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DETERMINING THE STARTING TIME OF CAR MOVEMENT TO STABILIZE THE INTERNAL PRESSURE AND THE TEMPERATURE IN THE TIRES

Karpenko V. O.[1], Kaps'kyy D. V.[2], Rudenko N. V.[1], Neskreba E. Ye.[1]
[1]Kharkiv National Automobile and Highway University
[2]Belarussian National Technical University

Abstract. Problem. *The* ***problem*** *of road safety does not lose its relevance in our time. The condition and performance of tires has a significant impact on the safety of road transport. Unfortunately, the tire pressure monitoring requirements of the developers are not always met. Naturally, now some modern cars are equipped with various systems for monitoring and even adjusting the internal tire pressure. However, there are relatively short periods of time during which the pressure and temperature in the tire change dramatically, and hence its other performance and properties. First of all, we are talking about dramatically changing weather conditions and the starting movement of the car. And then additional monitoring of tire pressure is needed.* ***Goal.*** *On the basis of the experimental studies carried out, to obtain the dependence of the temperature and pressure changes inside the tire on the time of car movement. To determine the initial period of time of car movement until the pressure and temperature in the tested tires stabilize.* ***Methodology.*** *The work used the technique of both bench tests of tires in the laboratory and road tests under real weather conditions by car. Based on the numerical processing of the experimental results, dependencies were obtained, using which it is possible to determine the increase in temperature and pressure in tires in the mode of starting movement of the car.* ***Results.*** *The analysis of scientific publications on this topic is performed. The time from the beginning of the car to the stabilization of temperature and internal pressure in the tires is determined, as well as the increase in temperature and pressure inside the tire during this period. The method of determining the starting time of the car to stabilize the internal pressure and temperature is proposed.* ***Originality.*** *In this work, for the first time, a method is proposed for assessing the temperature and internal pressure in tires in the mode of starting movement of the car, which makes it possible to obtain dependencies without resorting to further experimental studies.* ***Practical value.*** *Using the obtained dependencies for certain tires and under different weather conditions, it is possible to predict the change in tire pressure at the starting mode of the car's movement, and therefore make adjustments to this value, if necessary, which will have a positive effect on the safety of moving vehicles.*

Key words: *car tire, stability, vehicle steerability, safety, stabilization, pressure, temperature.*

Introduction

The tire condition significantly affects the operation of the whole car. Important performance characteristics, such as stability, steerability, safety, vibroacoustics, noise emission, fuel efficiency, travelling comfort, etc. depend on the tire as well [1–3].

After particular time of wheel movement at a constant speed, the tire acquires the temperature when an equilibrium is set between the influx of heat and its dissipation into the environment [4]. In the outlined interval of time, the tire warms up, adapts better to the road surface and the pressure in it is set within the limit recommended by manufacturers. After all, in Formula 1 mechanics cover the tires with thermal coating before races for good reason, to prepare the tires for the best performance characteristics the pilots are given a few laps before the start [5, 6]. Unquestionably, it is most unlikely that motorists afford to warm up the tires before driving and, moreover, to make races using a tortuous path of motion on the roadway. Therefore, in the initial period of operating time and especially when the night-time and day-time temperatures differ or in winter time, drivers are more likely to have problems while driving [7]. One of the reasons is the limited capabilities of tires when the temperature and pressure indicators differ from the recommended ones. So, it is crucial to know these characteristics while operating and also to have a knowledge of the minimum time for warming up tires. This specific issue is addressed in the present work.

Analysis of Publications

The temperature in Ukraine varies within the following limit (from 30 below zero to 40 above zero) [8]. The tire temperature is assessed either by the average temperature of the gas filler in the chamber or by the actual temperature at a given point of the tire section. The tire temperature depends on: its design, wheel load, inflation pressure of tire, wheel rolling speed, thermal conductivity of the material, ambient temperature and intensity of heat dissipation. The material of the pneumatic tire requires a certain temperature for creating the most favorable conditions to resist the movement and for longer service life. To achieve this, the temperature in the tire should be equal to 70–75°C at ambient temperature of 20°C. The tire material temperature up to 100°C can be considered as acceptable, from 100°C to 121°C is critical, and over 121°C is dangerous for the tire [4].

