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INFLUENCE OF OPERATING FACTORS ON THE EFFICIENCY OF THE VEHICLE BRAKE SYSTEM

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Abstract. The main system responsible for the safety of the car is its braking system. The efficiency of the braking system is assessed by several parameters, the main of which is the maximum braking force, which is generated in the braking mechanisms, usually it is disc or drum types of brakes. The analysis of peculiarities of designs of existing types of brakes of cars is carried out, advantages and disadvantages of each of them, characteristics of application and maintenance are substantiated. The main factors that have a significant impact on the efficiency of the car's brake system have been identified.

It was carried out the research of the influence of the main operational factors on the efficiency of the car's brake system: the pressure in the car's tires, contamination, and friction pairs of the brake mechanisms.

The method of conducting experimental test lane and road researches of influence of the chosen factors on indicators of braking efficiency of the car is developed. Test lane experimental studies were performed using the Bosch BSA 4340 brake test equipment, graphs of changes in the braking efficiency of each of the car's wheels based on the researches were built, depending first on the change in tire pressure, then on the presence of rust, grit, and grime and level of wear of mechanisms. The quantity of the maximum braking force of the car depending on three quantities of pressure in tires of wheels was identified: the pressure recommended by the factory of 0,18 MPa, the lowered and increased pressures 0.15 and 0.25 MPa respectively. The influence of motor oil caught in the brake mechanism or treatment with special pastes on the value of the maximum braking force is also determined. The influence of the state of the brake discs and pads on the braking efficiency of the car was also investigated, the braking indicators were measured before and after the replacement of the brake disc and pads.

On the basis of the conducted test line and road researches, conclusions are made and practical recommendations on prevention of reduction of brake efficiency of the car in the conditions of operation are offered.

Keywords: braking system, braking force, wheel alignment, experimental test lane

Introduction

Global car manufacturers indicate the acceleration time from zero to one hundred kilometres per hour in the specifications of a new car. On the other hand, there is an indicator that shows the braking time and the braking distance the car will take to reduce its speed to full stop. The vehicle's brake system is one of the key safety components of any vehicle the high requirements to which are demanded. It should provide the ability to quickly reduce the speed and full stop of the car in different driving conditions. In

researches aimed for improving the braking system, it is necessary to consider how the effectiveness of the braking system will be changed when the elements of the system are worn. Also, various operational factors have a significant impact on the change in the vehicle's braking system effectiveness, reducing the safety of the driver, passengers, and other road users. Therefore, the researches on the impact of various external influences on the car braking effectiveness, which significantly reduce the efficiency of the basic system of active safety of the car, are especially relevant today.

Problem Statement

Considering the relevance, the aim of the research was to investigate the influence of various operational factors on the braking performance of the car, using the road methods and testing lane, to determine the dependence of the influence of grime and wear of the brake mechanisms of the car, tire air pressure on the magnitude and character of the change in the braking force of the car. There is a problem of narrowing the number of factors that significantly affect the performance of the car braking system, determination of the most influential and most frequently occurring, because various factors have a significant impact on the effectiveness of the braking system in the operation of vehicles, which depend on operating conditions, the level of technical service and calendar of routine works.

Review of Modern Information Sources on the Subject of the Paper

In determining the indicators of the cars braking mechanisms, special attention is paid to their geometrical parameters, which during operation provide the ability of mechanisms to prevent the loss of friction forces when the mechanism body is heated [1, 2] and the influence of the temperature on the operation of the mechanisms [25].

A large number of authors are involved in researches on the influence of the various factors on the main indicators of the car's movement, in particular, the air pressure in the car's tires. For example, in [23] the attention is paid to the problem of ensuring the correct tire pressure in order to increase tire lifetime and reduce fuel consumption. While, it was found in [24] that the tire stiffness characteristic changes when the air pressure in the car tire decreases, which leads to an increase in the vehicle's braking distance, both straight and curved, and in insufficient steering of the vehicle.

Taking into account previous research, there is a problem of reducing the number of factors that significantly affect the performance of the car's braking system and determine the most influential ones. In fact, the factors that depend on the operating conditions, the level of technical service significantly affect the effectiveness of the braking system.

Objectives and Problems of Research

There are two types of brakes (disc and drum) are using in vehicles braking systems, their layout and size meet current requirements set by UNECE Regulation No. 13 [25].

