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THE INFLUENCE OF TIRE PRESSURE ON THE DYNAMIC CHARACTERISTICS OF THE CAR AND RESISTANCE TO MOVEMENT

The main task of car tires is to provide the necessary grip characteristics. When the tire pressure is normal, the load at the point of contact of the tire with the road surface is distributed evenly and at the same time good controllability, maneuverability and optimal fuel consumption are ensured. The optimal pressure value for a specific car brand is determined not by the tire, but by the car manufacturer, because the same size can be mounted on different models of cars with different weights and other characteristics. Usually, information about the pressure recommended by the car manufacturer is indicated either in the technical documentation for the car, or on a plate that can be placed on the end of the driver's door, the side pillar on the driver's side, the fuel filler flap or in the glove compartment. There is the label indicates the level of cold working pressure for the front and rear wheels, the maximum load on the car and the recommended tire size. In addition, the pressure value can be affected by such factors as the weight of the car, the size of the tires, the distribution of the load inside the car and even the time of year. It should also be taken into account that the pressure can change with climate change. In summer, as the temperature rises, so does the pressure in the tires. For example, when the temperature rises to 25°C, it increases by about 0.8 bar. And if the load is full, the pressure will be even greater. That is why car manufacturers indicate the permissible pressure value for a loaded car. This is an extremely important parameter for ensuring safety, which cannot be ignored. In winter, when the air temperature drops, the pressure in the tires also drops by about 0.8 bar, which should also be taken into account when pumping up the tires. The rolling resistance coefficient f of Kleber Viaxer tires 175/70 R13 82T was estimated along the coasting path of a Lada-112 car. Increasing the air pressure by 0.05 MPa reduces f by 1.3%, decreasing the pressure by 0.05 MPa increases f by 1.7%.

Key words: tire, car, drag coefficient, friction force, acceleration, pressure, temperature.

INTRODUCTION

The automotive world is currently looking for ways to reduce CO2 emissions.

One of the areas of search is reducing rolling resistance, which takes up a significant share of the fuel burned (and in the city, the bulk). Tire manufacturers have made significant strides in this area. The task of operators is to properly operate the car, in particular, the tires. First of all, it is necessary to maintain the recommended air pressure in them.

ANALYSIS OF LITERARY DATA AND PROBLEM STATEMENT

Tire pressure is one of the important indicators that affect the fuel consumption of any car. When the pressure decreases, the deformation zone of the tire in the contact patch increases, which leads to a noticeable increase in rolling resistance. An increase in rolling resistance leads to the engine having to consume more fuel to maintain the standard driving mode of the car.

A decrease in tire pressure and an increase in the load on the steering wheel lead to a change in the tension of the steering wheel.

Measuring the pressure on the tire resource determines and also studies the contact patch with the line.

At normal pressure, the contact patch is optimal, the load in the tire is distributed evenly. At low pressure, a higher load falls on the edges of the tire, i.e. the shoulder area, causing increased wear in this part of the tread. At high pressure, a higher load in the contact patch falls on the central part of the tread. In this case, the central part of the tire begins to wear out faster than the side blocks of the tread. Low pressure at high speed leads to unclear steering reactions (the speed of cornering decreases, the car skids more sharply, an unpleasant squeal occurs), which is unsafe, to wobbling of the rear axle on the side profile of the tire, which leads to the risk of unpredictable skidding of the car, to internal heating of the frame and, consequently, increased tire wear.

In recent years, a tire pressure monitoring system has become a mandatory additional device for passenger vehicles. Tire pressure monitoring systems can be different depending on the method by which the tire pressure is measured:

- indirect, when data on the air filling of the tire is obtained by the distance it travels in one revolution;
- direct, when special sensors are installed directly on the wheel itself that measure the pressure.

The most common and frequently used design of the tire pressure monitoring system is the first option. In essence, it is part of the electronic control unit of the ABS (anti-lock braking system), which are presented in the form of wheel speed sensors. Thus, the electronic system is able to determine the distance traveled by the tire of each wheel. However, it cannot compare the speed of an individual wheel, since the car rarely moves in a straight line, and on turns the path of the outer wheel will always be greater than the path of the inner wheels. The control system is designed in such a way that the speed of each two wheels located diagonally is summed up, the difference is calculated from the obtained results and divided by the average speed of each wheel. Inside the system, the received data is compared with the set control parameters and if they do not match, a control lamp (indicator) lights up on the dashboard.

