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Krzysztof PARCZEWSKI
Henryk WNĘK

MAKE USE OF THE FRICTION COEFFICIENT DURING BRAKING THE VEHICLE

WYKORZYSTANIE PRZYCZEPNOŚCI PODCZAS HAMOWANIA POJAZDU*

In this publication is presented use the tyre-road friction during vehicle braking. Results presented in this publication are based on the road tests of the vehicle equipped in the anti-lock brake system (ABS). Two kinds of tests applied were carried out - the road tests of vehicle making the manoeuvre of braking on the straight section of the road and on the curve of the road. The braking forces and the friction coefficients for the individual wheels of the vehicle were defined on the basis of road tests, including the border values of the friction coefficient.

Keywords: *friction coefficient, vehicle testing, braking vehicle, curvilinear track, slip of wheels, ABS.*

W publikacji przedstawiono zagadnienie wykorzystania przyczepności opony do nawierzchni jezdni podczas hamowania. Wyniki prezentowane w publikacji oparto na badaniach drogowych pojazdu osobowego wyposażonego w układ zapobiegający blokowaniu kół. Przeprowadzono dwa rodzaje prób stosowanych do badania wykorzystania przyczepności - badania pojazdu wykonującego manewr hamowania na prostoliniowym odcinku drogi oraz na łuku drogi. Na podstawie badań określono siły hamowania oraz współczynniki przyczepności dla poszczególnych kół pojazdu, w tym wartości graniczne współczynnika przyczepności.

Słowa kluczowe: *przyczepność, badania pojazdu, hamowanie pojazdu, tor krzywoliniowy, poślizg kół, ABS.*

1. The introduction

The tyres and the road surface condition were accountable for passing on forces from the vehicle to road during the motion of the vehicle. The values of forces transferred on the surface of the road depend on the parameters of vehicle and its motion. They are limited the friction forces on contact area of the tyre - road. The phenomenon of friction occurs on the wheel contact area with the road and encloses all conditions and mechanisms be present during this co-operation. At present, vehicles are equipped in arrangements preventing locking wheels while braking (ABS) what limits the range of the changes to be in operation on the area of limited wheel slip of the braking system. The problem of the co-operation of the wheel with road were introduced in the work while braking the vehicles on the rectilinear road and on the curve of the road, the appointed border values of the friction coefficients and the variation of these coefficients got from road tests.

2. Tyre – road friction

During the motion of the vehicle the mechanism of formation of forces on the contact area of the tyre with the road appear from contiguous and normal intensity of stress in the area of this contact area. Wheel load on the road are different in every place of contact area with the tyre and change both in the longitudinal and lateral direction. While rolling the problem of the assymetry of the trace of the co-operation comes still. Every unit of the tyre, being in the contact area, is responsible for the transfer of longitudinal and lateral forces.

There are two primary mechanisms [1, 2, 3, 4, 5, 6, 10] responsible for formation of the friction forces between tyre and road: hysteresis and adhesion. The adhesion comes into rise on the surface of the adhesion the force in the result of intermolecular bonds between the gum of the tread and the aggregate in the road surface. This influence is reduced with the presence of dirts or water in the area of contact. The mechanism of the bulk hysteresis comes into being in the result of the loss of energy while deforming the gum on agregate in the road. The friction comes into being in the order of this mechanism he is not „so affected" on dirts and the presence of water.

The motion of the vehicle can be divide on compliant with the longitudinal axis of the vehicle and in perpendicular direction to this axis. The tyre-road friction can be describeed using the coefficient of adhesion (the ratio of the tyre-road friction force to the wheel load force) [2]. The coefficient of adhesion is understood, as the relation of maximum contiguous resultant force transfers by wheel to the load force working on this wheel. The temporary coefficients of adhesion were marked during the analysis using relationship:

$$\mu = \frac{W}{F_Z}$$

The tire-road friction forces enclose together force transferred on the surface of the road in longitudinal direction X_K and

