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Experimental Solution of the Influence of Tire Pressure on Vehicle Consumption and their Service Life

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This article deals with the experimental investigation of the influence of tire pressure on fuel consumption and tire life in passenger cars. Using laboratory and real-world operational measurements, the dependence between tire pressure and temperature, contact patch size, tread wear, and changes in driving characteristics was analyzed. The results show that even slight deviations from the prescribed pressure can lead to increased fuel consumption, shortened tire life, and reduced driving comfort and safety. The article also draws attention to the insufficient use of pressure monitoring systems in practice and points to the economic and ecological impacts of underinflation. The experimental data are supplemented with graphs and tables that demonstrate the influence of pressure on tire behavior during driving.

Keywords: Passenger car, Experiment, Tire wear, Tire pressure, Driving comfort

1 Introduction

We have been seeing the tire pressure monitoring system in cars for over 10 years, but few people pay attention to it. Until the aforementioned "European Union regulation", this system was a privilege of additional equipment and, most importantly, it primarily concerned premium brands or models. According to the European Union standards EC 661/2009 and ECE-R 64, car manufacturers are obliged to equip all new passenger cars for the European market with a tire pressure monitoring system - TPMS (Tyre Pressure Monitoring System) from 1 November 2014. The reason is to ensure optimal tire inflation, which affects the production of harmful gas emissions, road safety, vehicle operation economy and driving comfort [1, 2,11].

The topic of tire pressure monitoring is interesting from the perspective of the technical solution of the system, it is based on theoretical knowledge of mechanics and thermodynamics, and also uses knowledge of electronics, automation and their evaluation using computer technology.

Reducing emissions (and fuel consumption) through correct tire pressure is based on the laws of physics – rolling resistance. Rolling resistance is one of the four basic vehicle resistances, namely air resistance (aerodynamic), acceleration resistance and climbing resistance. Rolling resistance is the product of the vertical wheel load and the rolling resistance coefficient. The rolling resistance coefficient is the ratio of the length of the radial reaction of the road due to wheel deformation (reaction to wheel load) to the dynamic radius of the wheel. This coefficient depends primarily on the road surface, tire deformation and wheel speed.

The effect of inflation will be reflected in the deformation of the wheel. Maintaining the prescribed pressure is important not only for reasons of reducing emissions and safety (ideal track, grip in corners, damage, tire detachment from the rim, water drainage - aquaplaning), but also for economic reasons (reducing fuel consumption and tire wear) and driving comfort.

Reducing the energy requirements of a vehicle can be achieved by reducing the driving resistance, i.e. tire rolling, climbing resistance (climbing resistance has an effect, but it cannot be reduced other than by choosing the route) and aerodynamic resistance. In case of poor inflation, rolling resistance increases and the tire wears out more. Wear is manifested by underinflation at the edges of the tire tread and overinflation in the center of the tire tread (Fig. 1).

When functioning properly, tire pressure measurement helps to operate vehicles with optimally inflated tires. Incorrectly set tire pressure also results in impaired handling.


a) underinflated b) prescribed pressure c) overpressured

Fig. 1 *The effect of not complying with the prescribed tire pressure on tread wear [10]*

2 Pressure ratios in a tire

When operating a vehicle, the effect of maintaining the prescribed tire pressure on driving safety is crucial. It is important to remember that a vehicle weighing more than one ton is in contact with the road only through a small area, approximately 200 cm^2 on each tire. Poor pressure results in impaired handling when driving and braking, and especially when cornering. In addition to pressure, handling is affected by:

- tire wear
- use of tires with appropriate speed and weight ratings
- use of seasonal tires (summer/winter)

The weight of the vehicle is transferred through the suspension to the wheel rims. In a front-engined passenger car, the weight ratio transferred to the front and rear axles is between 50:50 and 70:30. The weight of the vehicle is transferred to the tread, which is in contact with the road.

Fig. 2 shows the increase in rolling resistance for given wheel loads Zk when the tire pressure changes from 8 bar to 5 bar. Fig. 3 shows the decrease in tire pressure as a function of time, and Fig. 4 shows the effect of pressure on fuel consumption.

A decrease in tire pressure by 20% of the recommended value leads to a decrease in driving comfort and is manifested, among other things, by the so-called "floating" of the vehicle. This is more evident in combination with vehicle overloading or uneven loading. At a pressure higher than the prescribed pressure, the tires partially lose their damping ability and transmit more vibrations caused by road irregularities to the body. Table 1 shows changes in fuel consumption and a decrease in tire life at different underinflation values in percent.

