Method for regulation of permissible irregularity of brake forces on front axle

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Abstract. It is justified to evaluate the car's stability during braking, not only from the ratio of braking forces but also from their absolute value. Because the ratios of the braking forces do not accurately characterize the maximum value of the turning moment from the unevenness of the braking forces, on which ¬the stability of the car ultimately depends. Depending on the braking system's characteristics, emergency braking can occur either without wheel blocking or with a certain combination of blocked wheels; due to significant differences like braking, the permissible unevenness for the corresponding type of braking should be determined according to different criteria. An algorithm for determining the permissible unevenness of the braking forces on the wheels of the front axle of the car when braking with locked rear wheels and when braking without blocking the wheels has been compiled.

1 Introduction

One of the most important problems associated with the motorization of society is the problem of ensuring road safety. Among the important areas for reducing the number and severity of the consequences of road traffic accidents (RTA) is the improvement in the ¬process of operation of vehicles of the technical condition of their brake control. It accounts for about 50% of accidents related to the faulty state of vehicles. At the same time, the established requirements for vehicle stability during braking are not clear enough and, therefore, do not -adequately contribute to ensuring road safety. This determines the urgency of improving the regulatory framework regulating the braking properties of a car in operating conditions and methods for their control. This work aims to develop a method for normalizing the permissible unevenness of braking forces on the front axle [1-7].

2 Objects and methods of research

The research methodology included the collection of statistical data on the output parameters of the brake system of taxi cars in operation, theoretical analysis of the effect of changes in the technical state of brake systems on the stability of the vehicle braking process using mathematical modeling, and experimental verification of the results obtained. The object of the study is middle-class cars.

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At present, the unevenness of the braking forces on the wheels of the same axles is normalized either as a percentage of the difference in braking forces to a larger braking force or as a ratio of the difference in braking forces to their sum. Assuming a linear dependence of the braking forces on the drive pressure, these criteria are convenient for estimating the unevenness of the braking forces during bench testing since they depend only on the ratio of the braking forces and not on their absolute value. However, this is also the reason why these criteria do not accurately characterize the maximum value of the turning moment from the non-uniformity of the braking forces, on which the stability of the car ultimately depends [8-10].

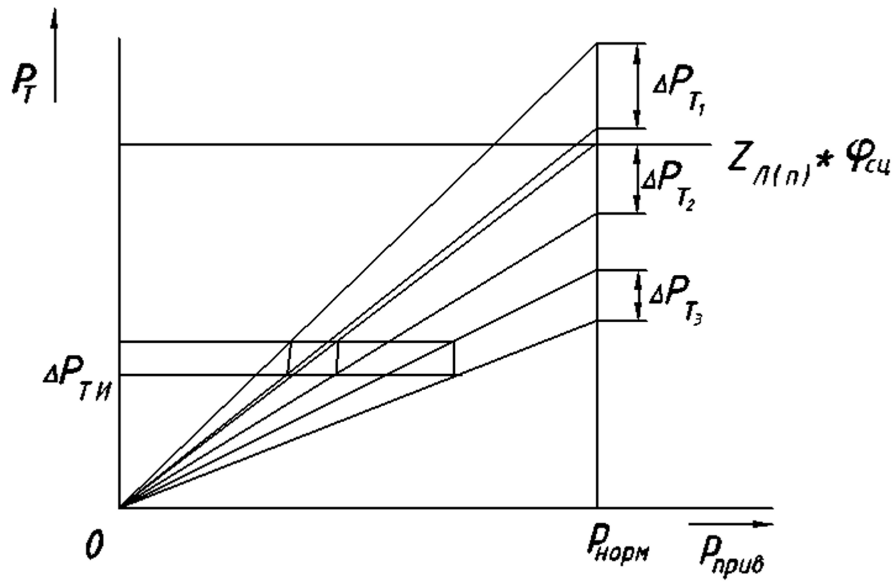


Fig.1. Influence of the efficiency of brake mechanisms on the absolute magnitude of the difference in braking forces on the wheels of the same axle.

From Fig. 1. it can be seen that depending on the magnitude of the braking forces realized under the adhesion conditions and the potential braking forces on the wheels of one axle, a car having the same relative unevenness of them can have a different operating unevenness and hence a different turning moment.

