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tire grip; car grip; grip coefficient

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ANALYTICAL RESEARCH ON THE GRIP VARIATION OF TWO-AXLE CAR

Summary. This paper presents a theoretical investigation on the decrease in grip coefficient of a car due to the car mass changes for three different running conditions-straightforward, motion in curve and braking. The grip of two types of cars - with forward and rear traction, equipped with three models of tires are studied. The results show a significant decrease of the grip coefficient in longitudinal and lateral directions.

АНАЛИТИЧЕСКОЕ ИССЛЕДОВАНИЕ СЦЕПЛЕНИЯ ДВУХОСНОГО АВТОМОБИЛЯ

Резюме. Представлено теоретическое исследование уменьшения коэффициента сцепления автомобиля в результате перераспределения массы при трех разных режимах – прямолинейное движение, поворот и торможение. Исследован коэффициент сцепления автомобилей с передним и с задним движущим мостом, оборудованных тремя моделями шин. Результаты показывают значительное уменьшение коэффициентов сцепления в продольном и поперечном направлениях.

1. INTRODUCTION

The tire characteristics influence strongly the performance of the car, including stability, maneuverability, and safety and so on [1 - 5, 12, 14]. It is known that change of the vertical load and inflation pressure in the tire causes a variation of some tire characteristics, such as the grip coefficient in longitudinal and lateral directions, mileage of the tire and so on [2, 3, 5, 7, 8, 12, 13].

The grip coefficient depends on the braking performance and handling of the vehicle on different road surfaces [4]. Some investigations show that the tire characteristics influences the steering geometry [10] and can be taken into account in process of steering axle design [11].

Variation of the grip coefficient is studied not only for the car tires, but also for the tires of semi-trailers [10, 11] and agricultural tractors [9]. Changing of the mass distribution between front and rear axles influences the grip, the slip of traction wheels and finally on tractor efficiency [9].

In series of publications [7, 8, 13 etc.], a research group, including the author, has reported results concerning the influence of different factors, such as vertical load, inflation pressure and wheel camber, on the tire grip coefficient.

A large volume of experimental data for tires with different dimensions and construction has been collected [8]. But, the relation between the change of tire grip coefficient and variation of the grip coefficient of the whole car has not been studied enough yet.

The main objective of the paper is to support clarifying the influence of vertical load change on the car grip coefficient during different cases of motion.

2. METHODOLOGY AND RESULTS

As objects of study were chosen, 2 cars from the small class (1300-1800 cm^3) – one with front traction and one other with rear traction.

Three typical cases of motion on horizontal and dry asphalt road have been studied:

- straightforward motion with different car mass and constant speed;
- braking at constant deceleration;
- Cornering at different constant speeds and radius.

At any of the cases, there is change in the vertical load of the wheels due to the change of car mass and camber (in curve, because of turning the steering wheels and deformation of the suspension). As it is determined [2-4, 7, 9, 10], this change of the load causes the tire grip coefficient to change.

The car grip coefficients in longitudinal φ_{ax} and in lateral direction φ_{ay} were evaluated as

$$\varphi_{ax} = \frac{\sum F_{\varphi x i}}{G_a} \quad ; \qquad \varphi_{ay} = \frac{\sum F_{\varphi y i}}{G_a} \quad , \tag{1}$$

where $F_{\varphi xi}$, $F_{\varphi yi}$ are the grip forces of every tire in the respective direction; G_a – car gravity force.

The grip forces of the tires were estimated using experimental data from previously done investigation [7], for three models of tires, whose characteristics are given in Tab. 1.

Table 1

Constructive data and characteristics of used tires

Model	Country	Tread pattern type	Wear, %	Maximal load, kg	Maximal inflation pressure, MPa	Type	Layers in the carcass *
BELSHINA 175/70 R13 82H	Belarus	Winter, asymmetric	0	465	0,36	Radial, tubeless	1N+2St+2N
GOOD YEAR 175/70SR13	England	Universal, symmetric	75	465	0,36	Radial, tubeless	1Pl+2St+1N
STOMIL 165SR13	Poland	Universal, symmetric	10	465	0,36	Radial, tubeless	2Pl+2N

* N – nylon; R – rayon; St - steel; Pl – polyester

The normal reactions acting on the wheels were determined, using an iterative method [1], realized through a developed computer program.

The grip's coefficients in longitudinal and lateral directions for each wheel were evaluated on the basis of experimentally obtained relations, as a function of the tire load and inflation pressure [7].