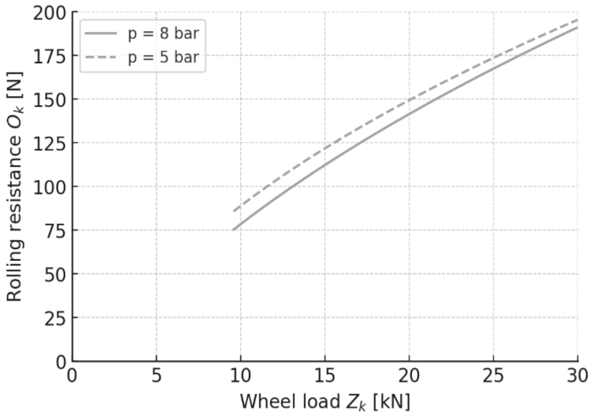

Fig. 2 *Tire rolling resistance at different inflation pressures [4]*

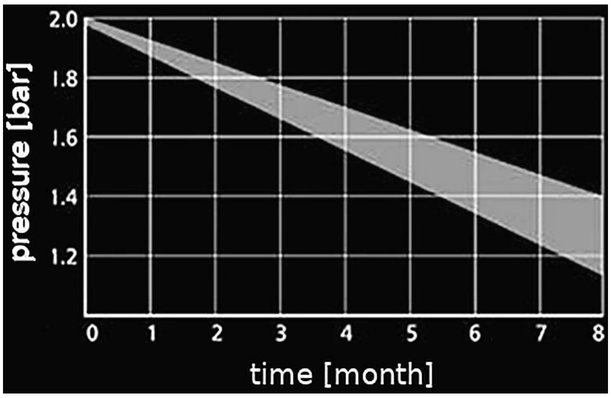

Fig. 3 *Tire pressure loss over time – inflated with air [4]*

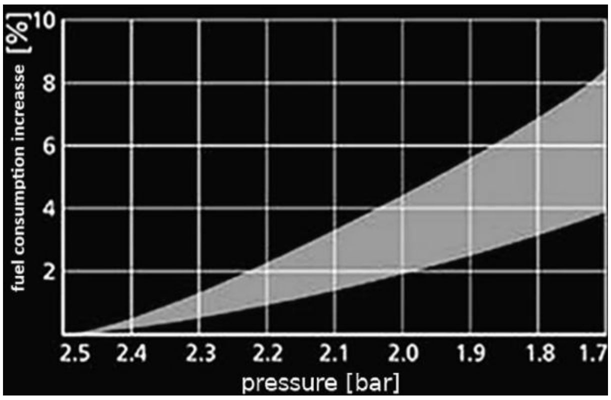

Fig. 4 *Dependence of fuel consumption on tire pressure loss [4]*

Tab. 1 *The effect of underinflation on fuel consumption and tire life [3]*

	underinflation 0,2 bar	**underinflation 0,4 bar**	**underinflation 0,6 bar**
Fuel consumption	1 % higher	2 % higher	4 % higher
Reduced service life	10 %	30 %	45 %

3 Experimental measurement of pressures and temperatures in passenger car tires

The first measurement was to determine how many passenger cars drive on roads with under-inflated or over-inflated tires. Tire pressure measurements were performed on 13 vehicles. The measurements were performed in service stations on vehicles not equipped with a tire pressure monitoring system. The measured tires were warmed up by driving. The air temperature was from -3 °C to 5 °C. Assuming that the service slope is mainly between 5 and 20 km (exceptionally otherwise), we can consider the tires to be slightly warmed up, i.e. the measured pressure is approximately 0.1 bar (5%) greater than at the beginning of the trip.

Of the 52 tires measured (13 vehicles), 26 were underinflated (of which) and 18 were overinflated. In Table 2, vehicles that would have a 1% higher fuel consumption and a 10% reduced service life due to underinflation are highlighted in color.

***Tab. 2** Tire pressure measurement on 13 passenger cars*

Deviation p [bar] of tires from the prescribed pressure				
Vehicle	**position LF**	**position RF**	**position RR**	**position LR**
1	-0.05	0.05	-0.10	0.00
2	-0.20	-0.20	-0.30	-0.20
3	0.30	0.30	0.50	0.40
4	-0.05	-0.20	0.10	0.05
5	0.00	-0.05	-0.05	-0.10
6	-0.15	-0.10	-0.05	-0.10
7	0.05	0.10	-0.05	0.10
8	0.00	0.00	0.05	0.00
9	-0.10	-0.10	0.00	0.00
10	0.25	0.25	-0.20	-0.20
11	-0.10	-0.05	0.35	0.30
12	0.00	0.15	0.05	0.15
13	-0.25	-0.30	-0.20	-0.20
* Positive values indicate overpressure, negative values indicate underpressure LF – left front, RF – right rear, RR – right rear, LR – left rear				