The advantages of such a system are:

- no need to install additional equipment, which significantly reduces the cost of the system as a whole;
- the ability to adapt it to the necessary changes in pressure parameters associated with replacing tires or other service work.

However, there are also a number of disadvantages:

- to "remember" normal parameters, the car needs to drive 30-50 km;
- after the indicator signal, the driver must visually inspect all wheels to determine if they are flat;
- the system does not allow you to determine a sharp drop in pressure (for example, if a tire is punctured);
- the system does not indicate a simultaneous drop in pressure in the wheels;
- the operability of the system is significantly affected by the degree of wheel slippage, vehicle load, and the condition of the car tires;
- in order for the indicator to light up, the pressure in the wheels must drop by at least 25-30 %;
- the tire pressure is not determined before the vehicle starts moving.

The principle of the control system with direct measurement of tire pressure is that the characteristics of the oscillatory circuit, consisting of a tire and a disk, directly depend on the elasticity of the tire, i.e. the air pressure in it.

The direct tire pressure measurement system consists of pressure sensors, a control unit, an antenna and a screen (display) and operates on the principle of measuring the pressure in each wheel.

Air pressure in a tire affects rolling resistance: with increasing pressure, the rolling resistance coefficient decreases, with decreasing pressure, it increases. This is a well-known truth, it is written in almost every article about tires, but often this information is unreliable: different authors report that a decrease in pressure by 0.01 MPa (0.1 bar) increases the rolling resistance coefficient by 2, 3 and even 5% - without indicating which tire they are talking about, how the tests were carried out, etc. Finding data on a specific modern tire is almost impossible. In the best case, the results of tests conducted by different organizations are published, and most often, as the closest, albeit indirect, indicator, the values of the coasting distance of the test car with different tires are given - but without changing the pressure.

The test we are interested in is described in [1]. The car is a Lada-112 (VAZ2112) with Kleber Viaxer 175/70R13 82T tires. The load is the driver and the operator of the Vbox Racelogic system, which measures the car's position using GPS satellite signals. The tests were carried out at a nominal pressure of 0.2 MPa (average coasting distance from a speed of 80 km/h is 1,175 m), increased to 0.25 (1,232 m, fuel consumption decreased by 1.6%) and decreased to 0.15 MPa (1,108 m, consumption increased by 2%). The braking distance was also measured, and other indicators were subjectively assessed. It was concluded that a slight decrease in fuel consumption with increased pressure and the corresponding savings in money do not compensate for the deterioration in performance properties.

AIM AND TASKS OF THE RESEARCH

The purpose of this article is to improve the accuracy of calculations of the movement of a car, for which purpose we derive the dependence of the coefficients of resistance to movement on the air pressure in the tires. To do this, we need to solve the following problems: 1) clarify the description of the resistance to the movement of a car by coasting, taking into account the air pressure in the tires; 2) find a solution to the direct problem - calculating the coasting path using the clarified description of the resistances; 3) find solution of the inverse problem - calculation of the coefficient of rolling resistance along a known coasting path.

RESEARCH RESULTS

The deceleration of the car during coasting is created by the forces of resistance to movement - aerodynamic resistance Pw, rolling resistance Pf and transmission idle resistance. The latter is usually not considered separately, it is implicitly included in the first two. Aerodynamic resistance depends on the air pressure in the tires indirectly, through the vehicle clearance [2, 3].

$$C_x = C_{x0} * (1+1{,}7*\Delta e), \tag{1}$$

where C_{x0} is the value of C_x at nominal clearance, Δe is the change in clearance compared to nominal, m (taking into account the sign).

The clearance will change by the amount of change in tire deflection (Δe=Δt), and the tire deflection (m) is determined by the load on the wheel G_k (N) and the tire stiffness Ct in N/m:

$$\Delta t = G_k / C_t\ . \tag{2}$$

Rolling resistance is conveniently calculated using approximating polynomials [3]. Let us assume that with a moderate change in tire pressure, the shape of the curve representing the dependence of the rolling resistance coefficient f on the speed v does not change, but only its ordinates change - with the proportionality coefficient K_t. Then

$$f = K_t * (Av^2 + Bv + C)\ , \tag{3}$$

where A, B, C are the coefficients of the approximating polynomial.