2.1. Results for a car with rear traction

The car with rear traction has the following main technical data:

- Car mass with 1 passenger - m_a=995 kg (545 front / 450 rear axle);
- Car mass with 5 passengers - m_a=1395 kg (635 front / 760 rear axle);
- Wheel base - 2,424 m;
- Front/rear track - 1,365 m;
- wheel camber 0,5°; king pin camber 6,16°; caster angle 4°.

The investigation was done at inflation pressure p = 0,20 MPa. The results obtained are shown on Fig. 1…6.

At straightforward motion and constant speed, when the car mass increases from 995 kg to 1395 kg, the car grip coefficients in longitudinal and lateral directions decreases for tires STOMIL by 6.3% and 7.1%, respectively and for tires GOODYEAR – by 3% and 2.5% (the values on Fig. 1 and 2 at $a_b = 0$ m/s^2). The decrease is evaluated in comparison with values concerning straightforward motion, constant speed and car mass 995 kg, when the grip is maximal.

At braking (Fig. 1 and 2), when the brake deceleration increases, the grip coefficients decreases. At deceleration 7 m/s^2, the decrease of car grip coefficients with tires STOMIL is respectively 3% and 3.6% with 1 passenger; 8.6% and 9.9% with 5 passengers. With tires GOODYEAR analog values are 1.5% и 1.2% at 1 passenger; 4.2% and 3.5% at 5 passengers. Two tires showed a small minimum in curves with 5 passengers at deceleration a_b = 2 m/s^2. Additional estimations were done, which showed that at the same deceleration, a uniform distribution of the mass between the wheels were present, and as a result, the decrease of car grip coefficients were minimal.

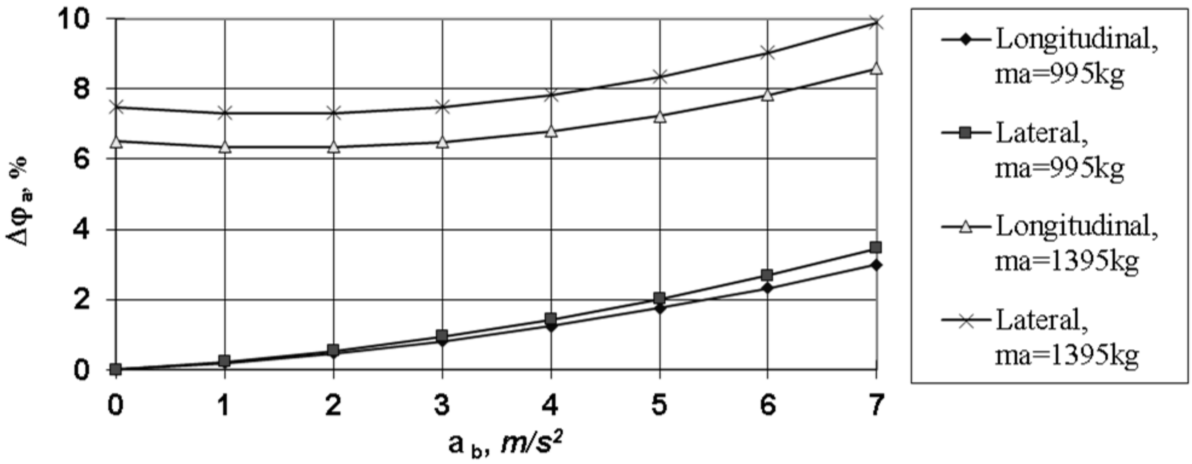

Fig. 1. Decrease of the car grip coefficients in longitudinal and lateral directions during braking with tires STOMIL 165SR13

Рис. 1. Уменьшение коэффициентов продольного и поперечного сцепления автомобиля при торможении с шинами STOMIL 165SR13