The main requirements for the stability of the car during braking are its absence from the safety corridor and limiting the angle of its turn. It is almost impossible to provide these properties in the entire range of external conditions and speed modes encountered in operation without trajectory correction using steering control, even if the vehicle's braking system is equipped with an anti-lock braking system. Therefore, it seems correct to limit the internal disturbing factors to a level that guarantees the preservation of the car's controllability and its being within the safety corridor during the driver's reaction time [5].

Depending on the characteristics of the braking system, the process of emergency braking can occur either without wheel blocking or with a certain combination of blocked wheels; due to significant differences like braking, the permissible unevenness for the corresponding type of braking should be determined according to different criteria [11-15].

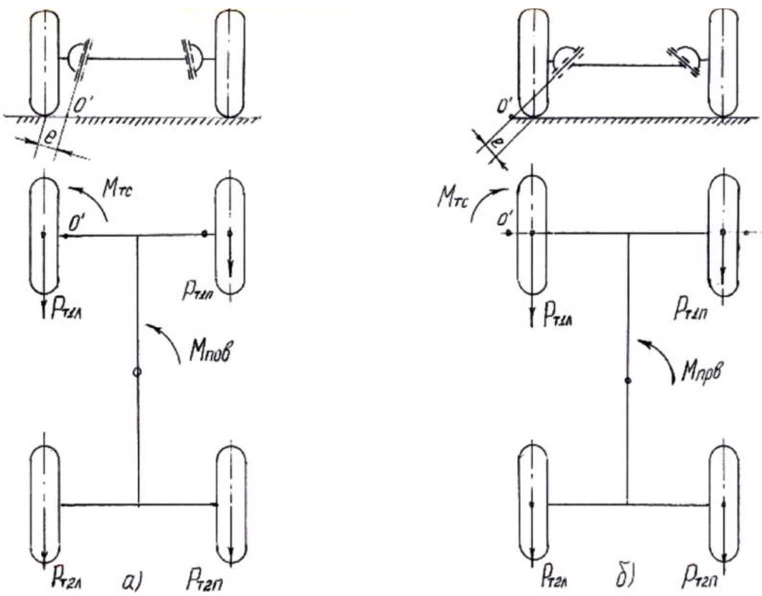


Fig. 2. Scheme of the action of the moments M $_{pov}$ and M $_{TS}$ at positive (a) and negative (b) running shoulders

The angles of the kinematic turn of the steered wheels are found in the equation:

$$J_c \cdot \theta_к = M_c + M_\lambda + M_{рк} + M_{Tc} \quad (1)$$

Where: J_c is reduced moment of inertia of the steered wheels of the vehicle and steering parts regarding axis of rotation of the wheel; M_c is moment due to tire rolling with slip and longitudinal axis tilt wheels; M_λ is reduced moment of viscous friction; $M_{рк}$ is reduced moment of elasticity of the steering; M_{Tc} is the moment due to the difference in braking forces on steered wheels.

When braking with fixed steering ($\theta_k = 0$), the steering angle and its derivative are taken equal to zero, so the moments of friction and elasticity of the steering can be ignored.

The moment from the action of lateral forces and the longitudinal inclination of the axis wheel turn:

$$M_c = N_1 \cdot r_к \cdot \sin \beta \quad (2)$$

where: β is at the goal of the longitudinal inclination of the axis of rotation of the wheel;

$r_{\hat{e}}$ **is rolling radius of the wheel.**

The moment due to the difference in braking forces is equal to:

$$M_{Tc} = (P_{Tл} - P_{Tп}) \cdot e \quad (3)$$

where *e* is wheel running arm.

As shown in Fig. 2, with a negative run-in arm, the moment M_{Tc} caused by uneven braking forces on the front axle is somewhat compensated for by the versatility M_{Tc} , and the car remains stable with a larger difference braking force on the front axle.

Braking from a high initial speed in the presence of uneven braking forces can lead to an uncontrolled skid, characterized by a complex car trajectory. Assessment of stability by finite values of turn angles of the vehicle and its lateral deviations is impossible. In addition, in a real situation, the driver, in the event of a car skid, usually tries to correct the trajectory with the help of the steering control; however, he does this not at the moment of the start of the skid, but after a certain period, called reaction time driver. For the driver's maneuver to be successful, it is necessary that the heading angle of the car by the end of this period does not exceed the critical value, after which an uncontrolled skid occurs. In this regard, evaluating stability by the magnitude of the heading angle and lateral deviation during the driver's reaction time is advisable. To determine its value, it is necessary to consider its components [1].