Next, we can formulate a differential equation

$$dv/dt = (P_w + P_f) / m_{rm} = (kF * v^2 + K_t * (Av^2 + Bv + C) * G_a) / m_{rm}\ , \tag{4}$$

where the streamlining coefficient k = ρ * C_x/2 (ρ – air density, kg/m^3; C_x – aerodynamic drag coefficient); F – frontal area of the vehicle, m^2; mpr – reduced mass of the vehicle, kg; G_a – vehicle weight, N.

Experience shows that it is more convenient to solve this equation numerically: select the step of change in speed Δv, for each i-th interval find the average speed v_{av}, assuming that on this interval the deceleration j_i is constant; calculate the resistance forces at this average speed, from their sum find the average deceleration ji; then you need to calculate the duration of the i-th interval Δti = Δv/ ji and the path of the car on this interval $\Delta S_i = \Delta t_i * v_{av}$; summing up the cumulative total, we obtain diagrams of the time and distance of the coasting from the initial speed to a complete stop. This algorithm is very easily implemented, for example, in the Microsoft Excel package. Now, by changing the coefficient Ksh, you can select a value for which the calculated path will be equal to the measured value. The minimum value of the coefficient of rolling resistance

$$f = C*K_t\ . \tag{5}$$

DISCUSSION OF THE RESEARCH RESULTS

Let us apply this method to the results described in [1].

The unladen weight of the Lada-112 is 1060 kg. We will take the weight of the driver and the tester with the equipment to be 180 kg. The sum of the reduced weights of the wheels and transmission is 37 kg. The reduced weight of the car m_{rm} = 1060 + 180 + 37 = 1277 kg.

According to [4], the frontal area is F = 1.944 m^2, the coefficient of aerodynamic drag is C_x = 0.335; we will assume from [5] that on the road it will be 10% greater: C_{xd} = 0.335 * 1.1 = 0.3685. The weather data are not specified in the article [1], we will assume the average air density to be 1.2 kg/m^3. Air resistance in nominal condition

$$P_w = 0{,}5 * 1{,}2 * 0{,}335 * 1{,}1 * 1{,}944v^2/12{,}96 = 0{,}033165v^2\ . \tag{6}$$

The dependence f(v) for SR, TR buses at the upper limit of the field of possible values is described by the expression [3]

$$f = 3{,}11238 * 10^{-7} * v^2 – 1{,}25429 * 10^{-5} * v + 0{,}013005. \tag{7}$$

The stiffness of 175/70R13 82T tires can be considered approximately 170 kN/m at a pressure of 0.2 MPa, 120 at 0.15 and 220 at 0.245 MPa [6, p. 260]. The corresponding tire deflections Δt (assuming a uniform load on the wheels) are calculated using formula (2), the aerodynamic drag coefficients C_x using formula (1). The results of calculations using the described method are given in Table 1 and illustrated in Fig. 1, which shows the f(p_w) graphs and the linear and quadratic approximation equations.

Additionally, the same calculation was performed in a simplified version, without taking into account the effect of tire pressure on air resistance. The results have remained practically unchanged.

CONCLUSIONS

Note that the given calculation is based on the generally accepted mathematical model of vehicle motion resistance. The actual picture is noticeably different, especially in the speed zone below 20 km/h (Fig. 2). However, taking these differences into account forces us to reconsider the accepted model of rolling resistance, which is not the purpose of this article.

Thus, the effect of changes in air pressure in the tire on rolling resistance is small. However, in high-precision calculations it must be taken into account, and our analysis provides a guideline for researchers.