The author of [9] takes up the position that heat production depends on the ratio of tire deformation and its rotational rate, vehicle speed and tire pressure. Temperature balance and rolling losses are stabilized within a time period from a few minutes to two hours of steady motion [3, 9]. The authors of [10] obtained the dependences of tire pressure change on the ambient temperature. Quantitative indicators of temperature change in the tire when a car is above sea level are presented. But it's not just environmental conditions that influence the tire performance. They are also affected by the gas filler in the tire and especially by the time and the mode of starting movement of a car. During this time, the tire heats up due to intensive contact with the bearing surface area. Heat is supplied to the tire tread, then its components are heated by the tire deformation, especially a breaker, a frame, an interlayer rubber, a sidewall and a bead. After this, heat is fed into the tire, the temperature goes up and, as a result, the pressure stabilizes [11].

Purpose and objective

The purpose of the paper is to determine the minimum time of car movement to stabilize the temperature and internal pressure in the tires to ensure traffic safety.

Task setting includes the analysis of experimental studies in order to determine the temperature and internal pressure in the tire while operating, to receive the dependences of temperature and pressure change in the tire on time at operating speed.

Studying the change in pressure inside the tire for different gas fillers depending on the ambient temperature

The required pressure measurements were taken in the tires filled with different gaseous fillers such as air, helium and nitrogen at different ambient temperatures for the unloaded tire. The results of these measurements are given in Table 1.

Table 1 – The results of measuring the pressure depending on the type of gas filler at different ambient temperatures

Temperature, °C	Pressure, МПа		
	air	nitrogen	helium
–20	0.180	0.186	0.189
–10	0.189	0.191	0.192
0	0.200	0.201	0.196
+10	0.205	0.208	0.203
+20	0.210	0.210	0.210
+30	0.220	0.219	0.217

The table shows that there is a difference in pressure values, but of course this affects the performance of a vehicle and this must be borne in mind. As the difference between the values is within the measurement accuracy, so in further experiments we will use only one gas filler, this is going to be air.

Experimental studies of the air temperature inside the car tire while car operation

Most commonly, bench [12] or driving [13, 14] tests are conducted for experimental studies of the tires.

The experiments were conducted both with the use of a drum bench in the laboratory and with the help of a car in real road conditions. At once it should be emphasized that in this case road tests have an advantage over bench ones as the contact between the tire and a real road under actual weather conditions is important. Therefore, in this paper we omit the results of bench researches.

In view of this, the field measurements were taken in the road conditions. The temperature and air pressure inside the tire served as a measuring parameter. Appropriate measurements were taken using temperature and pressure sensors mounted on the wheel disk (Fig. 1).

Fig. 1. Installation of the sensor for monitoring temperature in the tires

In this particular case, industrial sensors TPMS OE Sensor (Tire Pressure Monitoring System be the Orange Electronics Sensor) model P409 were used.

The information from the sensor was transmitted in real time by means of wireless communications.

This measuring control system allows to obtain consistencies, and so the overall results of a series of measurements can be considered true.

Experimental studies for assessing the air temperature mode inside the tire were conducted using modern tubeless tires of model 175/70R13, mounted on a technically serviceable car AvtoZAZ Sens. The measurement was taken simultaneously in 4-tires, where the pressure 0.21 MPa was set at the recommended ratio for operation. The air in the tire was supplied only after double filtration to prevent the condensate. At the time of road tests, the ambient temperature was 9°C, the humidity was 75 %, the air velocity was up to 3 m/s.

The driving tests were carried out on the public highway with two lanes in each direction delimited by the safety island. Although, the tests were conducted without creating obstacles to the movement of other vehicles, but under normal conditions and with the possibility of controlling a stable speed limit within the city.

The measurement itself started after a long stop of a car on the road side of the chosen route in order to determine the temperature in the tires equal to the ambient temperature. When this was done, the car sped up to 60 km/h within a minute and this speed (± 3 km/h) was controlled by the driver until the stable temperature of the air in the tires was set.

The analysis of the data given demonstrates that the stabilization of the air temperature in the pneumatic tires of this model occurs after 25–30 minutes from the start of movement. During this period of time, the tire material heated up, led to a reduction in hysteresis losses in the rubber due to a drop in intermolecular friction, which in turn decreased the coefficient of rolling resistance. The latter, by the way, fell thanks to a growth in internal pressure and lowering in tire deformation as well. It should be emphasized that the temperature measurement was taken in the rim area. It goes without saying that the temperature in the tread area inside the tire will be much higher [5]. However, our task is to achieve the temperature stabilization in the tire at a specific point.

