



Stress and Vibrational Analysis of Non-Pneumatic Tire and Study the Effect of the Spoke Curvature and Velocity on the Wheel Vibration Using Finite Element Method

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ABSTRACT: Tweel is a new type of non-pneumatic tire. The purpose of this research is to simulate the wheel from the beginning of the movement to reach the speed of 60 km/h and study the effect of spoke curvature and vehicle speed on the vibration amplitudes. Spokes curvature has an effect on the vibrational behavior of the spoke and the wheel. For this reason, in addition to the reference wheel with spokes curvature of 5 mm, two other models with spokes curvature of 4 mm and 6 mm are also modeled. This study has shown that with the change in the curvature of spokes, the amplitude of spokes vibration and its frequencies have changed dramatically. Two important disadvantages of this type of wheels are vibrations and making loud noises at speeds more than 80 km/h. For this purpose, the speed of the wheel in the simulation is increased to 100 km/h. It is observed that at speeds of higher than 70 km/h, the spokes of the wheel are highly vibrated. At this moment, spokes vibrational frequencies are as same as their natural frequencies and the resonance occurs. As a result, the designed wheel is useful at speeds lower than 70 km/h.

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1- Introduction

A non-pneumatic wheel structure named Tweel and proposed by Michelin company exhibits potential for the four critical characteristics of automotive wheels: (1) low energy loss on rough surfaces, (2) low vertical stiffness, (3) low contact pressure, and (4) low mass while relaxing some of the most restrictive design constraints imposed by pneumatic tire mechanics [1].

The purpose of this research is to simulate the wheel from the beginning of the movement to reach the speed of 60 km/h and study the vibrations and the effect of curvature and speed on its value.

2- Methodology

This simulation in ABAQUS/Standard has three steps:

1. Cooling: Steady state coupled temperature-displacement cooling analysis for a time period of 1 second from a temperature of 125°C to 25°C.
2. Loading: a load of 3665 N is applied at the hub center over a time period of 1 second. This weight corresponds to the quarter weight of the vehicle.
3. Rolling: rolling the wheel from rest to the speed of 60 km/h over a time period of 1 second and rolling at this speed for 0.5 seconds. Then increase speed to 100 km/h.

The current wheel design considered in this work is molded from Poly Urethane (PU) and consists of four different parts: (1) Ring, (2) Spokes, (3), Tread and (4) Rigid hub. A 3D

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geometric model of the wheel is shown in Fig. 1.

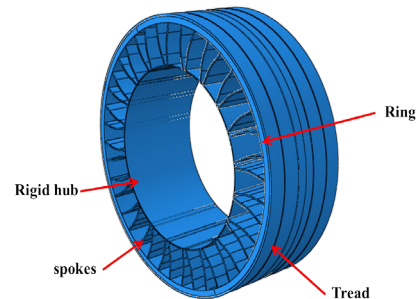


Fig. 1. Isometric view of the 3D wheel model

The polyurethane shear beam and spokes are modeled with hyperelastic isotropic materials modeled based on the Mooney-Rivlin strain energy potential. Hyperelastic materials are nonlinear and exhibit instantaneous elastic response up to large strains. The values for these hyperelastic material constants representing polyurethane are assumed to be [2]:

$$C_{10} = 7.5 \frac{\text{N}}{\text{mm}^2}, C_{01} = 0, D_1 = 0.0066 \frac{\text{mm}^2}{\text{N}}$$

The polyurethane tread is modeled with hyperelastic isotropic materials based on the Neo-Hookean strain energy potential. The values for these hyperelastic material constants representing polyurethane are assumed to be [2]:

$$C_{10} = 0.833 \frac{\text{N}}{\text{mm}^2}, D_1 = 0.1241384 \frac{\text{mm}^2}{\text{N}}$$



Thermal and density parameters for the material of the ring and spoke are given in Table 1.

Table 1. Thermal and density parameters for the material of ring and spoke [2]

Parameters	Reference wheel model
Coefficient of thermal expansion	0.002 1/K
Thermal conductivity	0.3 W/m.K
Specific heat	475×10^6 mJ/ton-K
Density	1.1×10^{-9} ton/mm ³

The density of tread is considered as 1.1×10^{-9} ton/mm³ [2] 3D stress elements of 8-node linear brick, hybrid and hourglass control (C3D8RH) are used in simulations.

The type of contact that is considered between the deformable tread and the rigid surface is surface-to-surface contact. The sliding formulation between the rigid surface and the deformable tread is assumed finite sliding. The tangential interaction property is defined as a penalty contact method with a friction coefficient value of 1. A normal Interacting surface interaction property is defined such that the pressure over closure is “Hard” contact. Also, the contacting surfaces are allowed to separate during the analysis.

