AME0003

Simulation of Light-Weight Truck LF3070G1's Tire Dynamics

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Abstract. Accurately analyzing the dynamics of automotive tires is an important task. In this research, a Finite Elements Method (FEM) model of the tire of the light-weight truck LF3070G1 is implemented in ANSYS Workbench sofware. The paper presents two analyses of the tire dynamics. The first analysis is when the tire is statically balanced between supporting the vehicle weight and the internal air pressure. The second analysis includes the dynamically balance while the vehicle is operating at different weight loads.

Each analysis includes two parts. In the first part, the mode shapes and the natural frequencies of the tire, which influence the tire's stiffness and damping constant, are experimentally determined. In the second part, numerical simulations are carried out to determine the tire's time-dependent maximum deformation.

Keywords: Tire of truck, Modeling of tire, Air pressure, Mode shape, Deformation.

1. Introduction

The wheel of Light-weight truck generally comprise a rubber tire, rim and wheel disc. The disc is where the wheel is mounted (to the wheel hub). Parameters of wheel are primarily determined by the speed and load-bearing capacity of the truck. The main requirements of light truck wheels are: High fatigue strength and long service life; high load capacity [1].

Tire modeling and analysis are used for a variety of purposes. For instance, an analysis of vehicle collision accidents uses a tire force model. In this paper, the physical parameters involved are estimated using a statistical method based on experimental results of the tire forces. The simulation results for the dynamics of vehicles with tire broken and loads the limits corresponding [2].

Another application is the analysis of the impact of the road micro-profile on the duration and the tire of the vehicle wheel contact with the road surface driving at different speed. Frequency characteristics of suspension motion and regularities of vertical movement of the wheel were identified after dividing the investigated road section according to driving modes. The analysis of the wheel contact with the road surface and the identified correlations enable engineers to determine the vehicle stability on selected quality roads [3]. The longitudinal and transverse forces distributed over the tire-road contact area were experimentally analyzed the use of the lumped parameters dynamic friction model for traction-braking control purposes. The distribution of normal forces in the tire-road contract area at different vehicle speeds was determined [4].

ANSYS Workbench 14.0 software is used to conduct the static analysis of a tire model developed from Natural Rubber vulcanizes and the factors describing the linear isotropic elastic behavior of rubber vulcanizes. The maximum inflation pressure of 0.2206 MPa and maximum load capacity of 515 kg are obtained from the tire size specification load index. The von Mises stress value of 0.9448 MPa obtained on application of vertical load of 5.15 kN is lower than the specified pressure on vertical loading [5].

2. Tire models

For the simple vehicle model, a tire may be represented by elastic and viscous resisting system of rubber components. With the model complexity increases with higher frequencies are analyzed, tire need to be represented in greater detail. The tires model are characterized by pressure, operating conditions, loads and its nonlinearities nature.

The Fiala tire model

In this model, lateral and longitudinal forces are computed by the model using as input parameters. The Maximum forces are of the model used take into account frictions coefficient μ_{max} and μ_{min} at full adhesion and sliding of normal conditions, not including slip conditions in the braking or driving while turning [6].

The Magic Formula tire model

The Magic Formula tire model is used by curve fitting an analytical expression of the generic empirical equation in different driving situations . The model is able to describe tire behavior the characteristics for either side force, torque or longitudinal force [7].

The FTIRE (flexible ring tire) model

Wheel is modeled as a rigid body masses interconnected by elastic elements. The tire vibration behavior at the interface of interaction between the tire and the uneven road is modeled in high precision [8].

The SWIFT model

The SWIFT model considers the tire dynamics in rotational and forward directions. It is an empirical model that is originally based on the Magic Formula combined with the rigid body model. One disadvantage of the SWIFT model is the various of wheel parameters used as well as simulation results in low accuracy and may not be well suited to bigger tires [9].

The Hohenheim model

The Hohenheim tire model has been validated for large agricultural tires. The model is a combination between an empirical and a physical model. It uses rigid body comprises of non-linear spring and damper elements to represent the forces and torques in different directions [10].

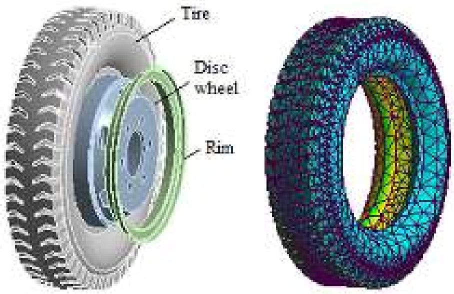
Other model

In dynamic analysis, tires are generally presented by empirical models. There are three principal tire models used: the elastic model, the string model, and beam model. In the elastic model, each small element of the contact patch surface is considered to act independently. The string model, lateral displacement of each element is resisted by the tension between the elements. The beam model does not allow discontinuous of either. The string and beam models are sometimes combined [11].