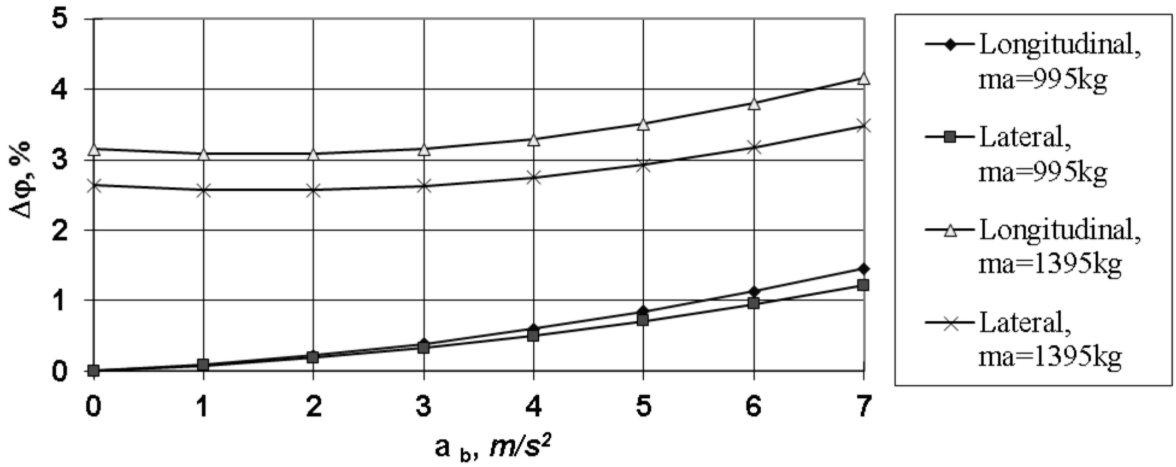

Fig. 2. Decrease of the car grip coefficients in longitudinal and lateral directions during braking with tires GOODYEAR 175/70SR13

Рис. 2. Уменьшение коэффициентов продольного и поперечного сцепления автомобиля при торможении с шинами GOODYEAR 175/70SR13

At cornering, the following regularities concerning car grip coefficients can be seen (Fig. 3…6). When the speed increases at constant radius or the radius decreases at constant speed, the car grip coefficients in both directions decreases in a non-linear mode. In these two cases of motion, the lateral acceleration and vertical load irregularity increases. In addition, different lateral inclination of the steering wheels influences the car grip. The effect of the decrease is stronger in cars with 5 passengers – it is up to 10-11% with tires STOMIL and 4-5% with tires GOODYEAR

At all cases of motion, the decrease of the car grip coefficients with tires GOODYEAR is less significant in comparison with other tire model.

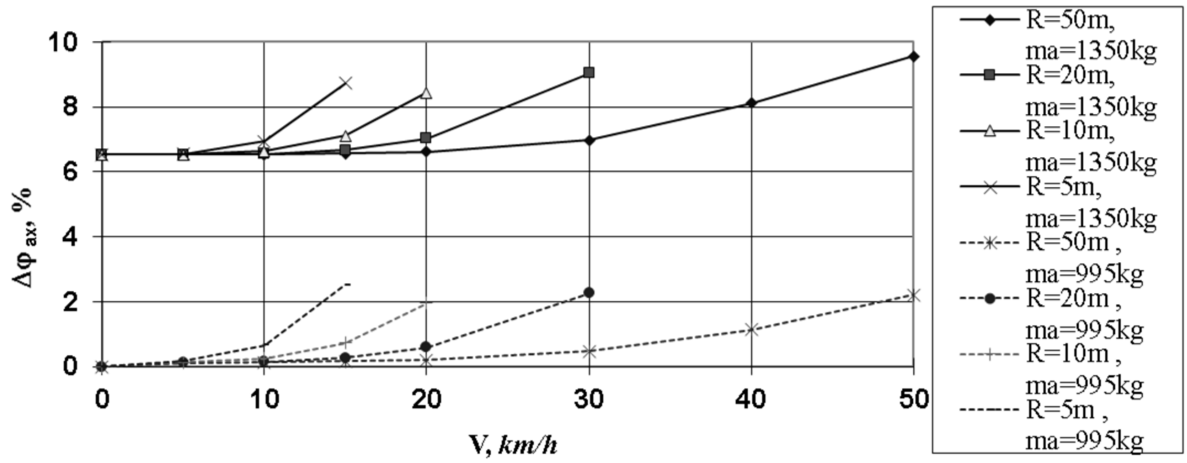

Fig. 3. Decrease of the car grip coefficient in longitudinal direction during cornering with tires STOMIL 165SR13

Рис. 3. Уменьшение коэффициента продольного сцепления автомобиля при повороте, с шинами STOMIL 165SR13