Before the driver can correct the trajectory of the movement, he must be informed about the deviation of the vehicle from the course. This information can be obtained in three possible ways:

- visually;
- through the lateral acceleration acting on the driver's body;
- through circumferential force on the steering wheel.

According to the data given in /2/, for the driver, changes in the heading angle and lateral accelerations that occur after 0.4 ... 0.6 s from the start of braking are most often most noticeable. This information time is added to the intrinsic reaction time of 0.3...0.5 s. The time required to turn the steered wheels, including the time of delay and actuation of the steering gear, reaches 0.2 ... 0.3 s. The total time required for information, the driver's reaction, and the operation of the steering gear are in the range of 0.9 ... 1.6 s. For brevity, in the following, this entire period of time is referred to as the driver's reaction time. Since the given range of its values is quite wide and requires specification, experimental studies were carried out, during which it was found that its average value is 1.24 s, and the maximum value is 1.5 s. Based on the driver with the worst reaction, it is taken equal to 1.5 s.

The parameters of the brake system of a vehicle that meets the requirements for braking efficiency are determined from the following expressions:

- total braking force:

$$P_T = j_{норм}^{сн} \cdot m_{сн} \tag{4}$$

- braking force on the wheels of the rear axle:

$$P_{T2} = Z_2^{сн} \cdot (j_{норм}^{сн} / g) \cdot \varphi_{сц} \tag{5}$$

- braking force on the wheels of the front axle:

$$P_{T1} = j_{норм}^{сн} \cdot m_{сн} - Z_2^{сн} \cdot (j_{норм}^{сн} / g) \cdot \varphi_{сц} \tag{6}$$

including:

- big braking force:

$$P_{T1б} = (P_{T1} + \Delta P) / 2 \tag{7}$$

- less braking force:

$$P_{T1м} = (P_{T1} - \Delta P)/2 \qquad (8)$$

When braking from a high initial speed, the car falls into an uncontrolled skid even with a slight unevenness of the braking forces on the wheels of the front axle, which is difficult to withstand under operating conditions. Therefore, when determining the - allowable unevenness, the speed of the start of braking must be limited to the minimum acceptable value, which can be taken as the most probable speed of the vehicle's involvement in the DTP. According to studies / 2 / its value is 5 bkm/h. The critical angle for a given speed, based on theoretical studies, is taken equal to 15°.

The coefficient of adhesion of the wheels to the road is equal to the maximum value since, in this case, the turning moment from unequal braking forces is the largest.

Permissible unevenness is determined for a car with a curb weight since its stability during braking in a given weight condition is worse than with a full weight.

The values of the parameters adopted in determining the coefficient of axial unevenness of the front axle are summarized in Table 1.

Table 1. The values of the parameters adopted in determining the coefficient of axial unevenness of the front axle

Parameter	Designation	Unit	Value
1	2	3	4
Driver reaction time	t_r	With	1.5
Wheel adhesion coefficient with the road	$\varphi_{\text{with c}}$	-	0.8
a) braking with blocking of the rear wheels			
Critical turn angle	ψ_{cr}	hail	15
Rate of most likely involvement in a crash	$V_{\text{road accident}}$	km/h	56
b) braking without blocking the wheels			
Maximum linear deviation of the	$l_{max} = \_ B/2$	m	1.75
Coefficient of axial unevenness of	K_{n2}	-	0.09

Determination of the permissible value of uneven braking forces of the front axle when braking with locked rear wheels. The most unstable is braking with unlocked front and locked rear wheels. In this case, the most important criterion characterizing the vehicle's stability during braking is the value of the vehicle's turn angle during the driver's reaction since exceeding the critical value of 15...20° leads to uncontrolled skidding. The main internal disturbing factor, in this case, is the turning moment from the uneven - braking forces of the front axle. Under the influence of this moment, an initial heading angle occurs, leading to curvilinear movement and skidding of the car's rear axle [6-7].