3. Simulation of the light truck tire

Tire structure and meshing

Tire's specifications of light truck depend on the respective requirements of various vehicle’s types and sizes, and total weight, and speed, and operating conditions. The dimensions, load ratings, specified inflation pressures and limited speeds are the main parameters of tire.- DIN 7804 is German standard for Light duty commercial vehicles [1, p576].



a) **b)**

Figure 1. Wheel and tire of Light truck

a) Wheel construction, b) Tire meshing (nodes: 77862, elements: 40722)

Light truck LF3070G1 has payload is 3000 kG, total weigh is 7150 kg. The number of wheels is 6 units size 8.25-16. Tire of light truck LF3070G1 made from Natural Rubber vulcanizes. The properties of material shown in Table 1.

Table 1. Properties of Light truck Rubber tire

No	Property	Value	Unit
1	Density	1000	Kgm^-3
2	Modulus	0.25	
3	Material Constant MU1	6.1803E+05	Pa
4	Material Constant A1	1.3	
5	Material Constant MU2	1180	Pa
6	Material Constant A2	5	
7	Material Constant MU3	-9810	Pa
8	Material Constant A3	-2	

Load on tire

Tire is subjected to the static nominal load as the wheel rolling slowly on a flat road surface. Tire is also subjected to the dynamic forces as the vehicle moves straight ahead over an uneven road surface or due to vehicle maneuvers such as cornering, and braking and accelerating process. Other forces can also be caused by the air compressed in tire, and errors in the assembling the rubber to the rim and wheel disc [1,p 574]. Images of the static loading and dynamic loading are shown in Figure 2.

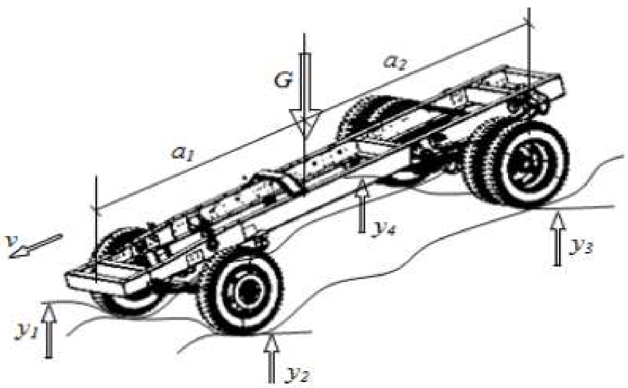


Figure 2. Load acting on the wheel of light truck

The static loading and dynamic loading are calculated by equation (1).

$$y_i = Y_i \, sin\left(\frac{2\pi v}{\lambda_0} t + \frac{2\pi}{\lambda_0}(a_1 + a_2) \right) \tag{1}$$

Where Y_i is vertical displacements of the front and rear tires, a_1, a_2 are distance from center of mass of the hung masses to front and rear axles, v is speed of vehicles [12].

4. Results Analysis

4.1 Vibration modes of the Tire

For the purpose of simulating the response of tire to road roughness the vibration modes can be represented by a parallel set of spring, mass, damper systems set so that one of the masses resonates at each of the simulation modes. Some mode shapes are shown in figure 3.

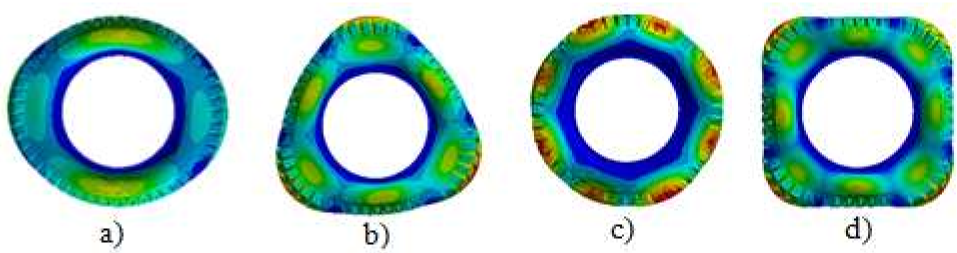


Figure 3. Vibration frequencies (f) and deformation (Df) modes of the Tire of light truck
a) Mode 12: f = 52.546 Hz, Dfmax = 17.585 mm
b) Mode 15: f = 61.726 Hz, Df max = 15.341mm
c) Mode 17: f = 68.099 Hz, Dfmax = 13.457 mm
d) Mode 20: f = 74.28 Hz, Dfmax = 15.597 mm

When the parallel second order systems are subjected to a random input then each will provide an input to the wheel hub corresponding to each particular vibration frequency. These inputs will be summed in amplitude and phase at the axle of light truck.

4.2 Influence of tire air pressure and the vertical load

The tire is used with the prescribed air pressure will have a good impact on moving vehicle safety, such as durability at high loads and speeds, the ability to transmit high braking and cornering forces to the road surface, as well as aquaplaning behavior on the wet surface. The impact of vertical load and the tire air pressure on a tire stiffness is given by equation (2).

$$k_r = \frac{G_R}{\Delta Z_{max}} \tag{2}$$

k_r is stiffness of the tire depending air pressure and rubber properties- structure of tire, G_R is the normal load of the tire, ΔZ_{max} is vertical load.