The disk mechanisms are one of the most widespread on the passanger cars, the main working element of it is a disk, rigidly mounted on the wheel hub. The drive of the system is connected to the brake disc caliper, in which the friction pads are installed. When braking, the pads are pressed to the disk with the help of the caliper pistons, and friction between them slows the rotation of the hub [10]. For drum brakes, a drum mounted on a hub is used, instead of a disc. Inside it, two crescent-shaped pads are placed on the fixed part of the hub. When braking, the drive provides expanding of the pads, as a result, they are pressed to the drum and its rotation is slowed down [17, 19].

Drum brakes slow the car by 20–30 % less effective than disc brakes [5], due to a number of the peculiarities, such as high surface dustiness by pad wear products, unstable contact area, low yield stress and overheating. Despite the disadvantages, the low cost, the protection against grime, the high braking force (due to the large friction area) and the wear resistance of the pads encourage the widespread use of such mechanisms.

It is possible to generate a high force in disc brakes. A cast-iron disk can be compressed very strongly, the braking power is limited only by the strength of the caliper and the thermal affect on the disk

itself [11]. The disk accepts heat influence well, removes heat and wear products effectively, and disc brake mechanisms are easily accessible and maintainable [12].

It is possible to distinguish a whole list of factors that have a significant influence on the performance of the braking system [13]:

– condition and the type of frictional materials;
– structural peculiarities of the brake system as a whole (type of brake mechanisms, radius of brake disks, etc.);
– climatic conditions, road surface condition, the grime of brake mechanisms;
– condition of brake fluid;
– condition of the suspension and of the undercarriage geometry ;
– tire pressure;
– temperature mode of brake mechanisms.

The wear of the brake linings of the brake pads and the defects of the brake pads (exfoliation of the material, cracks, overheating, etc.) requires replacement of the pads since the effectiveness of braking sharply decreases [16].

To control the condition of the brake discs, it is sufficient to measure their thickness [15]. Usually, the minimum disk thickness is indicated on the disk itself. If the thickness of a disk is minimum, there are cracks, grit and other defects or deformation of a disk surface, then the replacement of both, the disk as well as brake pads, is required.

Operating conditions also affect braking effectiveness. In the case of grime of the brake mechanisms (technical fluids, dirt, water, etc.), the braking efficiency can be significantly reduced for the short term or for the long term, which threatens road safety.

The brake performance is greatly affected by the condition of the brake fluid, which absorbs moisture from the air and condensation due to the constant change in operating temperatures. This leads to its thickening in winter and permanent corrosion of the hydraulic system metal. The boiling point of the brake fluid decreases by almost 70 °C at 3 % of water dissolved in the liquid, so replacement of the fluid is recommended every 2–3 years and in the presence of sediment or other defects [9].

The state of the suspension and the geometry of the undercarriage also affects the effectiveness of vehicles braking. Extra backlash, wear of various rubber housings and joints, incorrect geometry can cause the wheel to lose contact with the road or to change the trajectory during braking.

Uneven tire wear, low tread height, tire pressure have a significant effect on the road grip coefficient. At increased tire pressure, the tire contact area with the road surface decreases, and at reduced tire pressure, fuel consumption increased and tire tread intensive wore.

The temperature mode of the brake discs also has an effect on the brake properties, with insufficient heat recoil, the brake effectiveness may be lost due to overheating of the brake discs [1]. At different temperature modes, the brake discs have some differences in brake performance [2].

By analyzing the factors that affect the braking effectiveness, we can identify factors which researched not enough and those that have a significant impact on the braking performance. It is the tire pressure, the grime of the brake mechanisms and the state of friction pair during test lane and road examinations.

Also, there is a variety of pastes in the market to improve the properties of brake pads and discs, to reduce their wear. As well, it is not uncommon for even new brake pads to creak or make unpleasant noises during braking.

The improvement of the brake properties without changing the design parameters of the brake system, but with the help of special pastes is not sufficiently investigated. This method of improving the brake properties requires research and verification of the effectiveness of the use of such pastes and other lubricants [6].

The braking process, itself, is the generation of the resistance to the motion, which is controlled by the driver or an automated system due to which the vehicle reduces speed, stops, or stays in place. The braking properties of the car are its braking efficiency and movement stability during braking (the vehicle's

ability to maintain a given direction of movement and axes orientation during braking). According to current standards, the parameters of the efficiency of braking of a vehicle in road tests include: brake path, steady deceleration. In stand tests, the braking force and the difference of the braking forces of the wheels on one axle are used [3].

The law and relevant regulations in Ukraine provide for the possibility of diagnosing braking systems by the methods of road and test lane examination.

