance. Also, input by the vehicle driver via the steering wheel turns the tire to create a turn. During this turning process, forces acting on the tire block that are in contact with the road surface provide the necessary energy to change the vehicle's direction. While there are many tire features that contribute to the generation of these forces, tread deformation is one of the most important, as well known to the tire engineers [3].

As we all know, stiffness means the ability to resist deformation. In order to obtain the deformation characteristics of tread blocks, predictive models have been investigated. Ripka developed a new approach for simulating a siped tread block with long and small lamellae. Based on the Euler-Bernoulli beam, the most important limitation of this model was the ratio of the width and the length which cannot excess 1 to 10. For simulating stronger tread blocks, the beam theory of Timoshenko can be applied [4]. They also discussed the dynamics of siped tread blocks in contact with a mechanical model in consideration of the effect of surface texture, sliding velocity, normal contact pressure, temperature, tread block geometry and existence of a lubrication film [5,6]. Wies demonstrated the friction between tread-block elements and road, where snow, ice, water or a third-body layer were present in the tire-road contact area [7–9].

The finite element method (FEM) has become a quite convenient and powerful tool in the mechanical engineering for product design and development. In the tire industry, the development of a new tire line starts at the computer. The determination of the main trends and designs is performed by the means of numerical simulations and comparative evaluations. The most crucial aspect of a tire simulation is the realistic description of the processes in the contact interface between the tire tread and the road surface [10]. Conventionally, tire simulations are performed with axisymmetric models, which are obtained either by neglecting detailed tread

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pattern or by consideration of only circumferential sipes. These models give only a poor representation of the processes in the contact zone. The rapid development of computer facilities and mesh generation technologies now allows for the simulation of detailed tire models, in which the tread blocks are fully included [11]. Ozaki was devoted to the modeling of the tire–surface interaction with the analytical and finite element method [12]. Different from the traditional tire–soil interaction models in which the contact between tires and soils was described by nonlinear springs in the normal direction, the new analytical model added dampers accounting for the soft soil damping effects [13]. The effect of varied loads and air pressure on the tire was investigated by using commercial ABAQUS software [14–17].

In the present paper, we focus on the tread rubber deformation under different pattern geometry, load and velocity. In the first part, we present some basic concepts of the stiffness theory model of tread pattern block based on the Timoshenko beam theory, and a modified analytical model of tread block was developed for analyzing its deformation. In the second part, we develop a new tread pattern block deformation test device. In this context, the effect of pattern geometry, load and velocity on the deformation characteristics was investigated. In addition, the predicted results of the theory model can be verified by the test results. In the last part of the paper, the finite element models of the tread block with different geometric shapes were developed for studying the stiffness characteristics.

2. Mechanical model

Tread blocks generally have complicated geometry containing sipes, draft angles along the sides of the blocks and reentrant angles. There is no single equation that is known to cover all of these possible conditions. In selecting an approach, the boundary conditions of the problem to be solved should be considered. A rolling tire in contact with the road creates a contact region. Within this contact region, the tread blocks are deforming. The actual deformation depends on many factors including speed, load, cornering and torque. Furthermore, deformation may see varying levels of magnitude in different regions of the footprint. Characterizing all of these modes is formidable.

2.1. Equal cross section model

When the deformation of tread block is small and linear, it can be simplified to a cantilever beam (seen in Fig. 1). Here, b, L is the width and the height of the tread block, the distance S by the lateral force F of the road can be given by Eq. (1) [3].

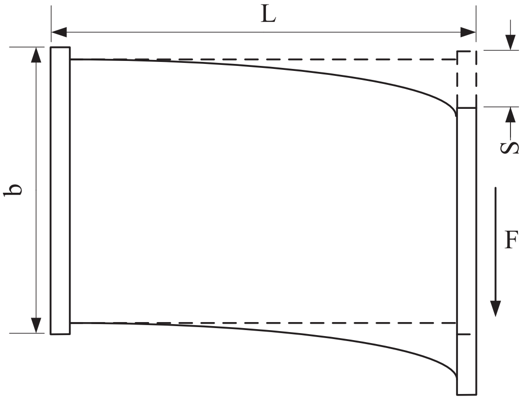

Fig. 1. The model of cantilever beam.

$$S=\frac{FL^3}{12\mathrm{EI}}+\frac{FL}{GA}=\frac{FL}{GA}\left[\frac{L^2}{36r^2}+1\right] \tag{1}$$

where E is the modulus, I is the moment of inertia, G is the shear modulus, A is the cross section area, r is the inertial radius of the cross section relative to the central axis.

The road surface may act as a mechanical lock preventing the tread blocks from slipping relative to the road surface. It is well known that slip occurs particularly at the footprint exit. However, it is assumed that no slips occur in the interior portion of the contact region for calculation of stiffness. It provides a reasonable characterization for the tread block in the interior region of the footprint in Eq. (1). Tread blocks may be compressed and bent so much that the vertical load is transmitted. Due to the compressive stress on the tread rubber, its effect on the stiffness can be considered [18]. The modified Eq. (1) can be shown in Eq. (2).

$$S=S_C\cdot\frac{FL}{G_0A}\left[\frac{L^2}{36r^2}+1\right]=\frac{FL}{GA}\left[\frac{L^2}{36r^2}+1\right] \tag{2}$$

where S_C is the correction coefficient, $S_C=G_0/G$, G_0 is the shear modulus under no compressive strain (N/mm^2), G is the shear modulus under compressive strain (N/mm^2).

As described in the literature [17], $S_C=0.9$, when the compressive strain of tread block is usually small. Hence, the lateral deformation stiffness K of tread block can be calculated by Eq. (3).

$$K=\frac{F}{S} \tag{3}$$

2.2. Variable cross section model

The draft angles of the tread block have an important influence on the wear, noise and wet performance of the tire, so cannot be ignored for detailed modeling of the tread block. The stiffness calculation of the tread block with the draft angle can be equal to the variable cross section beam. The cross-sectional characteristics of the variable cross section beam are variable, so it is difficult to calculate the deformation by use the integral method. Therefore, an equivalent column method is used for calculating the deformation, seen in Fig. 2.

The lateral deformation stiffness K_v of the tread block by the equivalent column method can be calculated by Eq. (4).

$$K_v=S_C\frac{A_{eq}G_0}{L}\left[\frac{36{r_{eq}}^2}{36{r_{eq}}^2+L^2}\right] \tag{4}$$

where A_{eq} is the equivalent area, r_{eq} is the equivalent inertial radius of the cross section relative to the central axis.Here,

$$r_{eq}=\sqrt{I_{eq}/A_{eq}} \tag{5}$$

where I_{eq} is the equivalent moment of inertia.

$$A_{eq}=\frac{12}{\frac{1}{A_0}+\frac{4}{A_1}+\frac{2}{A_2}+\frac{4}{A_3}+\frac{1}{A_4}} \tag{6}$$

where A_0, A_1, A_2, A_3, A_4 is the cross area under different position, seen in Fig. 2.