As performed studies have shown, the confidence interval with a 95 % of guarantee is ± 2ºC. It is important to note that the increase in temperature up to 8°C was obtained by measurements in each of the wheels and was almost constant, while the difference between measurements on adjacent wheels of ± 2°C was determined from the beginning of the measurement and actually was kept up during all the tests. It is also worth noting that there is no significant difference in setting the temperature balance for driving wheels (front axle) or driven wheels (rear axle), as the mode of movement was almost rectilinear and with a constant rotation rate.

Figure 2 presents the results of these tests and their statistical processing (the thick line is the average value of four measurements).

The conducted experimental researches enable to assess the value of temperature increase in the tires which is set while operating.

The air temperature inside the tire at the measuring point has increased by 8°C. Most certainly, a growth in temperature will boost the internal pressure in the tire. As part of the experiment performed in the paper on monitoring the air temperature in the tire, the measuring system enabled to measure the internal pressure (Fig. 3).

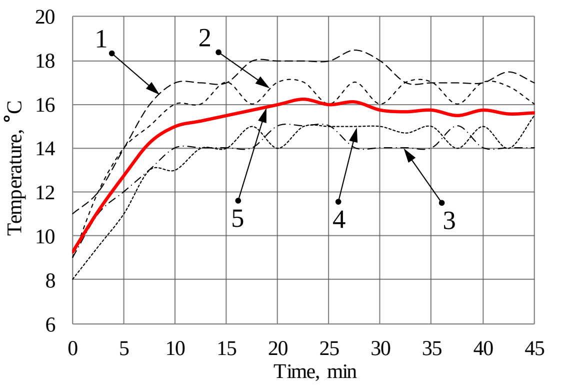

Fig. 2. The results of measuring the air temperature inside the pneumatic tire: 1 – rear left wheel; 2 – front left wheel; 3 – front right wheel; 4 – rear right wheel; 5 – average value

Fig. 3. Test measuring of temperature and pressure in the assembled tires

The results of these measurements and their statistical processing are depicted in Fig. 4.

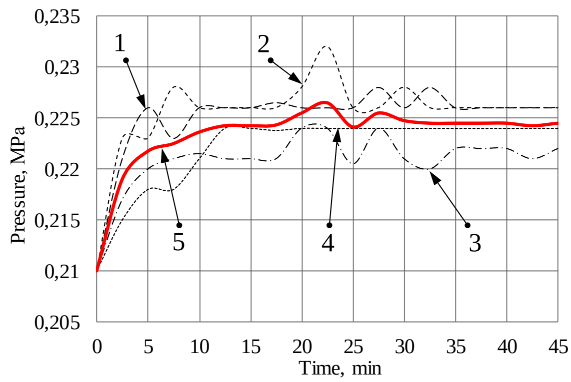

Fig. 4. The results of measuring the internal air pressure in the tire of model 175/70R13 while road testing: 1 – rear left wheel; 2 – front left wheel; 3 – front right wheel; 4 – rear right wheel; 5 – average value

Obtaining dependences of temperature and air pressure inside the car tire by approximating the results of experimental studies

The task of obtaining the dependence of temperature and pressure change in the tire while starting movement of a car, is solved numerically. The approximated graph, obtained experimentally, was given in Figure 2. Then, by adding a trend line to the graph, it is possible to get the most approximate dependence with high accuracy. From Figure 2 it is obvious that the dependence is most similar to the logarithmic function. From this perspective, to get the most convenient and easy-to-use formula at the same time, we choose the logarithmic type of trend line, but it should be borne in mind that the logarithmic function tends to increase at positive values of the argument, in our case it is time. The dependence obtained during the experiment indicates the stabilization of the temperature after a certain period of time. The formula achieved numerically will be correct only for the specific temperature increase range (from 0 to 25 minutes). If to use the trend line as a polynomial function, the accuracy will be higher, but the dependence will be quite cumbersome. In the case of the exponential function, the accuracy of approximation R^2 is 0.953, and polynomiality R^2 makes 0.989.

Fig. 5 shows an approximated influence curve of the tire temperature depending on the operating time, obtained experimentally and approximated to the logarithmic function.

