Features of simulation of the tire under conditions of movement of the car with acceleration

Alexander K. Sokolov, Alexander L. Svistkov, Lyudmila A. Komar,
Vladimir V. Shadrin and Viktor N. Terpugov
aleksandr_sokol@mail.ru

Abstract

The paper reports on a study of the influence of the Mullins softening effect on changes in the stress fields of a rotating car wheel under acceleration and braking conditions. In our opinion, this effect has received little attention in tire industry until recently. We have developed an algorithm to evaluate changes in the stress-strain of the wheel of the acceleration car taking into account the Mullins effect. With the algorithm proposed one can study the softening effect in different points of the tire during the turns of a wheel under acceleration conditions. The results of numerical simulations demonstrate that the softening effect should be taken into account even when developing a simplified model of a car wheel, in which the tire material is considered as isotropic, and the model tire has a simpler geometry than the real tire. It has been found that the deformation of the lateral surface of the tire calculated with the Mullins effect is significantly higher than the deformation obtained in calculations where this effect has been ignored. The degree of softening is evaluated in terms of the Ogden-Roxburgh model.

The purpose of this study is to investigate the influence of the Mullins effect [1-3] on changes in the stress-strain state in the moving wheel in such operating regimes as acceleration and braking. To our knowledge, the Russian tire industry has paid insufficient attention to this effect. It is ignored in many calculations, for instance, the rolling and head-on crash situations are described in [4-5] taking into account the complex structure of a tire, but ignoring the softening effect. Computer modeling of car tire softening is a complex mathematical problem. The material of a tire changes its properties during the first turn of the wheel, and these variations proceed differently at different points of this material. Accordingly, the pattern of strain distribution in the tire also changes. To obtain a stable solution allowing one to consider material softening accumulation in different parts of the tire, we have developed a special algorithm (Fig. 1).