Air pressure and normal load may be calculation by equation (3) and (4).

$$p_m = \frac{G_R}{A_{total}} \tag{3}$$

$$G_R = G_S \cdot \frac{l_s}{0.315} + 490{,}223 \quad [N] \tag{4}$$

Where: p_m is average air pressure in the tire, A_{total} is total of the contact patch area, G_S is calibrated mass weight of 50 kg in the experimental, l_s [m] is distance from center mass G_S to the axes rolling of arm.

By using the simulation in the Ansys Workbench software, we obtained of the impact of vertical load and the tire air pressure on the tire endurance. On the outer surface of tire at the pavement contact area exists a local singular deformation, as shown in Figure 4. The next images are enlarged to better describe the depth and width of the deformation mark. This deformation will change in depth when changing the tire pressure inside the tire. The tire will be damaged, causing unsafety of vehicle if this depth over the specified limitation.

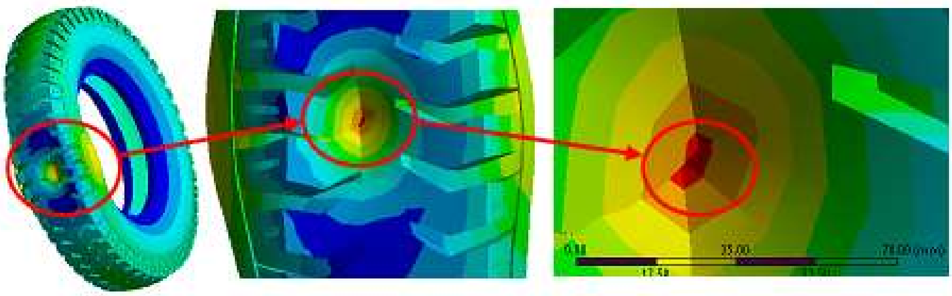


Figure 4. Influence of tire air pressure and the vertical load

The transient analysis graph shown in Figure 5 is the results by the data of depth of deformation in time with 4 different pneumatic pressure levels in tires of 0.3 Mpa, 0.4 Mpa, 0.5 Mpa and 0.6 Mpa. We find that at the lowest air pressure (0.3 Mpa), the depth of deformation will be greatest, and at the high air pressure (0.6 Mpa), the depth of deformation will be minimal. Based on this result, it is better to choose the air pressure level in tires from 4-5 (Mpa).

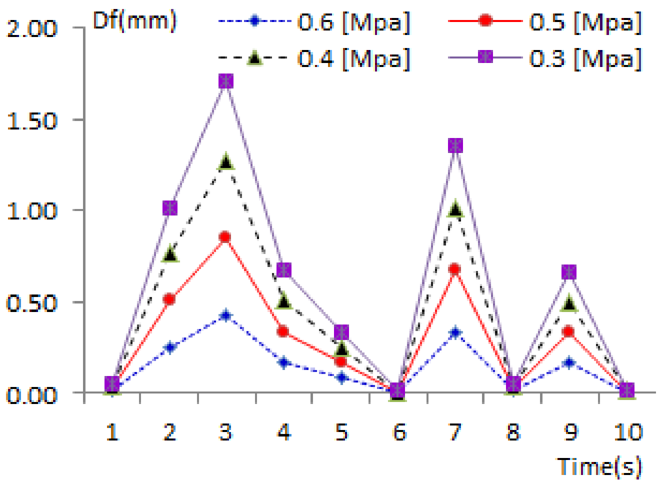


Figure 5. Transient of the Tire of light truck

The dynamic analysis of light truck tires with differences parameters such as rubber material properties, tire structure, loading on the tire, which takes the tire pressure is parameter changing for the simulation used, the remaining parameters will be the given variable. The cases of tire pressure and deflection corresponding results are presented in Table 2. Thus, on the same characteristics of tires, through simulation of dynamic analysis, we can choose the optimal air pressure to ensure tire durability and vehicle safety.

Table 2. Total deflection of the tire

Air pressure	0.3 [Mpa]	0.4 [Mpa]	0.5 [Mpa]	0.6 [Mpa]
Static [mm]	9.6414e-003	8.6072e-003	7.5753e-003	7.4662e-003
Harmonic [mm]	1.2725e-003	1.6967e-003	2.1209e-003	2.545e-003
Transient	7.03E-03	5.86E-03	4.69E-03	3.52E-03

5. Conclusion

The dynamic simulation conducted in Ansys Workbench software focuses on the effect air pressure to the deformation of rubber of tire. The results confirms that the low pressure make the tire deformed more than the high pressure. When the tire is highly deformed, it will increase the road contact, increase the rolling resistance, reduce the vehicle's movement speed, increase fuel consumption and cause tire damage.

On the depth of the singular deformation, the extreme limits measured range between 9.6414e-003 (mm) and 7.4662e-003 (mm) at the center of the contact point, values were obtained is loads beyond the prescribed limits. Based on this result, it is the best to choose the air pressure level in tires from 4-5 (Mpa).

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