When diagnosing the brake system of a vehicle in road conditions, the brake path or steady deceleration of a vehicle is determined. The braking force and the relative difference of the wheels braking forces of one axle are determined in test lane examination. Thus, requirements for technical condition and efficiency, not only for the regular and parking brake systems but also for the "emergancy" and auxiliary system, are established.

The research methodology is implemented on the equipment of the Training Center for Computer Diagnostics of Vehicles "Lviv Polytechnic - Bosch Academy", which has specialized equipment for diagnostic of the wheel alignment FWA 4430 and the tool control line SDL 4340, which, with the help of the test lane BSA 4340, allows to determine brake system efficiency parameters.

The structural base of the test lane BSA 4340 is a support device comprising two pairs of support rollers, a motor-reducer drives driver roller. Motor-reducer consists of an electric motor and reducer rigidly joint to it. [4]. The work of it is based on the principle of motion reversibility. The tested car is installed stationary, the "road" moves at a predetermined speed. The role of the road is performed by two pairs of rollers, on which the wheels of one axle of the car are installed. Simultaneously the testing of wheels brakes of one axis is carried out. The reactive moment of the body while breaking through the lever is perceived by a measuring system that consists of the sensor and the transformer and then transferred to the block of processing and display of information. The diameter of rollers of the stand and the distance between them are chosen for providing a stable position of cars during the brake system testing. For display of the measured magnitudes, test lanes are completed with a table, which includes the personal computer with the monitor and the printer. All the models of the BSA test lane series are completed with the device for measurements of forces which applied to the braking control systems.

The BSA 4340 test lane (Fig. 1), which is designed as monoblock with two couples of support rollers, is intended for measurements of parameters of car's brake systems.

a b

Fig. 1. A general view of the rollers of the test brake lane BSA 4340 (a) and position of the car at the test lane (b)

Diagnostics of the brake system at the test lane proceeds automatically. At turning on of the test lane equipment, the signal allowing the placing of the car on to rollers is indicated the on the monitor (Fig. 1, *b*). The front axle of the car is diagnosed first. After placing the car on to the rollers, they begin to rotate. Then

the operator performs the actions, which are specified on the monitor screen, a pedal of brakes is smoothly pressed, and he increases the brake force until the car axis will go away from rollers by the principle of reversibility of the motion.

At the end of the each stage of diagnosing, the maximum magnitudes (Fig. 2) are indicated. And we carry out measurements of the dynamics of change of the braking force (Fig. 2, *a*), determination of the maximum magnitudes for each of axes (Fig. 2, *b*) and we also define the efficiency of the parking brake for a rare axis (Fig. 2, *c*).

a b c

Fig. 2. Results of diagnosing of car brakesr: a – measurements of braking force;
b – maximum magnitudes for a front axis; c – measurements of braking force of the parking brake

Main Material Presentation

It is chosen the car Daewoo Nexia for researches. It is the car of the small middle class which was produced from 1995 to 2015. The car is with front-wheel-drive and the cross arrangement of the engine [18], it is equipped with two independent brake systems main and parking. The main brake system with diagonal division of contours is used in the car. The hydraulic drive consists of the main brake cylinder assembled with pressure regulators, the vacuum amplifier, brake mechanisms of front and rare wheels together with working cylinders and brake tubes [18]. The drive of the parking brake system is mechanical, it is carried out on brake mechanisms of the rare wheels.

Researches of brake efficiency at different values of the car's tires pressure were carried out by the means of the test brake lane BSA 4340. For the front axis of the Daewoo Nexia car the, recommended by the producing factory pressure is 0.18 MPa. Results of diagnosing at a given pressure in tires for a front axis of the car are shown in Fig. 3.