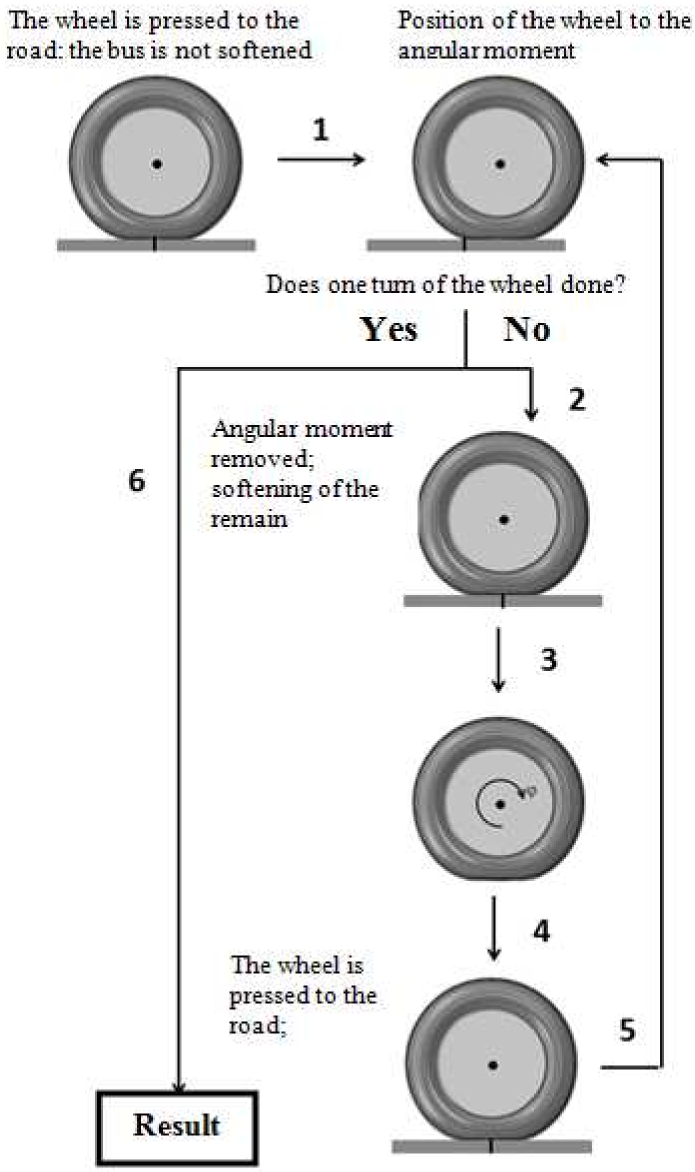


Figure 1: Algorithm for car tire loading

1 - road is shifted by the value l, which gives rise to an angular moment in the tire, the tire material softens.
2 - wheel does not make a rotation, the road turns back to its initial state, the angular moment disappears.
3 - road is removed, the wheel rotates to the angle ϕ;
4 - road is back to normal shape.
5 - if the wheel does not make a full rotation, the road is again shifted by the value l, which gives rise to an angular moment in the tire, the tire material softens;
6 - stress-strain state in the accelerated wheel tire is obtained in the calculation with consideration of the Mullins effect;
In step 3, the wheel turning angle ϕ is found from the $\phi = \frac{2d}{l}$, where d is the external wheel diameter, l is the road shift
This algorithm makes it possible to study the softening effect in different points of the tire during the first turn of a wheel under acceleration conditions.

The motion of the car wheel has been modeled for a 3D case. For the characteristics of the tire model, we have chosen a 1600 kg car, which accelerates from 0 to 100 kilometers per hour in 12 seconds. The value of force acting on the car is equal to 3700 H. A horizontal force of 1850 H is applied to the driving wheel. The tire pressure is assumed to be 0.17 MPa. The road is modeled as a rigid rectangular parallelepiped. The tire has the following geometrical characteristics: external diameter - 760 mm; track height - 180 mm; track width - 260 mm (Fig. 2).

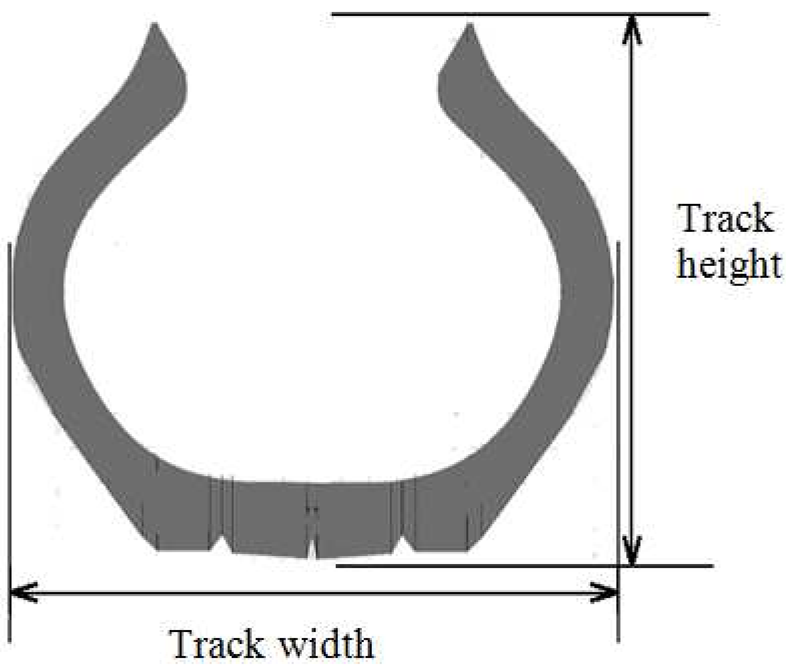
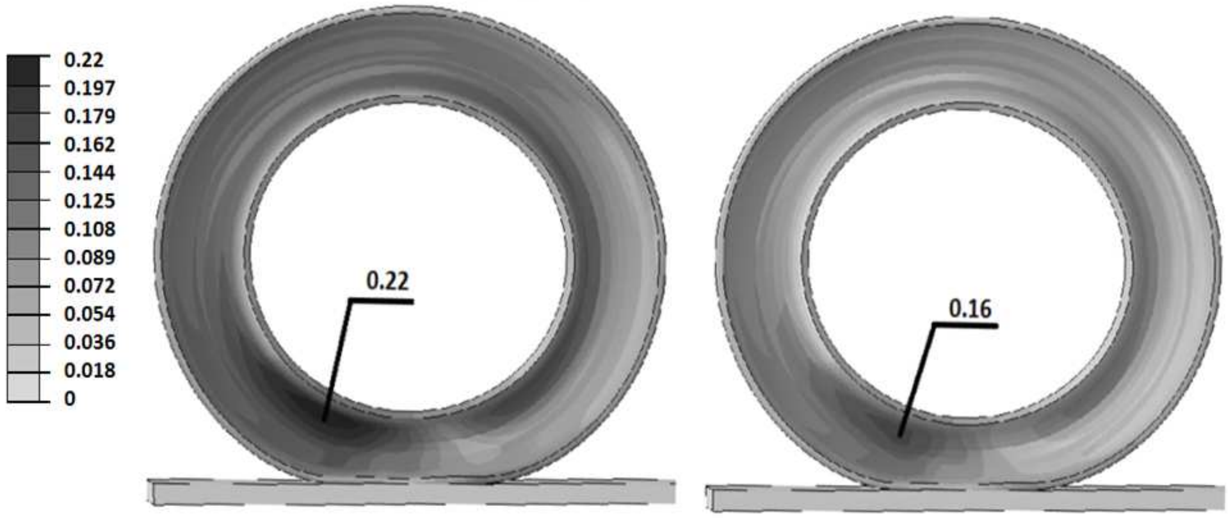