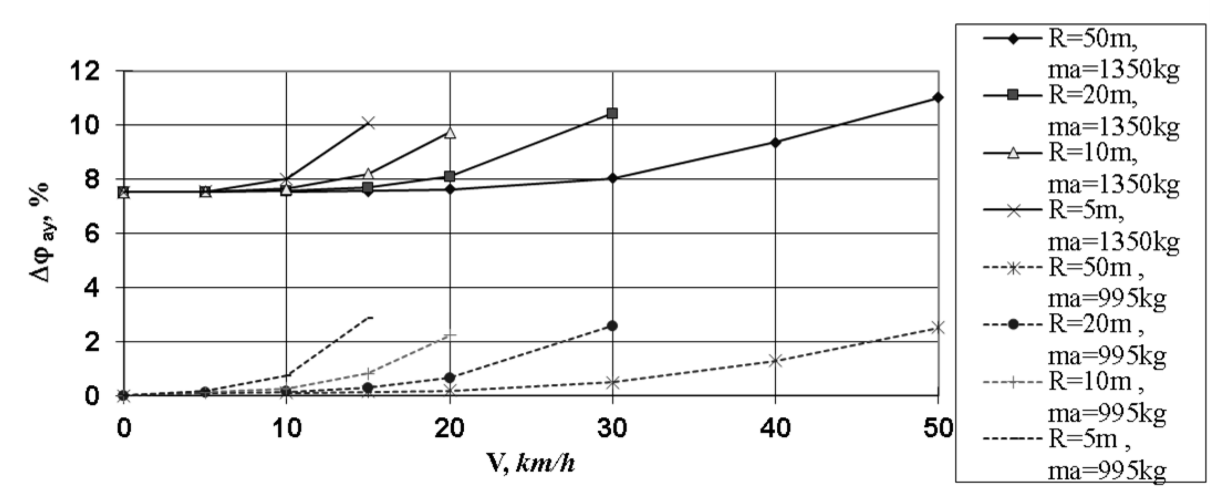

Fig. 4. Decrease of the car grip coefficient in lateral direction during cornering with tires STOMIL 165SR13

Рис. 4. Уменьшение коэффициента поперечного сцепления автомобиля при повороте, с шинами STOMIL 165SR13

2.2. Results for a car with front traction

The car with front traction has following main technical data:

- Car mass with 2 passenger - ma=1210 kg (700 front / 510 rear axle);
- Car mass with 5 passenger - ma=1520 kg (790 front / 730 rear axle);
- Wheel base - 2,492 m;
- front/rear track - 1,4 m.

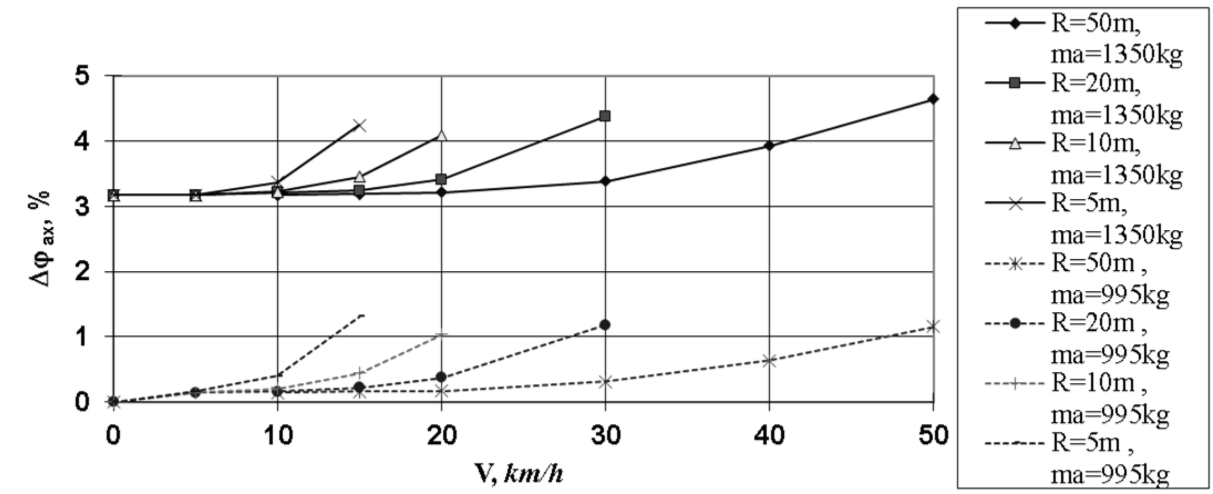

Fig. 5. Decrease of the car grip coefficient in longitudinal direction during cornering with tires GOODYEAR 75/70SR13

Рис. 5. Уменьшение коэффициента продольного сцепления автомобиля при повороте, с шинами GOODYEAR 175/70SR13