Table 1 Results of rolling resistance coefficient calculations

Pressure, MPa	0,15	0,20	0,25
Δ_t, m	0,0266	0,0188	0,0145
C_x	0,3394	0,335	0,3325
Run-out distance, m	1108	1175	1232
K_t	1,13882	1,0527	0,98589
Taking into account changes in air resistance			
f	0,015489	0,014317	0,013409
Relative change f, %%	+1,64	0	-1,27
Without taking into account changes in air resistance			
f	0,015563	0,014347	0,013369
Relative change f, %%	+1,74	0	-1,32

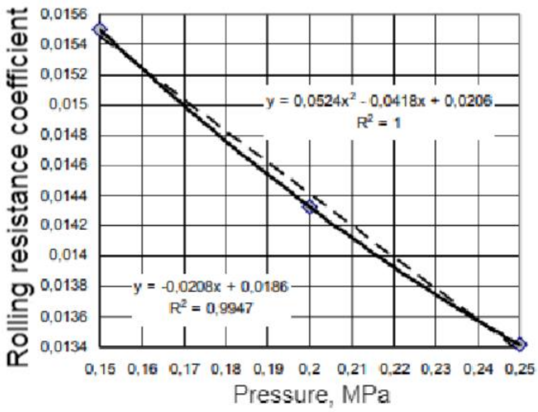

Fig. 1. Dependence of the rolling resistance coefficient of the tire 175/70R13 82T Kleber Viaxer on the internal pressure

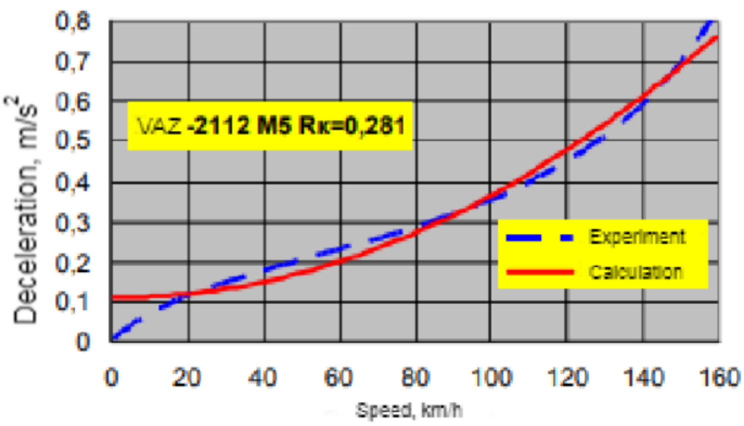

Fig. 2. Dependence j(V) of the Lada-112 (VAZ-2112) car (data processing by "Autoreview")

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***Ю.В. Зибцев, П.А. Ворошилов*. Вплив тиску в шині на динамічні характеристики автомобіля і опір руху.**

Основне завдання автомобільних шин - забезпечити необхідні зчіпні характеристики. При нормальному тиску в шинах навантаження в місці контакту шини з дорожнім покриттям розподіляється рівномірно і при цьому забезпечується хороша керованість, маневреність і оптимальна витрата палива. Оптимальне значення тиску для конкретної марки автомобіля визначається не шиною, а виробником автомобіля, адже один і той же типорозмір можна встановлювати на різні моделі автомобілів з різною вагою та іншими характеристиками. Зазвичай інформація про рекомендований виробником автомобіля тиск вказується або в технічній документації на автомобіль, або на табличці, яку можна розмістити на торці водійських дверей, бічній стійці з боку водія, лючку паливної горловини або в бардачку. На табличці вказується рівень холодного робочого тиску для передніх і задніх коліс, максимальне навантаження на автомобіль і рекомендований розмір шин. Крім того, на значення тиску можуть впливати такі фактори, як вага автомобіля, розмір шин, розподіл навантаження всередині автомобіля і навіть пора року. Слід також враховувати, що тиск може змінюватися зі зміною клімату. Влітку з підвищенням температури підвищується і тиск у шинах. Наприклад, коли температура підвищується до 25°C, вона збільшується приблизно на 0,8 бар. А якщо навантаження повне, тиск буде ще більше. Тому автовиробники вказують допустиме значення тиску для навантаженого автомобіля. Це надзвичайно важливий параметр для забезпечення безпеки, який не можна ігнорувати. Взимку при зниженні температури повітря тиск у шинах також падає приблизно на 0,8 бар, що також слід враховувати при накачуванні шин. Коефіцієнт опору коченню f шини Kleber Viaxer 175/70 R13 82T оцінювали вздовж руху накатом автомобіля Лада-112. Збільшення тиску повітря на 0,05 МПа зменшує f на 1,3 %, зменшення тиску на 0,05 МПа збільшує f на 1,7 %.

Ключові слова: шина, автомобіль, коефіцієнт опору, сила тертя, прискорення, тиск, температура.

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