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

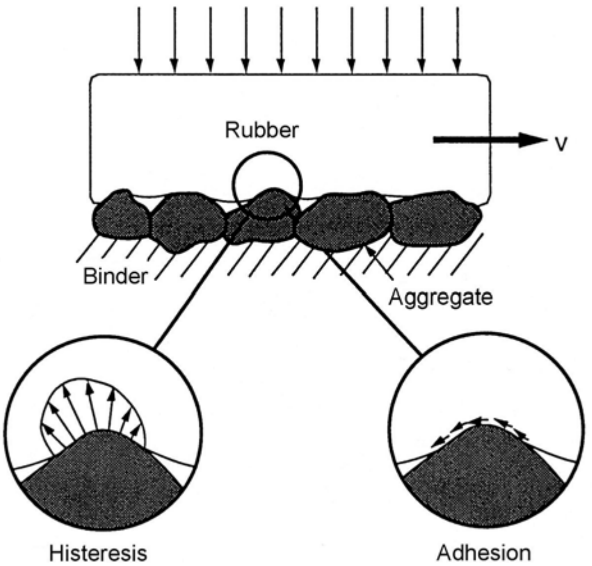

Fig. 1. Mechanisms of tyre-road friction

lateral direction Y_K. The resultant force W is limited the friction force of the wheel to the road surface F_μ.

$$W = \sqrt{X_K^2 + Y_K^2} \text{ and } W \le F_\mu$$

Considering individual wheels separately, we can assign the border values of the friction forces which can be transferred to road surface. The above mentioned relationship will simplify oneself during the vehicle motion on the straight, level section of the road because of the possibility of the omission of transverse forces. The whole wheel-road friction force can be used on braking in such case.

In the case of the vehicle motion on the curvilinear track of the road, the influence of lateralis force is smaller if the radius of turn is larger. In the case, when on wheel acts simultaneously longitudinal and transverse force with a simplify [9] one can record relationship defining the friction coefficient as:

$$\mu = \sqrt{\mu_x^2 + \mu_y^2}$$

where: μ_x - the coefficient of longitudinal friction,
μ_y - the coefficient of transverse friction.

While braking on the curve of the road the possible to use friction force in the longitudinal direction were limited by the centripetal force depend on the drive velocity and radius of turn. From this regard only part of the friction force can be used on braking the vehicle. The analysis the motion of the driving vehicle can mark what part of the friction coefficient can be used on braking on the circular track:

$$\mu_h = \sqrt{\mu_m{}^2 - \left(\frac{v^2}{g \cdot R}\right)}$$

where: μ_h - part of the friction coefficient used on braking the vehicle,
μ_m - friction coefficient (the maximum value of the relative friction force which can be got in given con ditions),
v - drive velocity,
R - radius of the track,
g – acceleration of gravity (9.81 m/s^2).

During the manoeuvres of speeding up or drive with the steady velocity (on the flat road) the whole wheels frictions is used relatively seldom. The full use of friction is more considerably often in cases of the braking manoeuvres on the straight road or on the curve track of the road, particularly during realize manoeuvres on the wet road, covered by snow or icy.

The use of anti-lock brake systems (ABS) limits the wheels slip. This will be result in the limitation of braking forces acting on the individual wheels of the vehicle.

The exploration of use of the friction of the vehicle during braking were introduced below.

3. Exploration of the tyre-road friction of the vehicle.

3.1. The assumption to exploration.

Two kinds of tests applied to the explore of use of the tyre-road friction were carry over - the testing of vehicle making the manoeuvre of braking: on the straight road section and on the curvelinear track.

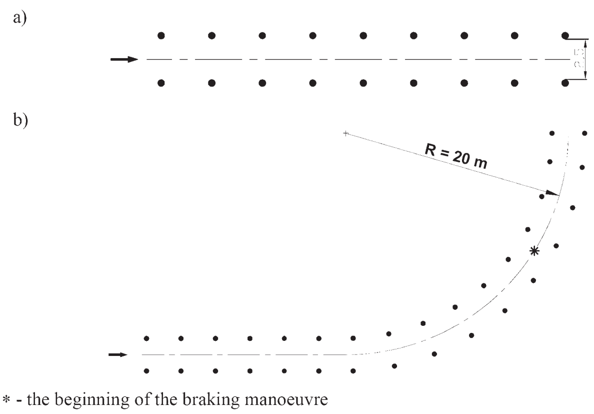

Fig. 2. The tracks of tests: a) braking on the straight section of the road, b) braking on the curve of the road

From the safety considerations the exploration was made on the dry and clean aggregate surface. The sensors were used to exploration thrusts installed in the brake system, head to the measurement of the longitudinal and lateral velocity, the sensor of force on the pedal of the brake, sensors to measure accelerations of the vehicle in directions X and Y, sensors to the measurement of the angular speeds of the motion of the car body and sensors to measurement of the turn angle and moment on the steering wheel [7, 8]. The weight of the vehicle resulted from his own weight, weight of measuring equipment and a driver.