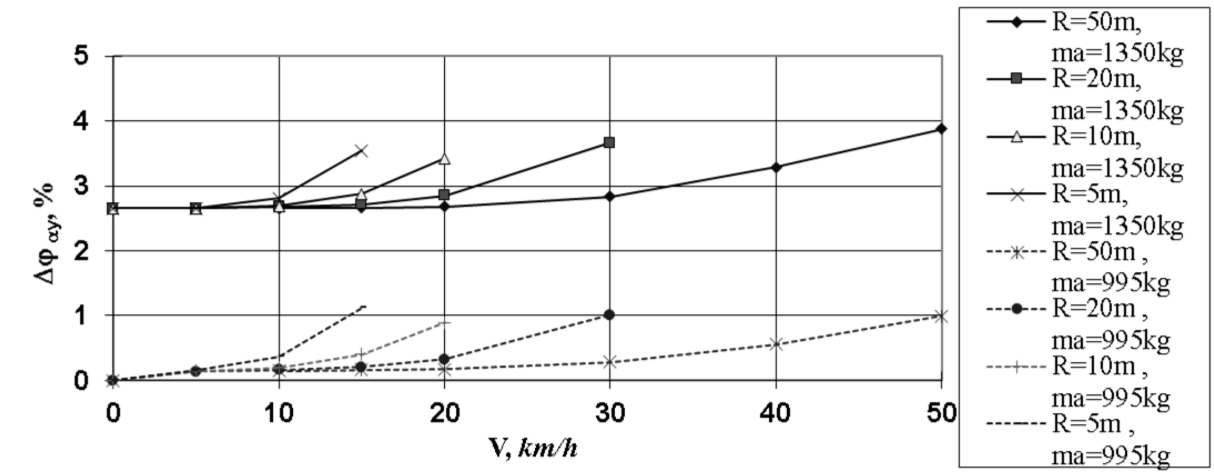

Fig. 6. Decrease of the car grip coefficient in lateral direction during cornering with tires GOODYEAR 175/70SR13

Рис. 6. Уменьшение коэффициента поперечного сцепления автомобиля при повороте, с шинами GOODYEAR 175/70SR13

The investigation was done using data for two models of tires - BELSHINA 175/70 R13 82H и GOOD YEAR 175/70 SR 13 4PR.

This time, only longitudinal grip coefficient and influence of the inflation pressure are regarded.

The results for the change of car grip coefficients with first tire model, BELSHINA 175/70 R13 82H are presented on Fig. 7 and 8. The influence of the braking deceleration is similar to that of a car with rear traction. At $a_b = 7$ m/s^2, the change in car grip coefficient is the following (Fig. 8): at inflation pressure 0.15 MPa – a decrease of 10.2%; at pressure 0.20 MPa - a decrease of 7.8% and at pressure 0.25 MPa – a decrease of 5.6%. The smallest decrease was evaluated at less car mass and high inflation pressure (Fig. 7).

On Fig. 9 and 10 are presented results with another tire model, GOODYEAR 175/70 SR 13 4PR. The same regularities as the ones with tires BELSHINA present. The main difference is a weaker influence of the inflation pressure on car grip coefficient in longitudinal direction, especially at less car mass (Fig. 9). The braking deceleration is also influenced more weakly.

On the basis of the results obtained for the car grip coefficient in longitudinal direction, the respective braking distance was evaluated with tires BELSHINA 175/70 R13 82H, braking deceleration $a_b = 7\ m/s^2$, three values of inflation pressure and two values of car mass (Tab. 2). In the third column, theoretically obtained values of car grip coefficient are shown, while in the fourth column, the values of the minimal braking distance $S_{b\ min}$ ***are*** given**.**

It is obvious that increase of the vertical load causes a corresponding increase in the braking distance. The biggest increase was obtained at low inflation pressure *p*=0.15 MPa and is 4.5%. At a bigger car mass, decrease in the pressure leads to increase in the braking distance up to 11.6%.

