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Evaluation of the tire pressure influence on the lateral forces that occur between tire and road

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Abstract. The main objective of the paper is to capture the behavior of a vehicle on a race circuit, depending on the different inflation pressures of the tires (underpressure and overpressure). Taking into account that in the cornering the forces and the moments of inertia rise due the vehicle mass, and an inertial force decomposes in two components, one in the longitudinal plane and one in the transverse plane, the work aims the assessing the lateral forces that appear, to the contact between the tires and the tread, depending on the inflation pressure. The results have a graphic interpretation, enabling a comparative study of them. Results have been obtained regarding the lateral tire forces that occur between the tire and the road. The differences between these forces were particularly noticeable in cornering, and the differences between these forces were interpreted according to the tire inflation pressure.

1.Introduction

The wheels and the tires are the connecting elements of the vehicle with the tread. Wheel components allow consideration of several variables that influence its effect on the vehicle running state [1]. The role of the tire is to take up the vertical loads and to generate, along with the track, the tangential forces to accelerate or decelerate the vehicle and the side forces to guide it. Overpressure or underpressure in the tire reduces its ability to have adequate grip. Not only will it contribute to excessive and asymmetrical wear on the tire, but it will also have a substantial influence on the tire, which can create hazards especially at high-speed corners.
The values of the tire pressure and of the loads on the wheel are parameters which have an impact on the contact area between tire and the road [2,3]. Depending on the rim size, the tire size and on the load on the wheel, the tire manufacturer offers recommended pressures for the vehicle for the front or rear wheels [4]. The lower is the tire pressure, the greater is the contact surface between the tire and the road, and thus the rolling resistance is greater. This has a negative effect on the tire and may occur the excessive tire heating and the premature wear [5]. The high pressure in the tire causes greater wear of the central section of the tire and under the extreme conditions may lead to the delamination of the tire [6].
The lateral tire forces that occur between the tires and the road play an important role in the vehicles dynamics, determining the slip angle of the wheel and therefore the vehicle's skidding angle and the vehicle yaw rate.
The lateral tire force is the force required to keep the vehicle on the cornering trajectory. This force is generated by the deformation of the tire which is in contact with the road surface. The lateral tire force is generally shown according to the sideslip angle [7].

Tire pressure can affect the tire's characteristics in a variety of ways. Being that the stiffness coefficients are essentially a measure of the elasticity of the tire, an increase in tire pressure will increase the stiffness of the tire [8]. This will in turn increase the lateral force. If an inflation pressure 70% above the design value is used, a 20% gain in tire stiffness can be obtained. Increasing pressure above this will then decrease stiffness [9]. Due to inflation pressure carcass stiffness is increases but simultaneously reduces the contact length of the tire it influences on cornering stiffness of tire [10].
Various vehicle dynamic simulation software programs have been developed. The paper [11] underlines a number of advantages for simulation software programs: reduce costs to build a model able to change the structure of the model at any stage and adapt the characteristics of the model requirements imposed in a short time. In [12], the estimated tire forces were close to the simulation values during all the process. The simulation and results analysis showed that the proposed tire model can estimate both the longitudinal and lateral tire forces under different driving conditions, which demonstrated its validity in vehicle dynamics analysis. The vehicle dynamics analyzing model was established by using Matlab/Simulink and CarSim platform.
The paper aims to evaluate the lateral tire forces that occur at the contact between the tire and the road in the case of underpressure, overpressure and the optimal inflation pressure of the tires for a vehicle running on a race circuit, by computer simulation using the software *IPG CarMaker.*

2. Material and methods

To analyze the effect of the inflation tire on the vehicle transversal stability, the simulations are performed using the numerical simulation tool *IPG CarMaker*. To run the simulation in *IPG CarMaker* software, the road must be loaded, with the desired manoeuvres [13]. The main graphical interface of the software, it can be seen in Figure 1.