To form an integrated tweel, tie constraints are used in the model. Four tie constraints which used in the modeling are as below:

1. The outer surface of the rigid hub and the interacting spoke surfaces
2. The outer surface of the inner coverage with the interacting spoke surfaces
3. The outer surface of the outer coverage and Tread
4. Both half tread models

To study the effect of spoke curvature on the vibration, simulations are carried out for spokes with different curvatures. Reference spoke curvature is 5 mm and two other models are 4 mm and 6 mm.

In Fig. 2, the spoke marker nodes have been displayed in both the initial and deformed geometries after loading. The time history of displacements of the marker nodes is recorded for four cycles during the steady rolling step.

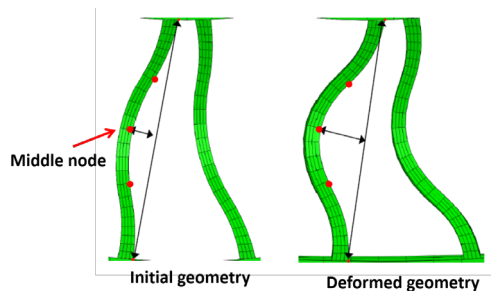


Fig. 2. Vertical spoke marker nodes in both initial and deformed geometries of the Tweel

1. Results and Discussion

In Figs. 3 and 4, Von Mises stress contours for loading and rolling steps are shown. These results show that this tire is able to bear the weight of 14660 N and roll at a constant speed of 60 km/h.

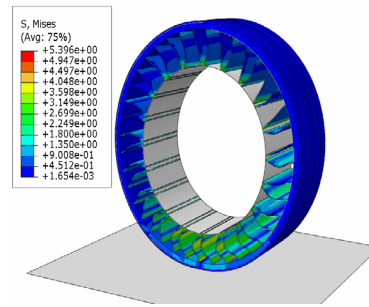


Fig. 3. Von Mises stress contour for loading step

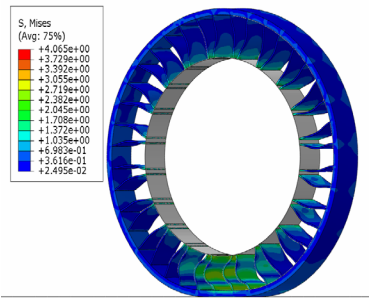


Fig. 4. Von Mises stress contour for steady-state rolling step at speed of 60 km/h

Fig. 5 shows the effect of spoke curvature on the amplitude of spoke vibration. The best curvature has the lowest vibration amplitude. In this study, the reference curvature has the best result.

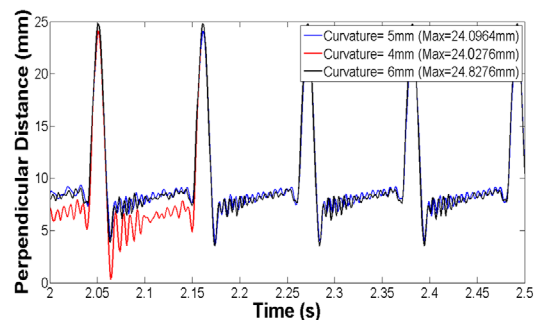


Fig. 5. Perpendicular distance of the middle node from the plane of spoke for three types of spokes curvature

Fig. 6 shows the behavior of the wheel at a speed of 100 km/h. Simulations are shown that this tire has high vibration amplitudes at speeds upper than 70 km/h and has not a good performance at high speeds.

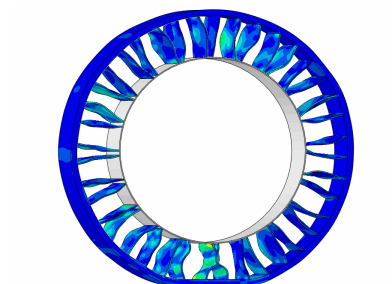


Fig. 6. A view of the wheel at a speed of 100 km/h

3- Conclusions

In this study, the 3D model of Tweel is modeled and simulated using ABAQUS/Standard software. The effect of spoke curvature and vehicle speed on the vibration amplitudes are

investigated. The simulations that are carried out in this study show that designed wheel is able to support the weight of 14660 N and rolls at a speed of 60 km/h. Also, It is observed that at speeds of higher than 70 km/h, the spokes of the wheel are highly vibrated. As a result, the designed wheel can be useful at speeds lower than 70 km/h.

4- Reference

- [1] T.B. Rhyne, S.M. Cron, Development of a non-pneumatic wheel, *Tire Science and Technology*, 34(3) (2006) 150-169.
- [2] M. Ramachandran, *Nonlinear Finite Element Analysis of TWEEL Geometric Parameter Modifications on Spoke Dynamics during High Speed Rolling*, Clemson University, 2008.