Thus when the vehicle decelerate during braking load is transfered from the rear to the front axle in proportion to acceleration. This results in the change of the border friction forces and in the effect of the use of the anti-lock brake system (ABS), the limitation of the braking force generated through brakes individually for any wheel. The loads of the vehicle wheels were calculated on the basis of the measurements of the location of the vehicle centre of gravity, and longitudinal and lateral forces resulting from the motion conditions. The change of the location of the centre of gravity resulting from the inclination of the vehicle was not considered to calculate the forces of the load on respective wheels. Braking forces for individual wheels were assigned on the basis of measured pressure in the brake system and the geometrical parameters of brakes. The influence of the wheels inertia was considered on braking forces caused on the change of their rotative velocity.

3.2. Test of braking on the rectilinear section of the road.

First test was carried out on the rectilinear section of the road. The driver keep up for the rectilinear direction of the track. He pressed on the pedal of the brake after the obtainment of the suitable velocity. The force of the pressure on the brake pedal assured to be active the anti-lock brake system (ABS).

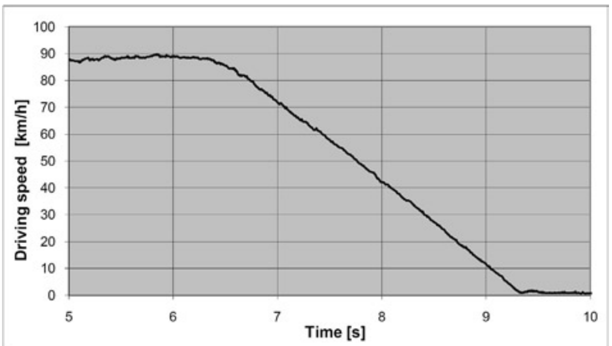

Fig. 3. The process of the driving velocity of vehicle during the test of braking on the rectilinear section of the road

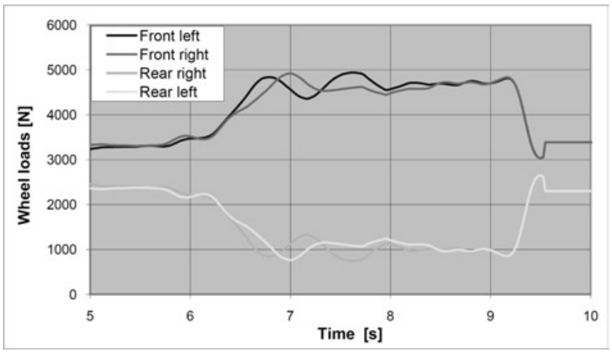

Fig. 4. The process of the loadings of the vehicle wheels during the test of brakeing on the rectilinear section of the road

On graphs were described visible braking load of front wheels and the clear difference of the quantity of braking force at the front and rear axis. Certain translation in operation of the brakes of right and left wheels were result from the inhomogeneity of background and small asymmerty of the loads of the vehicle.

3.3. Test of braking on the curve of the road.

Second test was carried out on the curved section of the road. The driver provided for steering wheel in such way the vehicle drived on the circular track. After conquest about 15 m on the circular track, the driver pressed on the brake pedal.

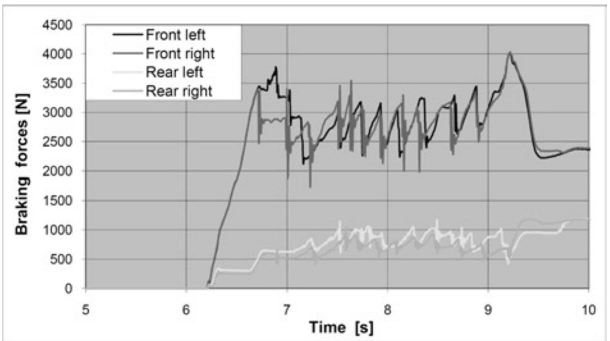

Fig. 5. The process of braking forces acting on the respective wheels of the vehicle

The force of the pressure on the pedal assured the working of the system ABS.

On figure 6 was introduced the track vehicle motion got on the drive test. Below were showed courses of loads changes of wheels (fig. 7), on the next graphs were showed forces acting on respective wheels of vehicle (fig. 8).