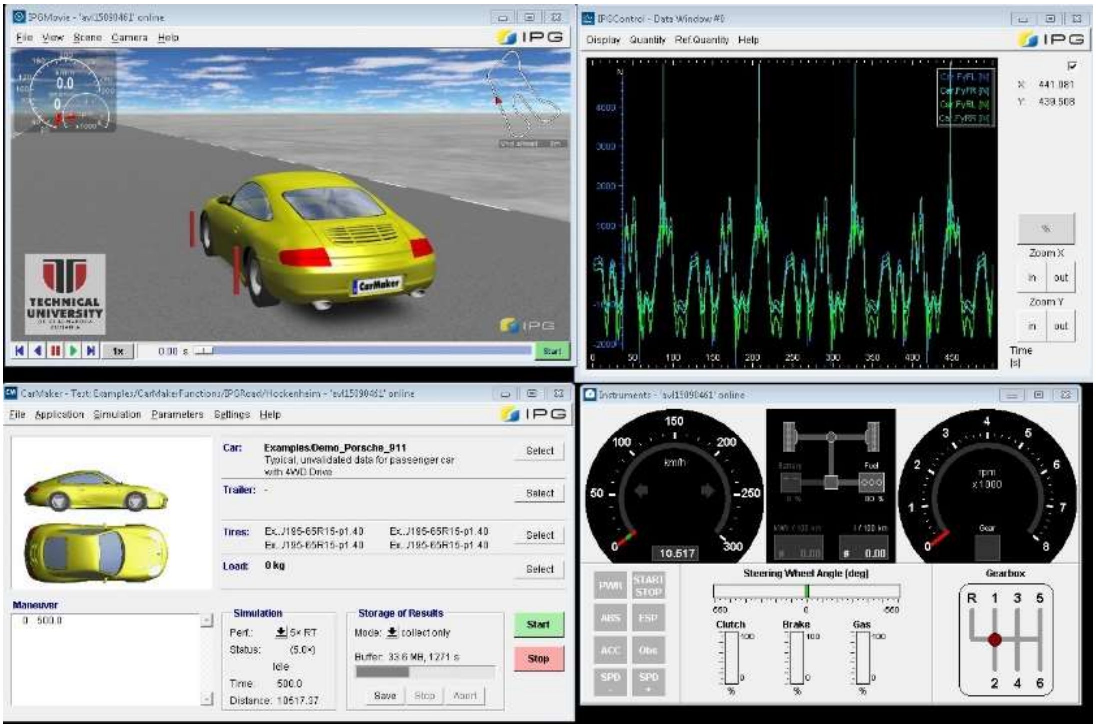

Figure 1. The graphical interface of the *IPG CarMaker* software

Within the framework of the presented paper, the simulations are carried out with the Porsche 911 Turbo vehicle. The main parameters of the vehicle are given in Table 1.

Table 1. The main parameters of the vehicle

Vehicle type	Porsche 911 Turbo
Unladen weight (EC)	1470 kg
Axle load front/rear	743/727 kg
Engine	3800 cm^3; (397 kW; 660 Nm at 1950 – 5000 rpm)
Tyre type	Continental
Tire dimension	195/45 R16 V
Length	4507 mm
Width	1880 mm
Height	1297 mm
Wheelbase	2450 mm

In *IPG CarMaker* software, three main axis systems are used [14] - see Figure 2:
- Frame Fr0: CarMaker inertial axis system – fixed origin, (0.X.Y) is the horizontal driving plane, and (Z) directed upwards.
- Frame Fr1: axis system of the vehicle where which respect the ISO sign convention where (X) points the forward driving direction, (Y) the left, and (Z) directed upwards.
- Frame Fr2: carrier axis system where (O) is the centre of the wheels, (X) the forward driving direction, (Y) is along the wheel spin axis and (Z) directed upwards. For every wheel there is a mountpoint (Mnt) defined within the Fr1 system