Another measurement was performed on ten vehicles to determine the heating of the tires during driving (approx. 37 min). The measurement was performed with optimally inflated tires and then with tires underinflated to the limit of 20%. Both measurements were performed on a specified circuit with mainly non-urban traffic with a permitted speed of 90 km.h^{-1} and also on a highway with a permitted speed of 130 km.h^{-1} (approx. 20% of the distance on the measured circuit).

***Tab. 3** Pressure and temperature changes while driving for tires inflated to the prescribed pressure*

Driving time 37 min	**position LF**	**position RF**	**position RR**	**position LR**
Pressure at the beginning p_{int0} [bar]	2.18	2.17	1.94	1.94
Tire/air temperature $T0_{ext}$ [°C]	5.0/5.4	5.0/5.4	5.0/5.4	5.0/5.4
Pressure at the end p_{int1} [bar]	2.48	2.47	2.15	2.19
Tire/air temperature $T1_{ext}$ [°C]	19.5/9.0	19.7/9.0	20.4/9.0	21.0/9.0
difference p_{int} [bar]	0.30	0.30	0.21	0.25
difference p_{int} [%]	12.10 %	12.15 %	9.77 %	11.42 %
difference T_{pneu} [°C]	14.5	14.7	15.4	16.0
* LF – left front, RF – right rear, RR – right rear, LR – left rear				

Tab. 4 *Pressure and temperature changes while driving with tires underinflated by 20%*

Driving time 37 min	position LF	position RF	position RR	position LR
Pressure at the beginning p_{int0} [bar]	1.84	1.81	1.50	1.46
Tire/air temperature T_{0ext} [°C]	13.0/5.8	13.0/5.8	15.0/5.8	15.0/5.8
Pressure at the end p_{int1} [bar]	2.03	2.04	1.67	1.63
Tire/air temperature T_{1ext} [°C]	19.0/6.3	20.0/6.3	21.0/6.3	21.0/6.3
difference p_{int} [bar]	0.19	0.19	0.17	0.17
difference p_{int} [%]	9.36 %	9.50 %	10.18 %	10.43 %
difference T_{pneu} [°C]	6.0	7.0	6.0	6.0
* LF – left front, RF – right rear, RR – right rear, LR – left rear				

It is evident from Tables 3 and 4 that during driving, the surface temperature of the tire and the internal temperature of the air in the tire increase due to deformation work. The measurement revealed a difference in pressure increase between 9.77% (with a temperature increase of 16 °C) and 12.15% (with a temperature increase of 14.5 °C). This pressure increase is a reaction to temperature changes in the air in the tire. The pressure increase was greater for the front tires, which are loaded by approximately 20% more than the rear tires. Measurements on underinflated tires were performed half an hour after the first drive, during which the surface temperature of the tires had not yet stabilized at the ambient temperature. The pressure increase was between 9.36% and 10.43%. In this case, the pressure increase was greater for the rear tires, where the initial pressure was at an extremely low value of 1.5 bar.

Further measurements were carried out for 10 minutes. The CLIP Panasonic 19 device equipped with VT55 software was used. The program allows measuring the pressure and internal air temperature. The temperature during driving increased by 5 °C and 6 °C and the pressure by approximately 0.1 bar. The maximum pressure increase was 5.6%. The measured values are in Tab. 5, graphically in Fig. 5. Fig. 6 shows the vehicle speed during the test drive.

Tab. 5 *Pressure and temperature changes while driving at the initial prescribed pressure (ambient temperature = 6°C)*

Driving time 10 min	position LF	position RF	position RR	position LR
Pressure at the beginning p_{int0} [bar]	1.9950	2.0025	1.9650	1.8975
Tire/air temperature T_{0ext} [°C]	5.0	5.0	8.0	9.0
Pressure at the end p_{int1} [bar]	2.0700	2.1075	2.0775	2.0100
Tire/air temperature T_{1ext} [°C]	11.0	10.0	14.0	15.0
difference p_{int} [bar]	0.0750	0.1050	0.1125	0.1125
difference p_{int} [%]	3.6 %	5.0 %	5.4 %	5.6 %
difference T_{pneu} [°C]	6.0	5.0	6.0	6.0
* LF – left front, RF – right rear, RR – right rear, LR – left rear				