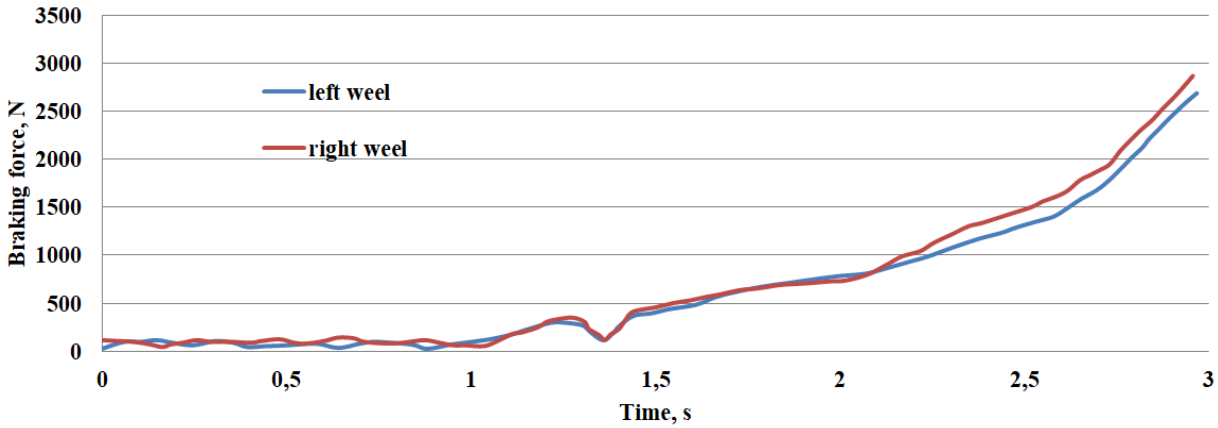
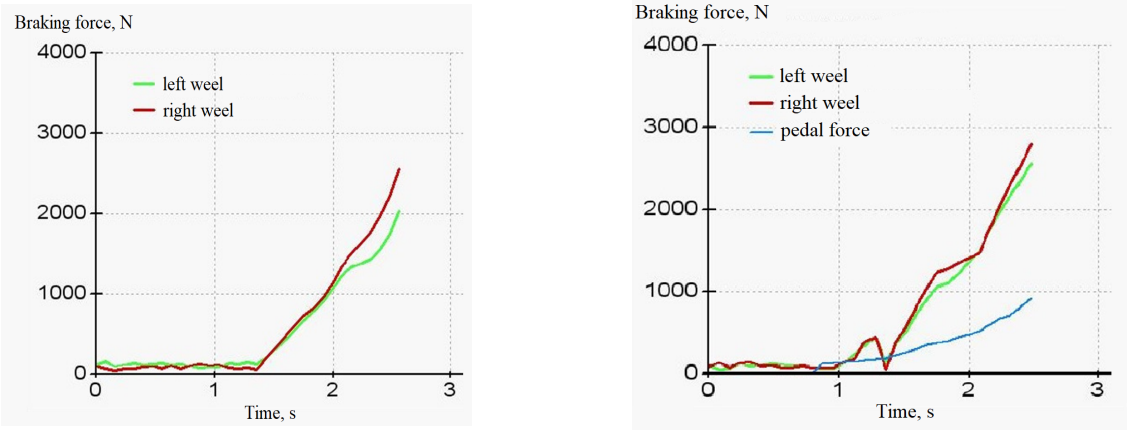


Fig. 3. Results of measurements of the efficiency of braking of a front axis
of the car at a recommended air pressure in tires

For recommended air pressure in tires, the change of indicators of braking for a front axis wheels of the car is in certain limits, the maximum braking force is 3012 N and 3102 N, the difference makes 3 %, resistance to the left wheel rolling is 166 N, to the right wheel rolling,is 157 N, the weight of a front axis is 675 kg.

Further, according to a method of carrying out tests, we set the pressure in tires less than the recommended norm at the level of 0.15 MPa by means of the compressor and the manometer. The lowered pressure increases the area of contact of the tire with a surface of rollers but brings to the increased wear of tires. The results of lane testing are given in Fig. 4, *a*. Similarly, we establish the pressure in tires above the norm at the level of 0.25 MPa. Results of measurement are shown in Fig. 4, *b*.



a b

Fig. 4. Results of measurements of the braking efficiency of a front axis of the car at lowered pressure in tires 0.15 MPa (a) and at increased pressure in tires of 0.25 MPa (b)

Also, road researches of the car tires pressure influence on indicators of its braking efficiency are carried out on the selected section of the road with a flat even covering and the reduced traffic flow with relative slope not more than 1.5 %. The research is carried out at a car speed of 40 km/h. In general, the method involves accelerating the car to a speed of 3–5 km/h more than necessary, and next disconnection of the gearbox with the engine and car rolling. When reaching the desired car speed, we are braking with the force that does not allow the complete lock of the wheels of the car. To measure speed (using GPS signal) and steady deceleration, we use a mobile phone fixed in the passenger compartment with the Accelerometer Meter app installed. The Accelerometer Meter program allows displaying the indications of the accelerometer in different modes (Fig. 5): meter (shows the accelerometer output along the axes and maximum and minimum values); graph (real-time graphical display with data storage as a text); spectrum (frequency spectrum of accelerometer data).