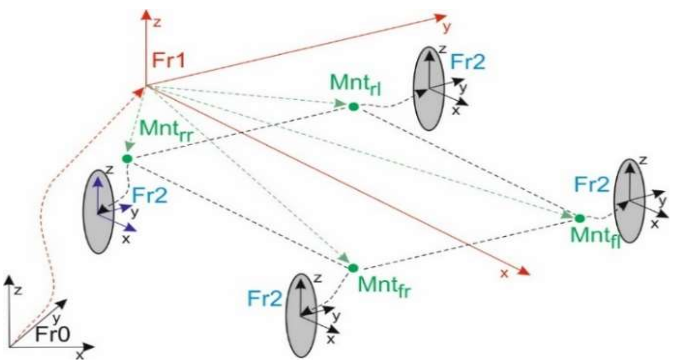

Figure 2. The main axis systems in *IPG CarMaker* software

Lateral force was analyzed on a short race circuit Hockenheimring (Germany) - 2.63 km (see Figure 3) for three different tire pressures: 1.4 bar, 2.2 bar (nominal pressure) and 2.9 bar.

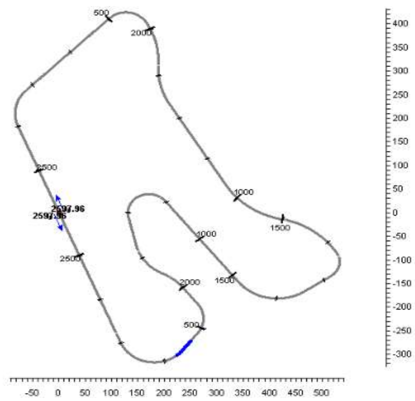

Figure 3. The short race circuit Hockenheimring

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The example of choosing the tire inflation pressure in the *IPG Camaker* software it can be seen in the Figure 4. The condition and the nature of the road was dry asphalt with the friction coefficient of 0.8.

Figure 4. The graphical interface for selecting the tire pressure

3.Results

The dependence between the lateral tire force and the lateral deflection angle that occurr between the tire and the road is of fundamental importance for the directional control and for the vehicles stability. Inflation pressure affects the tire's flexibility and the rolling resistance in various ways. Generally, the rolling resistance decreases as the inflation tire pressure increases. This is because, with increasing the tire pressures, the deformation of the tire decreases, respectively decreases the contact patch between the tire and the road. When the tire is in cornering at a certain angle, the contact patch deforms resulting a lateral force. The slip angle increases by increasing the lateral force. Figure 5 shows the evolution of the lateral tire force for all four wheels of the vehicle and for the three inflation pressures with which the simulations were made (FL-front left wheel, FR- front right wheel, RL- rear left wheel, RR rear right wheel). The lateral tire forces were captured for one-lap race. We can see a tendency to increase the lateral tire forces that appear on all the wheels for 1.4 bar inflation pressures. The lateral tire forces at 2.2 bar inflation pressure and respectively for 2.9 bar have values close to each other.