Figure 2: The geometrical characteristics of a car tire

Simulations indicate that the deformation of the lateral surface of the tire calculated with the Mullins effect is significantly higher than the deformation obtained in calculations, where this effect has been ignored (Fig. 3). The hyperelastic forth-order Ogden model is applied to describe the mechanical properties of an elastomeric matrix of the tire. The degree of softening is evaluated in terms of the Ogden-Roxburgh model [6].



a b

Figure 3: Distribution of the left stretch tensor fields found with (a) and without (b) taking into account the Mullins effect

Conclusions

We have developed an algorithm to evaluate changes in the stress-strain of the wheel of the moving car taking into account the Mullins effect. The results of modeling the behavior of an accelerated car wheel indicate that the distribution of deformations in the tire volume undergoes largest changes. Maximum equivalent Mises deformations have been observed on the tire lateral surface, which, in our opinion, may cause the formation of cracks in the tire. Changes in stress fields have been insignificant because of two opposite mechanisms: on the one hand, deformations increase and, on the other hand, the material softens. It has been found that the stress-strain state should be analyzed in each point of the car wheel diameter taking into account different degrees of the Mullins softening effect. Summing up, the softening effect modeling allows one to accurately predict the serviceable life of tires. In this study we focus on the significance of considering the Mullins effect, which enables the wheel model to be simplified significantly; the anisotropic and viscoelastic properties of an elastomeric matrix are neglected in the model. Our simulations also show that even such a simplified formulation of the problem makes it possible to reveal an essential difference in the stress-strain state obtained in calculations performed with and without consideration of the Mullins effect.

Acknowledgements

The study was supported by RFBR and Perm Ministry of Industry of Innovations and Science (grant 14-08-96013 r_urals_a), and the Complex Program UB RAS 15-10-1-18.

References

[1] Mullins L., Tobin N.R. Stress softening in rubber vulcanizates. Part I. Use of a strain amplification factor to prescribe the elastic behavior of filler reinforced vulcanized rubber // J. Appl. Polym. Sci., 1965. V. 9. P. 2993–3005.

[2] Patrikeev G.A. Glava XXII. Tekhnologiia kauchuka i reziny. V kn. Obshchaia khimicheskaia tekhnologiia / pod red. S.I. Vol'fkovicha. – M.–L.: Gosudarstvennoe nauchno-tekhnicheskoe izdatel'stvo khimicheskoi literatury, 1946. V. 2. P. 361—427.

[3] Komar D.V., Svistkov A.L., Shadrin V.V. Modeling of hysteresis phenomena under loading rubbers / Vysokomolek. soed., 2003. V. 4. P. 692—696.

[4] Ryzhov S.A., Il'in K.A., Varjuhin A.N. Proektirovanie shin s ispol'zovaniem programmnogo kompleksa ABAQUS [Designing tire using a ABAQUS] // SAPR igrafika., 2006. V. 1. P. 77—81.

[5] Vol'skaja N.S., Levenkov Ja.Ju., Rusanov O.A. Modelirovanie avtomobil'noj pnevmaticheskoj shiny, vzaimodejstvujushhej s tverdoj nerovnoj pornojpoverhnost'ju [Simulation tire interacting with the solid support] // Nauka i Obrazovanie, 2013. V. 1. P. 107—124.

[6] Ogden R.W., Roxburgh D.G. A pseudo-elastic model for the Mullins effect in filled rubber // Proceedings of the Royal Society of London, 1999. V. 455. P. 2861–2877.

Alexander K. Sokolov, Institute of Continuous Media Mechanics UB RAS, Perm, Russia
Alexander L. Svistkov, Institute of Continuous Media Mechanics UB RAS, Perm, Russia, State National Research University, Perm, Russia
Lyudmila A. Komar, Institute of Continuous Media Mechanics UB RAS, Perm, Russia
Vladimir V. Shadrin, Institute of Continuous Media Mechanics UB RAS, Perm, Russia, Perm State National Research University, Perm, Russia
Viktor N. Terpugov, Perm State National Research University, Perm, Russia