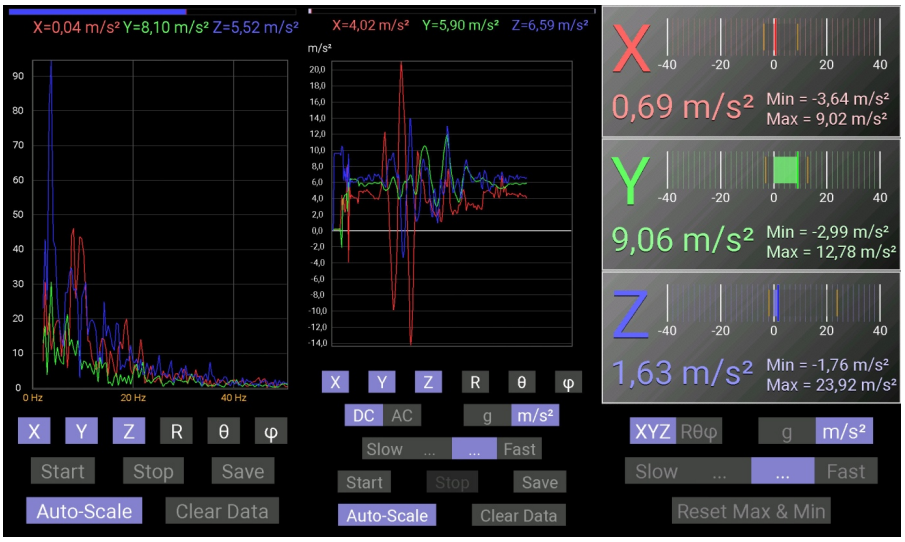


Fig. 5. Accelerometer Meter Screenshots of the accelerometer sensor signal in three views

The measurement of the brake path is carried out using a measuring tape. Results of the research are shown in Fig. 6.

a b c

Fig. 6. The results of road tests of the braking efficiency of the car at the recommended tire pressure of 0.18 MPa: a – fixed phone in the passenger compartment; b – a general view of the area for determining the traces of braking; c – screenshot of the program Accelerometer Meter

We set the tire pressure at the level of 0.15 MPa with the use of a hand pump with a pressure gauge and carry out the same researches as with the recommended tire pressure. The results are shown in Fig. 7.

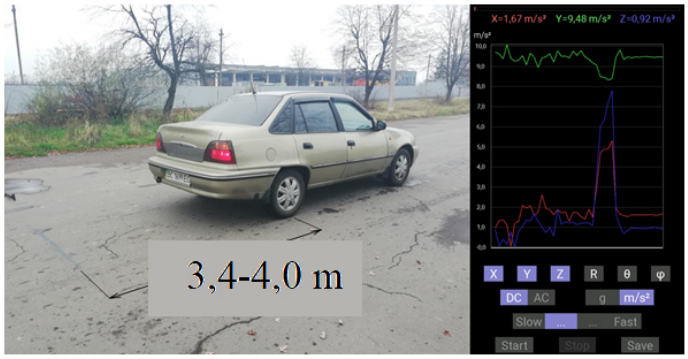


Fig. 7. General view of the section of the road for the braking traces determination and a screenshot of the program Accelerometer Meter in road studies of the braking performance of the car under reduced tire pressure of 0.15 MPa

Similarly, we set the tire pressure within 0.25 MPa. Results of the research at this tire pressure are shown in Fig. 8.

Fig. 8. General view of the section of road for the braking traces determination and a screenshot of the program Accelerometer Meter in road researches of the braking efficiency of the car at high tire pressure of 0.25 MPa