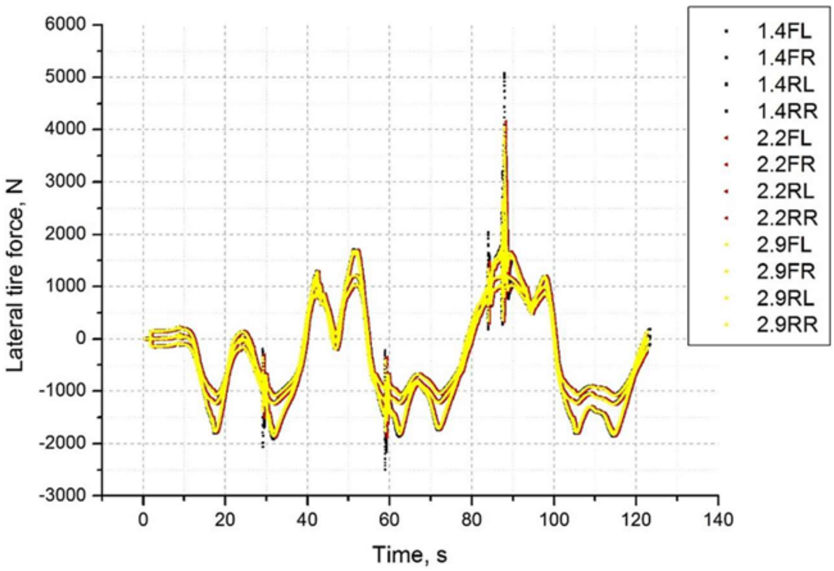

Figure 5. The evolution of the lateral tire force for all wheels at different tire inflation pressure

Figure 6 shows the lateral forces on the right front wheel of the vehicle for the three inflation pressures of the tires. The lateral tire force is greater for the inflation pressures of 1.4 bar up to 1000 N, reaching in tight corners to a maximum value of approximately 5000 N. This is due to the low tire inflation pressure, the contact patch between the tire and the road is greater than the tire with the nominal inflation pressure, or in the case of overpressure.

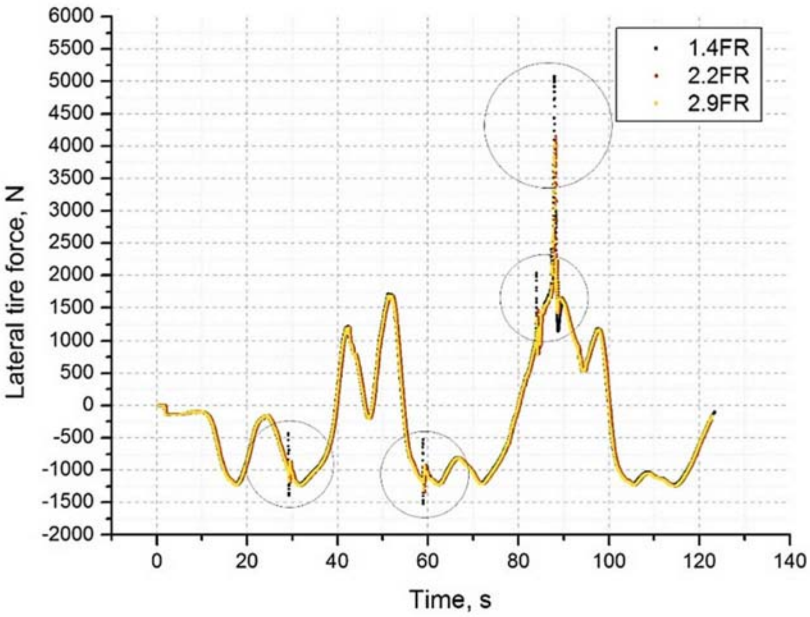

Figure 6. The lateral tire force for the right front wheel

The slip angle increases by increasing the lateral tire force. The maximum value of the lateral tire forces in the case of 2.2 bar respectively 2.9 bar have very close values reaching the maximum value of approximately 4000 N.

4.Conclusions

As a result of the computerized simulations, it can be noted the influence of the tire inflation pressure on the lateral tire forces that appear at the wheels of a car running on a race circuit. A vehicle with low inflation pressure of the tire will tend to lose the grip and will appear less receptive in cornering. The tire develops lateral forces due to the side slip angle between the tire and the road. The side slip angle of the tire increases at low tire pressures. The decreasing of the tire inflation pressure will increase the load on the tire, thus increasing the deformation of the tire and the tire solicitations, which will lead to the increasing of the losses energy, to the increasing of the rolling resistance, respectively to the increasing of lateral forces at the contact between the tire and the road.
The results of the simulations can be developed by following the effects of the tire inflation pressure on the forces at the wheels that occur on different natures and states of the road and the effects of the air temperature on the tires on these forces.

Acknowledgment

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