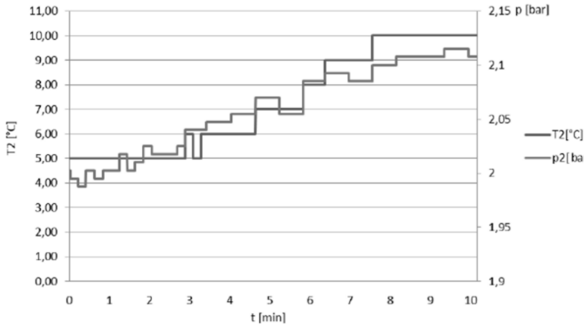

Fig. 5 *Course of change in pressure and internal air temperature of RF tires*

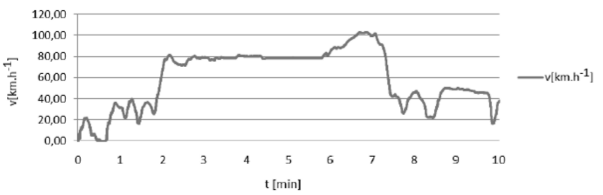

Fig. 6 *Test drive speed profile*

4 Discussion and Conclusion

The measured results confirm the known relationship between tire pressure, tread deformation, rolling resistance and, secondarily, fuel consumption and driving safety. At lower pressure, the contact patch area and tire deformation increase, which increases rolling resistance and accelerates uneven wear; on the contrary, overinflation reduces the damping capacity and worsens comfort and adhesion in the central part of the tread (schematically see Fig. 1). These relationships are supported in the introduction of the work by the basic physical explanation of rolling resistance and practical arguments of safety and operating economy.

A short operational investigation of 13 vehicles (52 tires) showed that a significant part of the tires were not inflated to the prescribed value: 26 were underinflated and 18 were overinflated. This indicates that common user practice maintains the pressure outside the optimal range in the long term, especially in vehicles without an active pressure display on the dashboard.

The dynamic tests showed the expected warming of the tires and the increase in internal pressure during the ride. In a 37minute test, the pressure of properly inflated tires increased by 9.77 to 12.15% (accompanied by an increase in surface temperature of 14 to 21 °C), with the front tires showing a larger increase in pressure corresponding to the higher axle load. When driving with an underinflated tire of approximately 20 %, the pressure increase was measured at 9.36 to 10.43%, with the starting pressures being significantly lower (around 1.5 bar for the rear wheels). A shorter 10minute ride confirmed the trend of smaller but rapid changes: an increase in temperature of 5 to 6 °C and in pressure of approximately 0.075 to 0.113 bar (i.e. 3.6 to 5.6 %).

In terms of operational impacts, the findings also correspond to aggregated data from the literature and practice: underinflation by 0.2/0.4/0.6 bar increases fuel consumption by approximately 1 %/2 %/4 % and at the same time shortens the life of the tire by 10 %/30 %/45 %. With average annual mileage, even a relatively small pressure deviation generates significant costs and environmental burdens – both through higher consumption and faster tire replacement.

The practical implication of "warm inflation" is worth noting. Most drivers only top up the tire after a short drive (the gas station is not "near home"), when the tire is already slightly warmed up and the pressure is about 0.1 bar higher than "cold". Without correction, systematic overinflation "cold" or a false feeling of the correct pressure can occur. The discussion of the paper therefore emphasizes the importance of direct TPMS systems with pressure display (and ideally also temperature), which allow correction to conditions and early warning of a drop – in contrast to indirect (only limit) detections.

Recommendations for practice: check and adjust the pressure when cold, regularly (at least once a month and before a long trip), take into account the load and speed regime (motorway), use direct TPMS with temperature information, respect the manufacturer's prescribed values and seasonal tires with an adequate load capacity/speed index.

Impact on consumption and service life: Underinflation by 0.2/0.4/0.6 bar increases consumption by approximately 1 %/ 2 %/4 % and shortens the service life of the tire by 10 %/30 %/45 %. Even small pressure deviations thus accumulate significant costs and environmental consequences.

Practical conclusion: The operating recommendation is – maintain the pressure according to the manufacturer when cold, check it regularly, adjust it according to the load for long or fast trips and use direct TPMS (ideally with temperature). This can simultaneously reduce fuel consumption, extend tire life and increase safety.

In the next part of the work, the set of measurements will be expanded (more vehicles, different tire sizes and designs), cover the seasons and speed regimes, quantify the direct relationships between pressure, rolling resistance and consumption on a roller test bench and validate predictions in long-term operation.

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