Within the M 1 category, vehicles differ significantly in terms of weight, size, and layout. To assess the influence of the listed factors on the permissible unevenness of the braking forces, calculations were performed for prototypes corresponding to cars of large, medium, and small classes. Mass distribution along the axles varied from 30 to 70% per axle. According to the calculation data, graphs of the dependence of K_n on the dimensions and mass of the car and its distribution along the axes are plotted, shown in Fig.4.

It can be seen from them that the permissible unevenness of the braking forces on the front axle increases with an increase in the mass and dimensions of the car and decreases when the center of gravity of the car shifts to the front or rear axle. An increase in the mass of the car and its dimensions leads to an increase in the moment of inertia around the vertical axis, which requires the application of a more significant turning moment to reach the critical angle in the same period. The shift of the center of gravity towards the rear axle increases the lateral force on it from the centrifugal force [3]. The shift of the center of gravity towards the front axle leads to a decrease in the moment of resistance to the lateral movement of the rear axle. In general, the influence of the location of the center of gravity of the car in the longitudinal plane is less significant than the influence of the moment of inertia, which is mainly determined by the dimensions and weight of the car. Reducing the track of the front wheels causes a smaller turning moment from the uneven braking forces with the same value.

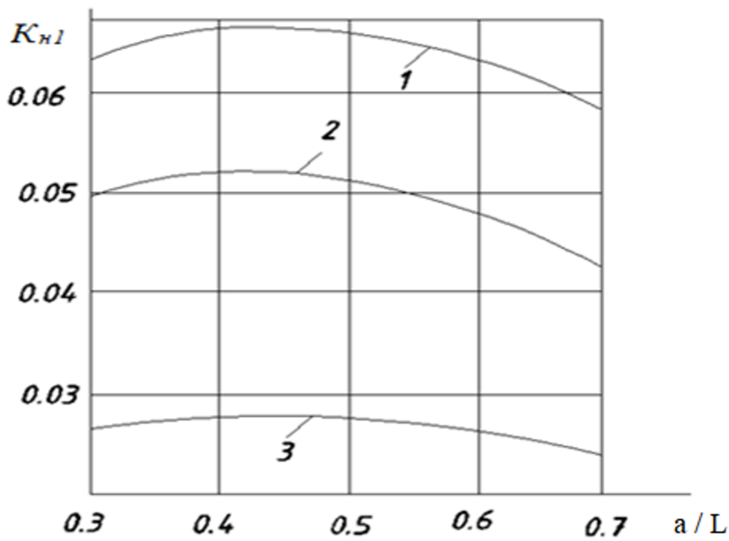


Fig. 3. The dependence of the permissible uneven braking forces on the front axis from the location of the center of gravity when braking with locked rear wheels. 1 is large class car, 2 is medium class car, 3 is small class car

Determination of the maximum permissible value of uneven braking forces on the wheels of the front axle when braking with unlocked wheels.

A car's braking with unlocked wheels is characterized by a slight lateral displacement of the center of gravity and a relatively small change in the heading angle. Therefore, as a criterion for assessing the magnitude of the maximum non-uniformity of the braking forces of the axles, it is necessary to take the permissible linear deviation of the vehicle during the driver's reaction time[8,9].

Since the braking process under consideration is the most stable, the maximum allowed speed on highways can be taken as the speed of the start of braking. Under these conditions, the admissible unevenness can be taken as its value, at which the linear deviation of the car during the driver's reaction does not exceed half the traffic safety corridor, and the wheels of the car do not have side slip [11].

Considering the results of theoretical studies, when solving the equations, the friction coefficient was taken equal to the maximum value, and the specific braking force was equal to the standard value for the total mass.