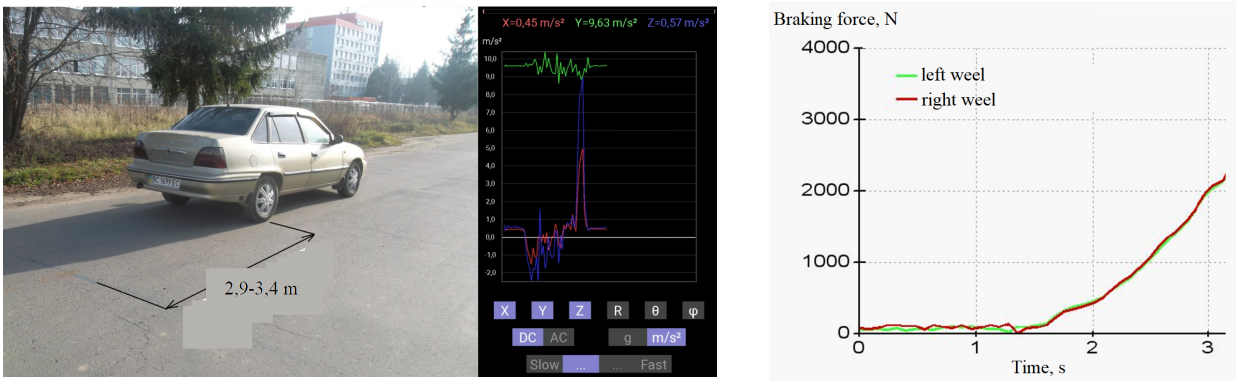
Hexagonal boron nitride was purchased to investigate the possibility of increasing the effectiveness of the car's brakes through a use of different pastes. It was chosen in the result of the analysis of forums and internet reviews. This paste is positioned as the best means of improving the brake properties. Hexagonal Boron nitride is chemically stable, not decomposed by acids and alkalis, it is a white crystalline powder, formula BN with a melting point of 3000 °C, and a density of 2.34 kg/dm^3. It is used for the synthesis of superhard materials, as an additive in obtaining refractory, high temperature, heat and electrical insulation material, as well as solid lubrication.

Boron nitrite hexagonal (the so-called “dry cream”) exists in the form of powder. For the application of this powder we use white spirit, mixing it with the powder, (Fig. 11, *a*). A mixture of BN is applied to the working surface of the brake pads (Fig. 11, *b*) and brake disks with the help of a brush (Fig. 11, *c*).

a b c

Fig. 11. Preparation for the research of the possibility of improving the effectiveness of the car's brakes with a use of pastes: a – solvent and paste boron nitride; b – brake pads after applying the paste; c – brake disc after applying the paste

After the first braking, the white spirit evaporates and boron nitrite remains on the friction surfaces. In theory, it has the property of filling the micro-irregularities contained on the surface of the brake disc and pads, which increases the contact area of the brake pads and the disc. Results of the study of the effectiveness of the paste application by the method of road research are shown in Fig. 12, *a*.



a b

Fig. 12. General view of the road section for braking trace determination and screenshots of the Accelerometer Meter program in road research of vehicle braking efficiency when applying BN paste (a) and in the laboratory conditions (b)

Using test lane (Fig. 12, *b*), the maximum braking force did not increase, but the sensitivity of the brakes increased and the possibility of dosage the braking force increased. The braking force is distributed more evenly, which improves the braking properties. After operating the vehicle, a characteristic shine appeared on the brake disc.

The effect on the brake efficiency of the vehicle's brake discs and pads was also researched. The diagnosing of the braking force was held on the brake test lane after the installation of new pads and, at the same time, road tests were carried out to examine the dependence of the brake efficiency on the condition of the friction pair.

The brake pads were replaced with new ones (Fig. 13). The brake disc is left unchanged. Immediately after replacing the brake pads, after driving a few kilometers, the diagnosing of the braking efficiency was held (Fig. 14).

As a result, the braking efficiency has been reduced because, in order to achieve better braking properties, it is necessary to drive a sufficient number of kilometers to grind new brake pads to the disc, which, due to its operation, has irregularities and defects, which reduces its effective contact area.

Fig. 13. Photo of the new FSO car brake pads

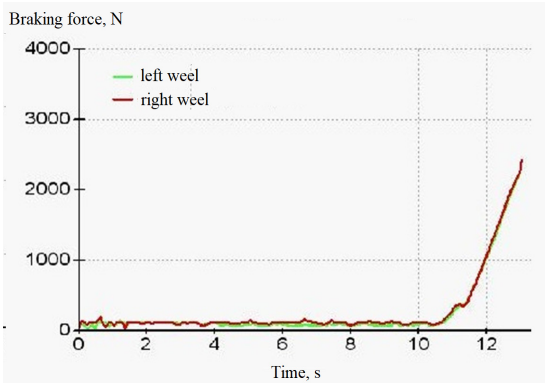


Fig. 14. Results of measurements of the efficiency of braking of a front axis of the car after installation of new brake pads (without grinding)

The additional replacement of the brake discs with new ones was carried out (Fig. 15).

Fig. 15. Photo of the general view of the brake disc before and after its replacement

After grinding a new pair of friction when a vehicle passed more than 500 km, the braking performance with a test lane was measured. The results didn't change if to compare with what measured at a normal tire pressure of the front axle braking efficiency.

Conclusions

In general, the summarized digital results of the measurements of the braking efficiency of the front axle of a car under the action of various operational factors are shown in Fig. 16. The maximum braking force of 2867 N can be clearly seen at the recommended tire pressure. All further influences of factors or improvements lead to a practically significant reduction in the maximum braking force, sometimes almost twice, when the brake mechanisms are cgrimed with the engine oil.