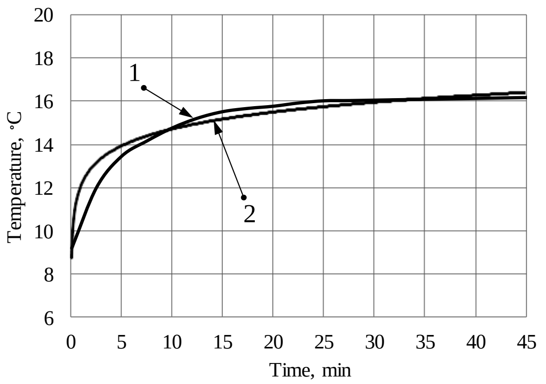

Fig. 5. Dependence of air temperature inside the pneumatic tire: curve 1 is the approximated dependence obtained experimentally; curve 2 is the logarithmic function

The temperature (T) inside the tire, °C, is determined by the formula:

$$T = 1.1065\ln(t) + 12.123, \quad (1)$$

where t – is the time when the temperature is determined, min.

As it was mentioned before, the accuracy of temperature determination is quite high. It can be said that the probability of correct calculation is equal to 0.953.

In much the same way as for the formula of temperature determination, we define the dependence of pressure on time. The curve of this function is presented in Figure 6 in the form of a logarithmic dependence, because it is more convenient to use and at the same time has a high accuracy (the certainty of approximation $R^2 = 0.97$).

Thus, the tire inflated with air up to an internal pressure of 0.21 MPa after setting the heat balance will increase the temperature up to 8°C and, as a consequence, there will be a growth in pressure to 0.016 MPa, which is over 7%.

Tire pressure (P), MPa:

$$P = 0.0023\ln(t) + 0.2178, \quad (2)$$

where t – is the time when the pressure is determined, min.

As for the dependence of temperature on the starting time of car movement, the formula (2) is true only for a period of time from 0 to 25 minutes.

While operating a vehicle it is necessary to take into account the increase in temperature in the tire and in pressure respectively, as the change in tire pressure directly affects the performance characteristics of a vehicle.

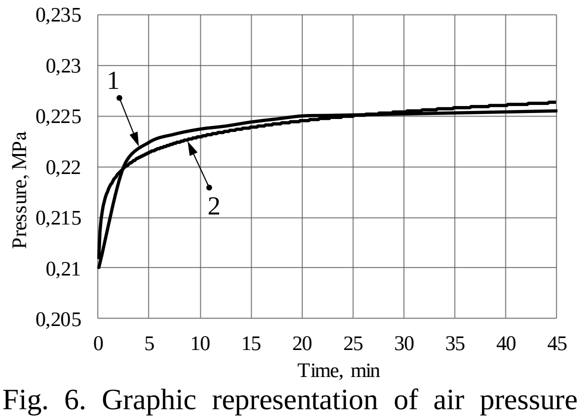

Fig. 6. Graphic representation of air pressure inside the pneumatic tire: 1 – approximated dependence obtained experimentally; 2 – logarithmic function

The author of [10] has already defined that the inflation of the tires should be conducted at the temperature closest to the temperature conditions of tire operation and by all means inflating the "cold" tires, i.e. when a car was stationary for the last two hours or ran at low speed no more than 3 km.

Conclusions

The paper suggested a method for determining the time from the start of car movement to the stabilization of pressure and temperature in the tires, also the empirical dependences of temperature and internal pressure change in the tires have been obtained. The following conclusions have been made based on the obtained results of the dependence of temperature and internal pressure change in the tire on the starting time of car movement:

- in order to achieve the recommended tire pressure, it is necessary to take into consideration not only the weather conditions but the operating modes and the starting time of car movement;
- the stabilization of temperature and pressure in the studied tires occurs within 25–30 minutes. This is the minimum period of time when a tire is not yet fully adapted to the road conditions and requires greater attention from the driver;
- the increase in tire temperature during this period of time is approximately 50 %, the boost in internal pressure in the tire makes 5–10 %, these figures are true (with small deviations) for both front and rear wheels;
- the received dependences of temperature and internal pressure change in passenger car tires allow to predict their deviation without needing the additional experiment but with the high accuracy;
- it is significant to know an incremental value of internal pressure in the tire in order to prevent dangerous situations while driving, as they are caused by insufficient stability and vehicle steerability while starting movement.