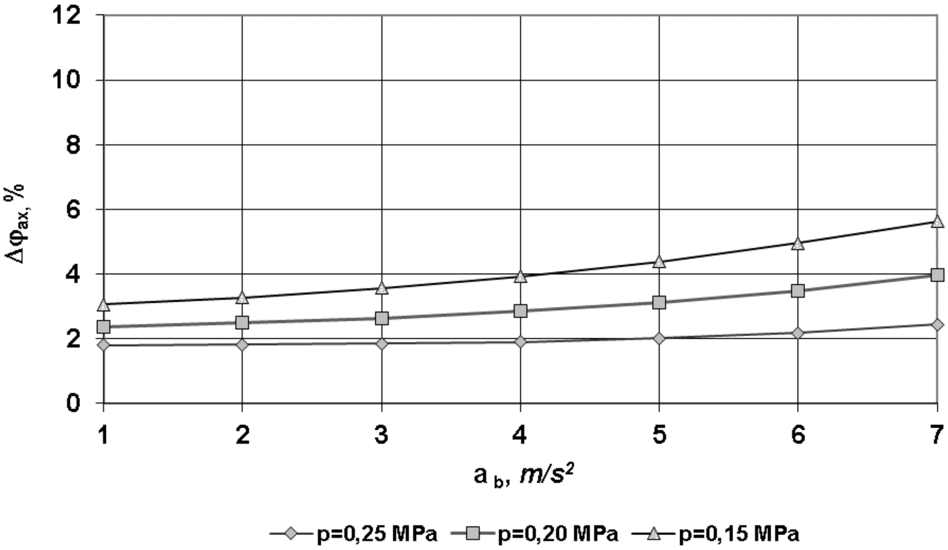

Fig. 7. Decrease of the car grip coefficient in longitudinal direction during braking with tires BELSHINA 175/70 R13 82H and car mass m_a=1210 *kg*

Рис. 7. Уменьшение коэффициента продольного сцепления автомобиля при торможении, с шинами BELSHINA 175/70 R13 82H и массе автомобиля m_a=1210 *kg*

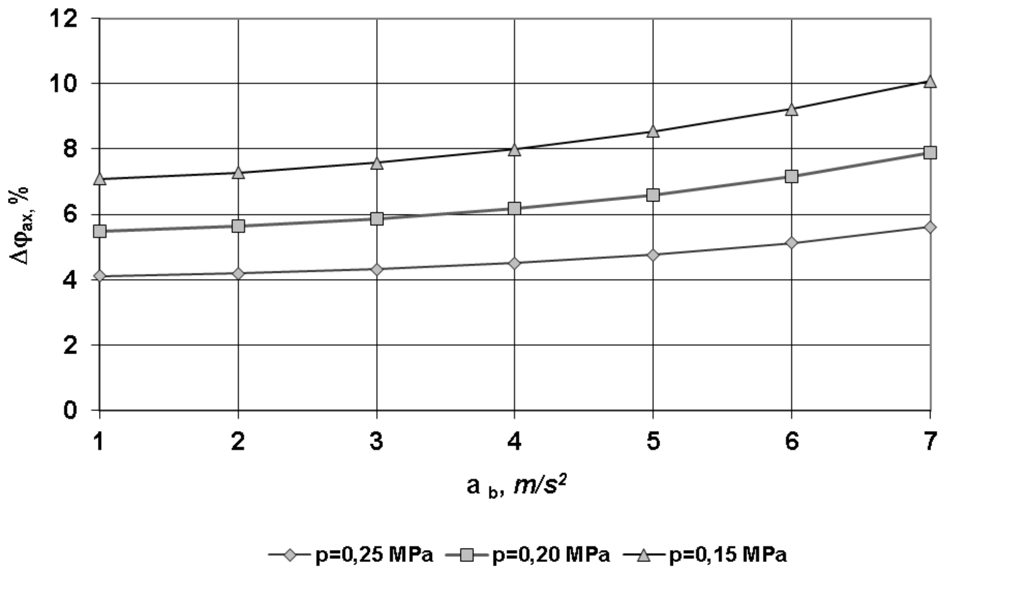

Fig. 8. Decrease of the car grip coefficient in longitudinal direction during braking with tires BELSHINA 175/70 R13 82H and car mass m_a=1520 *kg*

Рис. 8. Уменьшение коэффициента продольного сцепления автомобиля при торможении, с шинами BELSHINA 175/70 R13 82H и массе автомобиля m_a=1520 *kg*