According to the results of the researches of the dependence of the braking performance of the car on the operational factors, the following conclusions can be made:

– compliance with the recommended air pressure in the tires of the car increases its life and also provides the maximum braking force on the wheels of all considered variants;

– at the reduced tire air pressure, the braking distance during road researches decreased by - 0.1–0.5 m, with the appearance of intense wear of the tire tread, and according to the results of testing on the test lane the braking forces decrease by 10–11 % with the increasing of the difference of the forces on the wheels of one axle of the car;

– there is an increase of the braking distance by 1–1,5 m, in the test lane researches and there is a slight decrease in the braking force (- 3 %) at high pressure of air in the tires of the car at road tests;

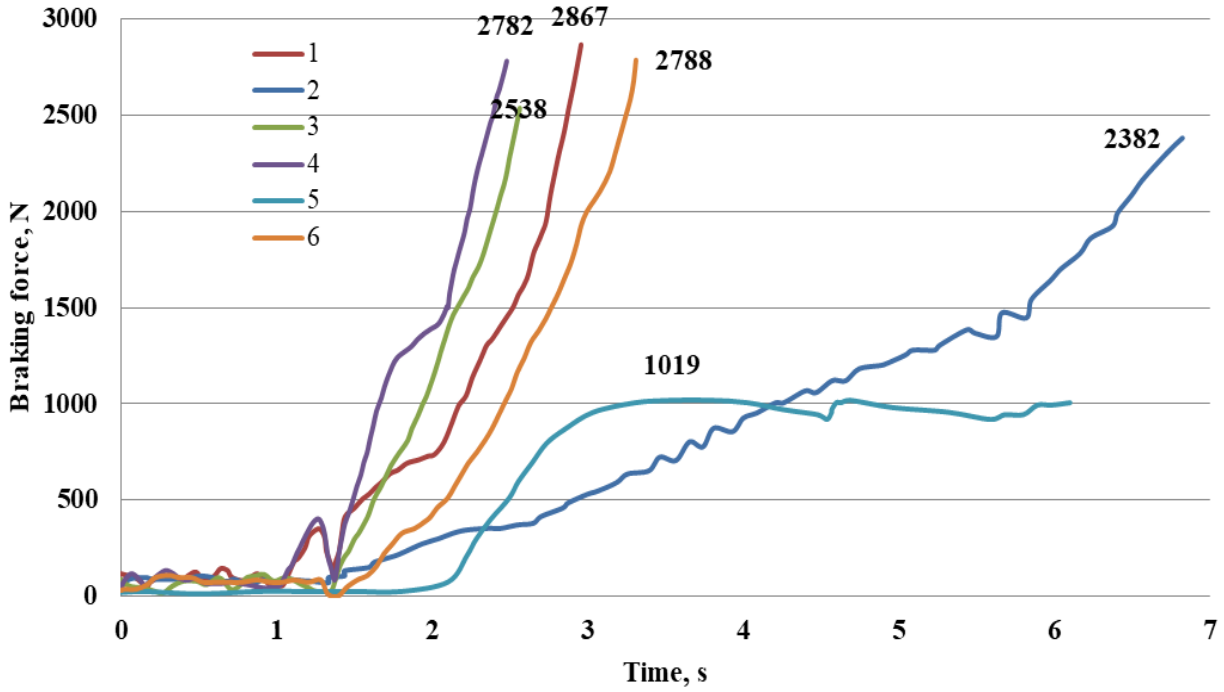


Fig. 16. Reduced results of measurements of the braking effectiveness of the front axle of the car under the action of various operational factors are summarized: 1 – at the recommended air pressure in the tires; 2 – after installing new brake pads; 3 – under reduced tire pressure; 4 – at high tire pressure; 5 – when the brake mechanisms are grimed with engine oil; 6 - when applying BN paste

– when the brake mechanisms are grimed with oil, there is a sharp decrease in the braking force (almost up to one third of the technically correct value), a double increase in the braking distance, according to road measurements, and unpredictability when operating the vehicle. The braking force reduced to 35.5 % of the maximum braking force at the recommended tire air pressure;

– when trying to improve the braking efficiency of the system using dry ceramics, there is the invariance of the maximum value of the braking force, improving the appearance of the brakes (available gloss), decreasing of the difference between the value of the forces on the wheels of one axle of the car;

– when replacing the brake pads with new ones, during the period of grinding without sufficient mileage, a slow increase of the maximum braking force is observed, a relative decrease in the braking force is 17–20 %.