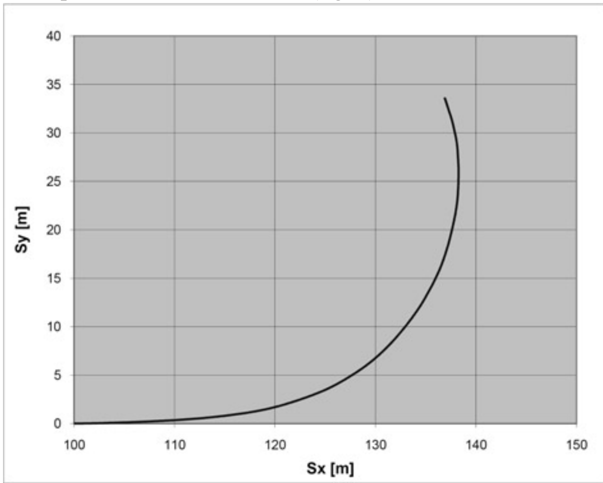

Fig. 6. The track of the vehicle motion during the test of braking on the curvelinear road

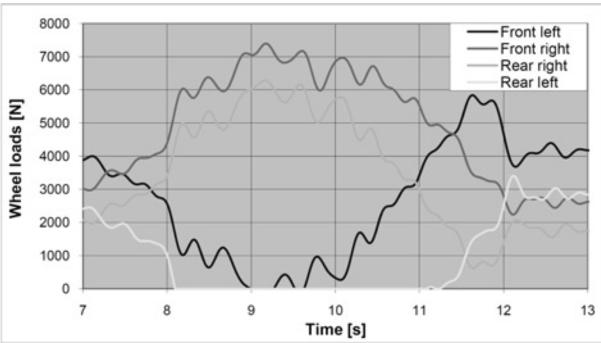

Fig. 7. The process of the wheel loads during the test of braking on the curvelinear road

On the figures were introduced visible changes of the loads on right and left wheels while braking on the curvilinear track. It can see also the clear difference of the quantity of braking forces the front and rear axis, corrected regard of the schedule of wheel loads and centripetal force acting on the vehicle. One can notice that the loads of the rear wheel left is close to the zero what is produce desired results the limitation of the brak-

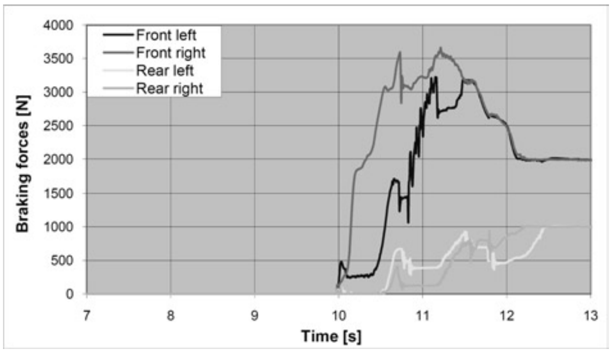

Fig. 8. The process of braking forces acting on the respective wheels of the vehicle

ing pressure by anti lock system in the circuit of the brakes of rear wheels in the initial phaze of braking and the same fall of the braking forces to small values.

4. Analysis of tests results of the friction forces utilization

Utilization of the friction forces of the vehicle wheels during the road tests of braking on the rectilinear section and on the curve of the road was calculated on the basis introduced above analyses and the results of road tests. On figures 9 and 10 was presented values appointed, the used coefficients of friction and the border values of these coefficients resulting from the conditions of the motion.

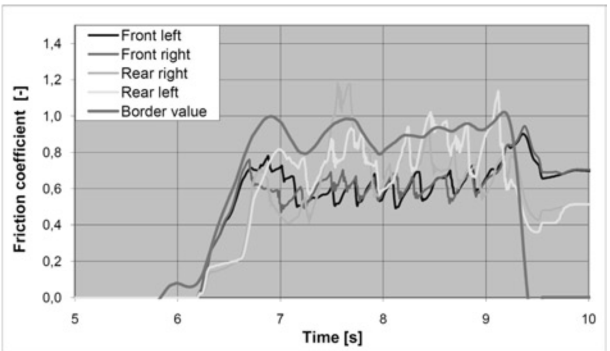

Fig. 9. Coefficients of braking friction on the rectilinear section of the road.

One can notice that in first case the maximum value of the used friction coefficient for front wheels oscillates around value 0.75, and is larger for rear wheels and oscillates around value 0.8.