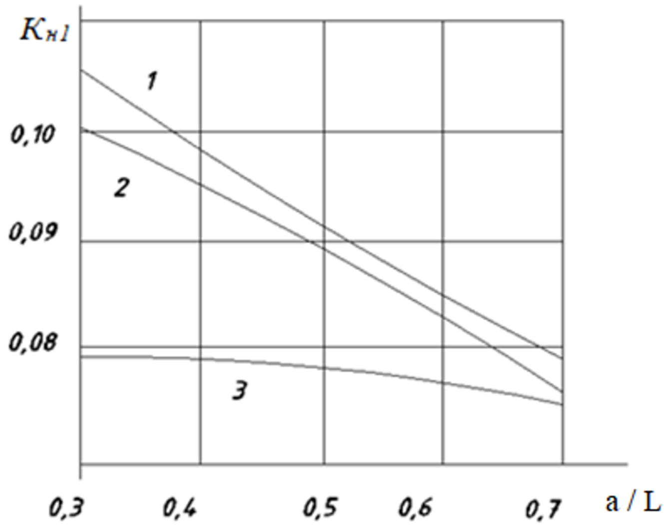
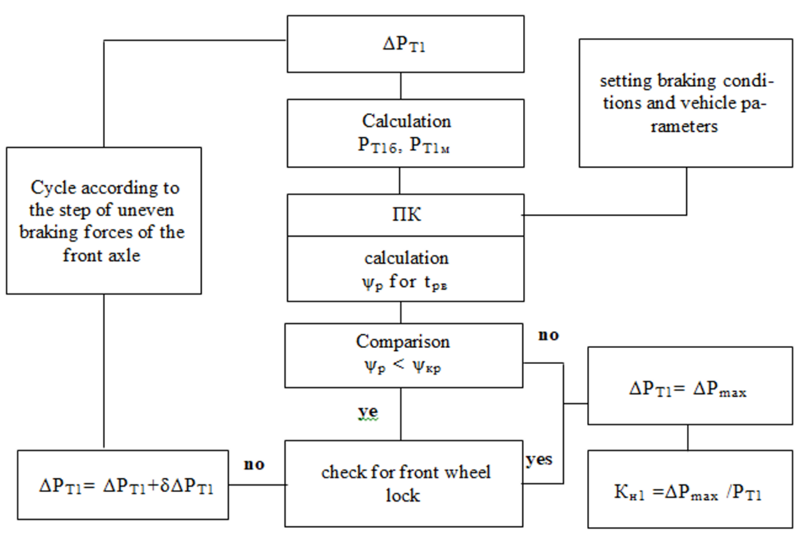


Fig. 4. The dependence of the permissible uneven braking forces on the front axis from the location of the center of gravity when braking with unlocked wheels. 1 is large class car, 2 is medium class car, 3 is small class car

When braking with unlocked wheels, the total turning moment is equal to the sum of the moments from the uneven braking forces on the wheels of the front and rear axles. The uneven braking forces on the wheels of the rear axle have a smaller effect on the car's stability when braking compared to the front axle. However, if the turning moments coincide in the direction, the stability of the car during braking deteriorates significantly. When determining the permissible unevenness of the braking forces on the wheels of the front axle, the worst case was adopted. At the same time, $K_{n2} = 0.09$, since the results of a statistical survey of the state of the brake system of vehicles in operation showed that in most cases, K_{n2} satisfies the current standards [12-15].

a) Braking with locked rear wheels



b) Braking without blocking the wheels

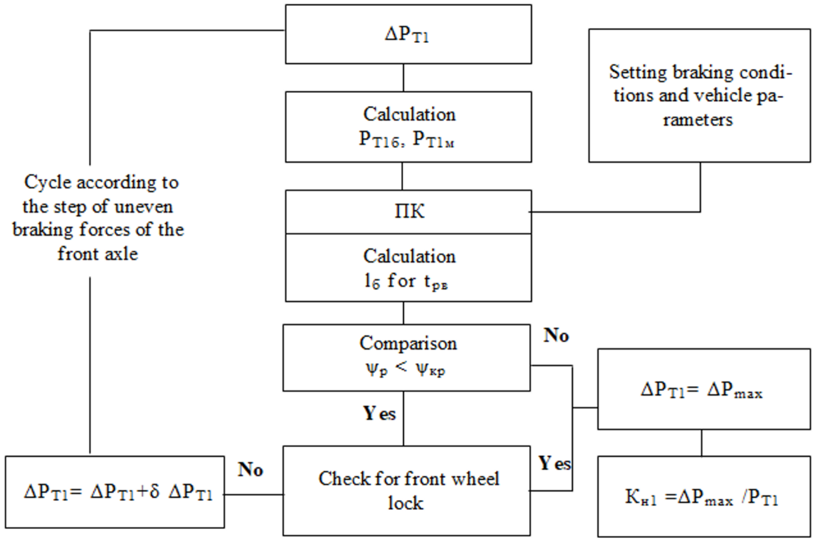


Fig. 5. Algorithms for determining the permissible uneven braking forces on the wheels of the front axle