References

[1] G. S. Gudz, M. V. Globtchak, O. L. Kolyasa, Ya. P. Yavorskyy, *Teplovyy rozrachunok avtomobilnyh dyskovyh galm na typovyh regymah vyprobyvan'*. Monographiya. – L'viv, Liga-Pres, 2007. [In Ukrainian].

[2] G. S. Gudz, M. V. Globchak, T. G. Mys'kiv, *Rozrakhynok parametriv dyskovogo avtomobilnogo galma stosovno energoemnosty.* Proektyvannia, vyrobnytstvo ta eksplyatacia ATZ i poizdiv. Lviv, 1995. [in Ukrainian].

[3] DSTU 3649-97. Zasoby transportny dorogny. Ekspluatatciyny vymogy bezpeky do tekhnichnogo stany ta metody kontrolyu. Kyiv, V-vo standartiv., 1997. [in Ukrainian].

[4] I. Yu. Saraeva, Otsinka galmivnoi efectyvnosty atomobilya na rolykovomy stendy z vykorystanniam obladnannia firmy Bosh. Kharkiv, *Zbirnyk naykovyh prats HNADU*., vyp. 28. s. 23–27. 2011. [in Ukrainian].

[5] V. S. Kyzmin, Metodyka eksperemental'nyh issliedovanyy eksplyatacionnyh svoistv elementov tormoznoi systiemy avtomobyley. *Nauchnyy vestnyk DGM*, Donetsk. – v.2., pp. 88–93, 2009. [in Russian].

[6] V. A. Byletskyy, *Ysovershenstvovanie metodyky y technycheskyh sredstv diagnostyky tormoznych system avtomobyley*: Avtoreferat dys. na soiskanie ychenoy stepeny kand. tehn. nauk spets. 05.22.20. "Transportnye systemy gorodov y promyshlenyh tsentrov". Kiev. 2003. [in Russian].

[7] DSTU 3333-96 Stendy rolykovy dlia perevirky galmivnyh system dorognyh transportnyh zasobiv v umovah ekspluatacii. Kyiv. Dergstandart Ukrainy/ 1996. [in Ukrainian].

[8] A. L. Burov, T. K. Makashev, *Osnovy tehnicheskogo obslygevaniya avtomobyley.* Moskva, MGYU, 2009. [in Russian].

[9] V. Derevyanko, *Tormoznyye systemy legkovyh avtomobiley*. Izdatelstvo Petit. 2006 [in Russian].

[10] L. V. Gurevych, R. A. Melamud, *Tormoznoe upravlenie avtomobilya.* Moskva, Transport. 2006. [in Russian].

[11] Y. V. Balabyn, V. Y. Salnykov, Ye. N. Nykulnykov, *Polygonnye ispytanya avtomobyley po opredelenyyu efectivnosty deystvyya tormoznyh system.* Moskva, NYYNavtoprom, 1972. [in Russian].

[12] A. A. Revyn, S. V. Tyuryn, A. S. Gavrylchnko, *Obosnovanie factorov, vlyyayushchyh na effectivnost' tormogenia v procese ekspluatacyy lehkovyh avtomobyley*. Molodoy uchenyy. 2016. [in Russian].

[13] https://mehanik-ua.

[14] https://lektsii.coml.

[15] http://autopark.pp.ua.

[16] Daewoo Nexia N100 Ustroystvo, eksplyatatsiya, obslygevanye, remont. 2002. [in Russian].

[17] https://auto.today.com.

[18] DSTU UN/ECE R 13-H-00:2004 Yedyny tehnichni prupysy shchodo oficiynogo zatverdgennya lehkovyh avtomobylyv stosovno galmyvannia (UN/ECE R13-H-00:1998, IDT) [in Ukrainain].

[19] J. Caban, P. Droździel, D. Barta, & Š. Liščák, (2014). Vehicle tire pressure monitoring systems. Diagnostyka, 15(3), 11–14.

[20] K. Parczewski, (2013). Effect of tyre inflation preassure on the vehicle dynamics during braking manouvre. Eksploatacja i Niezawodność, 15, 134–139.

[21] P. Zagrodzki, (2009). Thermoelastic instability in friction clutches and brakes–transient modal analysis revealing mechanisms of excitation of unstable modes. International journal of solids and structures, 46(11-12), 2463–2476., https://doi.org/10.1016/j.ijsolstr.2009.01.033.