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Karpenko Volodymyr[1], Professor, Dr. Sc., Prof. Machine Parts and TMM Department,
tel. +38 050-938-67-55,
e-mail: 56vak56@gmail.com,
Kaps'kyy Denys[2], Professor, Dr. Sc., Prof. Transport Systems and Technologies Department,
tel. (+375-29)-6865323,
e-mail: d.kapsky@gmail.com,
Rudenko Nataliia[1], Associate Professor, Cand. Ped., Ass. Prof. Foreign Languages,
tel. +38 097-282-19-65, e-mail: rud_nat@ukr.net,
Neskreba Eduard[1], student of the Automobile Faculty, tel. +38 066-583-70-97,
e-mail: eeneskreba12@ukr.net,
[1]Kharkiv National Automobile and Highway University, 25, Yaroslava Mudrogo str., Kharkiv, 61002, Ukraine,
[2]Belarussian National Technical University, 65, Nezavisimosti Avenue, Minsk, 220013, Belarus.

Визначення стартового часу руху автомобіля до стабілізації внутрішнього тиску та температури в його шинах

Анотація. Проблема. *Проблема безпеки дорожнього руху не втрачає своєї актуальності й на сьогодні. Стан та експлуатаційні характеристики шин суттєво впливають на безпеку руху автомобільного транспорту. На жаль, не завжди дотримуються вимог розробників щодо контролю тиску в шинах. Але нині деякі сучасні автомобілі обладнані різноманітними системами контролю та навіть корегування внутрішнього тиску в шинах. Однак існують відносно невеликі проміжки часу, протягом яких тиск і температура в шині різко змінюються, а отже,змінюються й інші її експлуатаційні характеристики та властивості, зокрема під час зміни погодних умов змінюється стартовий рух автомобіля. І тоді додатковий контроль тиску в шинах є необхідним.* ***Мета.*** *У процесі експериментальних досліджень отримати залежності зміни температури та тиску всередині шини від часу руху автомобіля. Визначити стартовий період часу руху автомобіля до стабілізації тиску та температури в досліджуваних шинах.* ***Методика.*** *У роботі використовувалась методика стендових випробувань шин у лабораторії та випробувань за дорожніх реальних погодних умов на автомобілі. Ґрунтуючись на числовому обробленні результатів експерименту, були отримані залежності, за допомогою використання яких можна визначити приріст температури та тиску в шинах в режимі стартового руху автомобіля.* ***Результати.*** *Здійснено аналіз наукових публікацій з цієї тематики. Визначено час від початку руху автомобіля до стабілізації температури та внутрішнього тиску в шинах, також визначено приріст температури та тиску всередині шини за цей період. Запропонована методика визначення стартового часу автомобіля до стабілізації внутрішнього тиску та температури.* ***Наукова новизна.*** *У роботі вперше запропонована методика аналізу температури та внутрішнього тиску в шинах в режимі стартового руху автомобіля, що дозволяє отримати залежності без додаткових експериментальних досліджень.* ***Практичне значення.*** *Використовуючи отримані залежності для певних шин та*

за різних погодних умов, можна прогнозувати зміну тиску в шинах в стартовому режимі руху автомобіля, а отже, вносити корективи цієї величини в разі необхідності, що позитивно вплине на безпеку автомобільного транспорту.

Ключові слова: *автомобільна шина, стійкість, керованість, безпека, стабілізація, тиск, температура.*

Карпенко Володимир Олександрович[1], д.т.н., проф. каф. деталей машин і ТММ,
тел. +38 050-938-67-55, 56vak56@gmail.com,
Капський Денис Васильович[2], д.т.н., проф. каф. транспортних систем і технологій,
тел. (+375-29)-6865323, d.kapsky@gmail.com,
Руденко Наталія Всеволодівна[1], к.п.н., доц. каф. іноземних мов, тел. +38 097-282-19-65,
rud_nat@ukr.net,
Нескреба Едуард Євгенійович[1], студент автомобільного факультету ХНАДУ,
тел. +38 066-583-70-97, eeneskreba12@ukr.net,
[1]Харківський національний автомобільно-дорожній університет, вул. Ярослава Мудрого, 25, м. Харків, 61002, Україна.
[2]Білоруський національний технічний університет, проспект Незалежності, 65, м. Мінськ, 220013, Білорусь.