3 Results and Discussion

Normalization of the linear deviation of the car for the mode of road tests. When controlling stability by the method of road tests, GOST establishes as a standard indicator the linear deviation of a car in any weight condition during emergency braking from a speed of 40 km/h. With an increase in the braking start speed, the sensitivity of the car's turn angle and lateral deviation to uneven braking forces increases significantly if the car does not go beyond the safety corridor (3.5 m) during testing, that is, its linear deviation did not exceed 1.75 m, this does not yet guarantee that similar results will be obtained - when braking from higher speeds. Consequently, the standard value of the linear deviation for the test speed regulated by GOST should be tightened compared to the given values, which are mainly determined by the roads' width and the vehicles' dimensions. Increasing the speed of the start of braking to bring the test conditions closer to operational ones is not advisable since this reduces the safety of tests due to the possible uncontrolled skid when the rear axle wheels are blocked; in addition, the areas required for brake tests increase significantly. Since the linear deviation standard is set for the category as a whole without taking into account the features of the braking system of specific vehicles, it is necessary to take into account various possible braking options. When braking from a speed of 40 km/h with unlocked rear wheels, or all unlocked wheels, the linear deviation of the car is insignificant, which makes it difficult to determine it instrumentally; however, since at higher speeds, the braking process proceeds with the same combination of locked wheels, the stability of the car is maintained. A more dangerous case is braking with the rear wheels locked, and even for a braking start speed of 40 km/h, the linear deviations are quite large and can be determined based on the permissible value of the braking force unevenness and vehicle dimensions. To obtain the numerical value of the standard, mathematical modeling of the braking process of exemplary vehicles was performed, the mass and geometric characteristics of which varied based on possible values within the

M1 category, the values of the variable parameters, and the calculated values of linear deviations are given in Table 2.

Parameters of exemplary vehicles adopted for modeling the braking process and permissible values of the linear deviation during braking from speed 40 km/h.

Table 2. M1 category, the values of the variable parameters, and the calculated values of linear deviations

Class car	Weight, kg	Moment inertions	Geometric dimensions, m						Linear - deviation
			D	IN	L	TO	A	h_o	
small	950	820	3.33	1.5	2.16	1.22	0.81	0.58	1.32
average	1820	3150	4.76	1.82	2.80	1.47	1.33	0.64	1.25
big	3150	7960	6.11	2.02	3.45	1.58	1.68	0.68	1.21

Based on the results of this study, taking into account the statistical composition of the passenger car fleet at the time of preparation for the revision of GOST 25478-91, the standard linear deviation for category M 1 was taken equal to 1.25 m and is given in the standard.

4 Conclusion

Based on the results of the study, the following conclusions were formulated:

1. The most unstable is braking with unlocked front and locked rear wheels. In this case, the most important criterion characterizing the vehicle's stability during braking is the value of the vehicle's turn angle during the driver's reaction time since exceeding the critical value of 15...20° leads to uncontrolled skidding.
2. Within the M 1 category, vehicles differ significantly in terms of weight, size, and layout. To assess the influence of the listed factors on the permissible unevenness of the braking forces, calculations were performed for prototypes corresponding to cars of large, medium, and small classes. Mass distribution along the axles varied from 30 to 70% per axle.
3. A car's braking with unlocked wheels is characterized by a slight lateral displacement of the center of gravity and a relatively small change in the heading angle. Therefore, as a criterion for assessing the magnitude of the maximum non-uniformity of the braking forces of the axles, it is necessary to take the permissible linear deviation of the vehicle during the driver's reaction time.
4. The analysis of options showed that, concerning passenger cars, compliance with the standard γ=0.64 and axial unevenness of braking forces on both axles K_n=0.09 does not guarantee vehicle stability during emergency braking, which indicates the existing shortcomings in the accepted system of standardization of brake performance properties. Basically, these shortcomings are a consequence of the actual implementation of the braking forces and their distribution along the axes are not considered. Simply tightening the standards to bring them closer to the values of the corresponding new vehicles in service conditions is ineffective. In addition, tightening, for example, the coefficient K_{n1} to 0.05, which is less than allowed for new cars (K_{n1} \u003d 0.08), in some cases does not guarantee the stability of the car. Thus, a new method for standardizing vehicle stability indicators is required, which takes into account the dynamics of the braking process under operating conditions.

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