Simulation of Light-Weight Truck LF3070G1’s Tire Dynamics

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Abstract

Being accurately analyses of the dynamics of automotive tires is essential for a wide range of technologies. There are two primary aims of this study: 1. To investigate the use of a Finite Elements Method (henceforth, FEM) in the light-weight truck’ tire (LF3070G1) 2. To implement in Ansys Workbench software in the simulation. Two analyses of the tire dynamics were used. The first analysis was used when the tire is statically balanced between supporting the vehicle weight and the internal air pressure. The second analysis includes the dynamical balance while the vehicle is operating at different weight loads. Each analysis includes two parts. The first part was the mode shapes and the natural frequencies of the tire since it has an influence on the tire’s stiffness and damping constant. The second analysis employed numerical simulations and it was carried out to determine the tire’s time-dependent maximum deformation.

Keywords: Truck tire, tire model, air pressure, mode shape, deformation

1. Introduction

The wheel of Light-weight truck generally comprises a rubber tire, rim and wheel disc. The disc is where the wheel is mounted (to the wheel hub). Parameters of the 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 and high load capacity [1]. Extensive research has shown that tire modeling and its analysis are used for a variety of purposes. For instance, an analysis of vehicle collision accidents is used for modelling a tire force. Data for this study were collected using the estimation of the physical parameters, and it involved a statistical method of the tire forces experiment. This study also provided results for the dynamics of vehicles with tire broken and loads the limits corresponding [2].

Previous research findings have also revealed the impact of the road micro-profile on the duration and the tire of the vehicle wheel contact with the road surface driving at a 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 study has attempted to analyze the wheel contact with the road surface and identified correlations. It was found that it enables engineers to determine vehicle stability on selected quality roads [3]. The study indicated longitudinal and transverse forces distributed over the tire-road contact area. The analysis of the use of the lumped parameters dynamic friction model for traction-braking control purposes was explored. The distribution of normal forces in the tire-road contact area at different vehicle speeds was determined [4].
Regarding the Ansys Workbench 14.0 software, it is used to conduct the static analysis of a tire model developed from natural rubber which has a hard texture and to identify factors regarding the linear isotropic elastic behavior of the specific rubber. The maximum inflation pressure of 0.2206 MPa and maximum load capacity of 515 kg is obtained from the tire size specification load index. The von mises stress the value of 0.9448 MPa obtained on application of a 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 an elastic and viscous resisting system of rubber components. With the model complexity increases with higher frequencies are analyzed, tire needs to be represented in greater detail. The tires model are characterized by pressure, operating conditions, loads and its nonlinearities nature.

The flat 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 to take into account friction coefficient $\mu_{\text{max}}$ and $\mu_{\text{min}}$ 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
The 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 variety 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 a rigid body comprises of non-linear spring and damper elements to represent the forces and torques in different directions [10].

Other models
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 the German standard for Light duty commercial vehicles [1, p. 576].
The light truck LF3070G1 has a payload of 3000 kG, and weigh 7150 kg. The number of wheels has six units in size, ranging from 8.25-16. The tire of the light truck LF3070G1 is made from natural rubber, as shown in Table 1.

Table 1. Properties of the light truck with 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**

The tire is used to the static nominal load since the wheel rolls slowly on a flat road surface. The 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. As can be seen from Figure 2, other forces can also be caused by the air compressed in the tire, and errors in the assembling the rubber to the rim and wheel disc [1, p. 574].
The static loading and dynamic loading are calculated as in equation (1).

\[ y_i = Y_i \sin \left( \frac{2\pi v}{\lambda_0} t + \frac{2\pi}{\lambda_0} (a_1 + a_2) \right) \]  

(1)

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

4. Results Analysis

4.1 Vibration modes of the tire

To simulate the response of tire to road roughness, the vibration modes can be represented by a parallel set of spring, mass, damper systems set. Thus, one of the masses resonates at each of the simulation modes. Some mode shapes are provided in Figure 3.

![Figure 3. Vibration frequencies (f) and deformation (Df) modes of the light truck's tire](image)

- a) Mode 12: \( f = 52.546 \text{ Hz} \), \( Df_{\text{max}} = 17.585 \text{ mm} \)
- b) Mode 15: \( f = 61.726 \text{ Hz} \), \( Df_{\text{max}} = 15.341 \text{ mm} \)
- c) Mode 17: \( f = 68.099 \text{ Hz} \), \( Df_{\text{max}} = 13.457 \text{ mm} \)
- d) Mode 20: \( f = 74.28 \text{ Hz} \), \( Df_{\text{max}} = 15.597 \text{ mm} \)

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

4.2 Influence of tire air pressure and the vertical load

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

\[ k_r = \frac{G_R}{\Delta Z_{\text{max}}} \]  

(2)

\( k_r \) represents a stiffness of the tire depending on the air pressure, the properties of the rubber, and the structure of the tire. \( G_R \) is a normal load of the tire, while \( \Delta Z_{\text{max}} \) is a vertical load.

The air pressure and normal load may be used as calculation, as shown in equations (3) and (4).

\[ p_m = \frac{G_R}{A_{\text{total}}} \]  

(3)

\[ G_R = G_s \cdot \frac{1}{0.315} + 490,223 \text{ [N]} \]  

(4)
While $p_m$ is the average air pressure in the tire. The $A_{total}$ is a total of the contact patch area. $G_S$ is a calibrated mass weight of 50 kgs used in the experimental. $l_i$ [m] is used to measure the distance from the center mass $G_S$ to the axes rolling of the arm.

By using the simulation in the Ansys Workbench software, the results of the study indicated the impact of vertical load and the tire air pressure on the tire endurance. It was also found that there is a local singular deformation on the outer surface of the tire at the pavement contact area (see 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 and causing unsafety of vehicle in the deeper part over the specified limit.

![Image](image1.png)

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

Figure 5 presents the results from the data of depth of deformation in time in four different pneumatic pressure levels of the tires (0.3 Mpa, 0.4 Mpa, 0.5 Mpa and 0.6 Mpa). The results of this study indicate 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. This study found that it is better to choose the air pressure level of tires ranging from 4-5 Mpa.

![Image](image2.png)

**Figure 5.** Transient of the tire of light truck

The present study was designed to determine the effect of dynamic analysis of light truck tires with differences parameters such as rubber material properties, tire structure, loading on the tire. The current study found that there is a tire pressure occurs when the parameter changed using simulation. 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 the 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
This study set out with the aim of assessing the importance of the dynamic simulation conducted in Ansys Workbench software. It was designed to determine the effect of the air pressure on the deformation of rubber of the tire. This study confirms that the lower pressure, the more deformed of the tire in the high pressure. When the tire is highly deformed, it will increase the road contact, the rolling resistance. It was also found that it can reduce the vehicle's movement speed, and increase fuel consumption and causing the damage of the tire.

Regarding the depth of the singular deformation, the extreme limits are measured and ranged between 9.6414e-003 (mm) and 7.4662e-003 (mm) at center of the contact point. Values were obtained and the loads are beyond the prescribed limits. These findings may help us to understand it is the best to choose the air pressure level in tires, ranging from 4–5 Mpa.

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