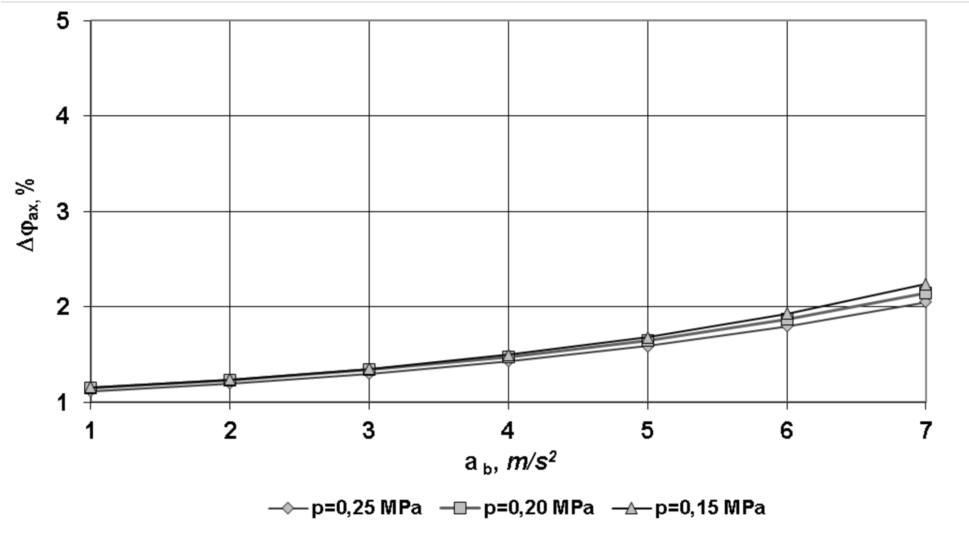

Fig. 9. Decrease of the car grip coefficient in longitudinal direction during braking with tires GOODYEAR 175/70SR13 and car mass m_a=1210 *kg*

Рис. 9. Уменьшение коэффициента продольного сцепления автомобиля при торможении, с шинами GOODYEAR 175/70SR13 и массе автомобиля m_a=1210 *kg*

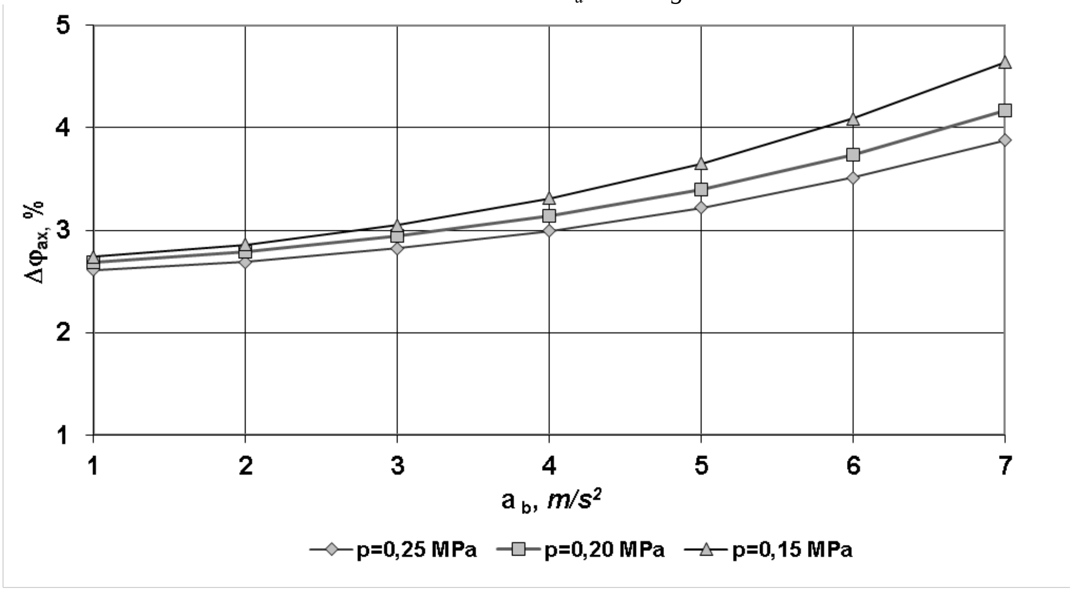

Fig. 10. Decrease of the car grip coefficient in longitudinal direction during braking with tires GOODYEAR 175/70SR13 and car mass m_a=1520 *kg*

Рис. 10. Уменьшение коэффициента продольного сцепления автомобиля при торможении, с шинами GOODYEAR 175/70SR13 и массе автомобиля m_a=1520 *kg*

An experimental verification of the analytically obtained results was done under road conditions. The results shown in the last column of Tab. 2 as $S_{b\ exp}$, prove to be at sufficient level with the theoretical results.

Similar verification was done also for the car with the rear traction and it gave approximately the same level of proof.

3. CONCLUSION

Finally, from the analytical study carried out and the results obtained, the following conclusions can be drawn:

1. With increase in mass, the car grip coefficients in longitudinal and lateral directions decrease significantly – up to 10-11% for tires STOMIL 165SR13. The effect becomes stronger during braking and, additionally, during cornering, because of the change of mass distribution between wheels and irregularity of load on different wheels.
2. The decrease in the car grip coefficient depends on the tire construction and wear. With one of the tire models, the grip coefficient decrease is over 2 times less than with another model in the same running conditions.
3. In the braking regime, with the increase in car mass, the braking distance also increases, and this has to be considered. The main cause for this effect is the change in vertical load distribution between the front and the rear axles. The increase is stronger at low inflation pressure and high braking deceleration. At the conditions of this investigation, the change of the braking distance can reach 10%.
4. From a practical point of view, to ensure good grip, the following recommendations can be made. On hilly road, with many curves, do not drive on top speed. The tire inflation pressure has to be maintained at a high possible level, especially for fully loaded vehicles.

Table 2

Results from experimental verification

***p*, MPa**	***m_a*, kg**	***φ_{ax}***	***$S_{b\ min}$*, m**	***$S_{b\ exp}$*, M**
0,25	1210	0,772	7,82	7,50
0,25	**1520**	**0,748**	**8,06**	**7,85**
0,20	1210	0,729	8,27	8,00
0,20	**1520**	**0,702**	**8,59**	**8,49**
0,15	1210	0,692	8,71	8,45
0,15	**1520**	**0,662**	**9,12**	**8,97**

References

1. Кацов, Д.А. *Изследване върху стабилизацията на управляемите колела на колесен трактор 4x2 – теглителен клас 14 kN*. Канд. диссертация. Русе, ВТУ. 1987 [In Bulgarian: Katzov, D. *Investigation on stability of front wheels of an agricultural tractor 4x2 – tractive class 14 kN*. PhD thesis. Ruse. University of Ruse. 1987].
2. Литвинов, А.С. *Управляемость и устойчивость автомобиля*. Москва: Машиностроение. 1971. 416 с [In Russian: Litvinov, A. *Steerability and stability of the vehicle*. Moscow: Machinostroenie. 1971. 416 p.].
3. Кнороз, В.И. и др. *Работа автомобильной шины*. Москва: Транспорт. 1976. [In Russian: Knoroz, V. & et al. *Work of the automobile tire*. Moscow: Transport. 1976].
4. Ezzat, M.F. & Mourad, M.A. & Yousef, M.M. Experimental Investigation of Static Friction Coefficient between Vehicle Tyre and Various Road Conditions. *International Journal of Vehicle Structures & Systems*. 2014. Vol. 6(1-2). P. 1-7. ISSN: 0975-3060. Available at: http://www.maftree.org/eja.
5. Gillespie, T. *Fundamentals of vehicle dynamics*. Warrendale. 1992.
6. Heisel, H. *Advanced vehicle technology*. The Bath Press. UK 1989.
7. Ivanov, R. & Roussev R. & Ilchev P. The influence of the normal tire forces on the vehicle's critical speed. *Proceedings of the Institution of Mechanical Engineers, Part D. Journal of Automobile Engineering*. 2007. Vol. 221. P.13-23.
8. Ivanov, R. & Rusev, R. & Ilchev, P. A laboratory investigation of tyre sliding grip coefficient. Lithuania. *Research Journal" TRANSPORT"*. 2006. Vol. 21. No 3. P. 172-181. ISSN: 1648-4142.

9. Janulevičius, & Pupinis, G. & Damanauskas, V. Effect of tires' pressure on the kinematic mismatch of a four-wheel-drive tractor. *Mechanika*. 2013. Vol. 19(1). P. 73-80, ISSN: 1392-1207.
10. Matthäus, B. Alberding. *Steering of semi-trailers.* A dissertation No. 21573, submitted to ETH ZURICH for the degree of Doctor of Sciences, presented by Dipl.-Ing. Matthäus Bernhard Alberding, University of Stuttgart. 2013.
11. Özkan, B. & Aptoula, E. & Heren, T. & Mandacı, H. & Can, Ç. *Minimization of tire wear for tractor semi-trailers with command steering.* BURSA, OTEKON 7 - Otomotiv Teknolojileri Kongresi. 2014.
12. Raimpel, J. *Fahrwerktechnik*. Vogel. Wurzburg. 1986.
13. Rusev, R. & Ivanov, R. & Capitani, R. & Angelov, B. *Variation of the vehicle grip coefficient in braking and driving regimes*. Italy. Firenze. Atti del DMTI. 2006.
14. *The Pneumatic Tire*. National Highway Traffic Safety Administration. DOT HS810561. 2006. 707 p.

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