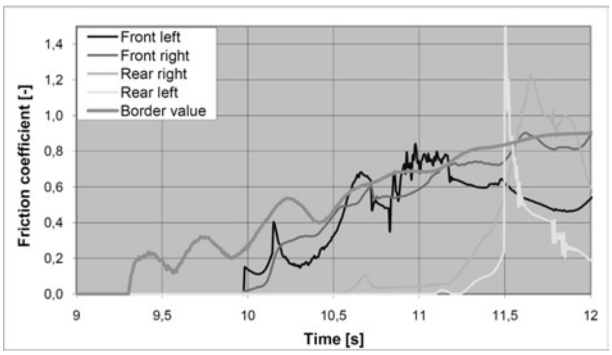

Fig. 10. The friction coefficients while braking on the curvelinear track of the road

In the case of braking on the curvelinear track of the road the level of used friction coefficient grow up from the beginning of braking to the maximum value together with with decrease of the drive velocity. The value of friction coefficient is larger for the front right wheel (with cornering load) than for left wheel. They stabilize the coefficients value after decrease of the velocity of the drive. The friction coefficients of rear wheels are clearly smaller in the initial stage of braking and they grow up to maximum values. Differences between the coefficients values for front wheels, result from the their inaccuracy of estimation caused omission of the inclination influence of the side car and from the considerable difference of the loads of the right and left side of the vehicle.

The exploration of braking the vehicle on the curve of the road allowed to delimitation of border total coefficient of friction (fig. 11) appointed on the basis of the friction ellipse.

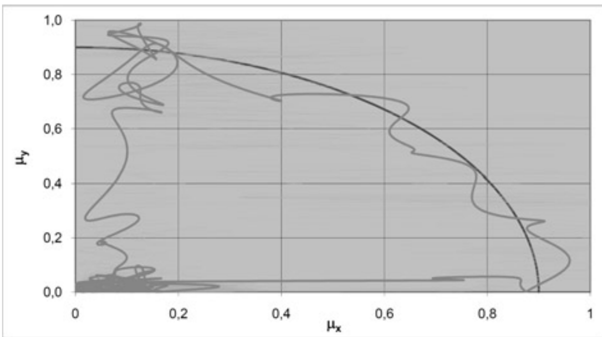

Fig. 11. The border values of friction coefficients got during the test of braking on the curve of the road (the fricrion ellipse was marked the thick line)

5. Recapitulation and conclusions.

The exploration of the friction forces acting between wheels and surface of the road, showed that the friction force (while emergency braking on the rectilinear road) is used in the complete since the initial moment of braking, until to the stop of the vehicle. Uploading of the front axis and unloading of the rear axis produced desired results the clear differentiation of pressure in brake circuits what allows to complete use of the wheels friction forces. Small difference among the individual wheels of one axis, are results depends on the local conditions of friction and is generating by small inequality and dusty surface of road.

In the case of braking on the curve of the road the limitation of longitudinal friction results from the occurrence of centripetal force. The system ABS (preventing locking the wheels while braking) does not allow to achieve large longitudinal force, assure suitable conditions on proceed lateral forces and keep of the stability of the vehicle motion. The correction arise from the motion on the curvelinear track of the road gets smaller together with from the drive velocity is smaller. The clear differentiation of the individual wheels loads, particularly the sides - right and left, it arise from the working of centripetal force. Asymmerty generated by the load the vehicle by the only driver additionally influence on the quantity of individual loads and unreeled forces braking. Similarly as while braking on the straight line section of the road, the considerable differences of pressure be presented in the circuits of brake front and rear wheels.

The friction forces of front wheels is used in the complete, however in the case of the rear wheels full use of friction follows just near the lower velocities of the drive of which the rear left wheel loses the contact with the road temporarily and rear right put under load partly. The clear growth of braking force on rear wheels follows what causes the considerable enlargement of force braking after the crossing of the border speed where switch off the ABS system. This state was showed on drawing 11, on which also is presented the border values of the friction coefficient appointed from the ellipse of friction (got from road testing).

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Krzysztof PARCZEWSKI, PhD (Eng.)
Henryk WNĘK, PhD (Eng.)
Department of Internal Combustion Engines and Vehicles
University of Bielsko-Biała
ul. Willowa 2, 43-300 Bielsko-Biała, Poland
e-mail: kparczewski@ath.bielsko.pl, hwnek@ath.bielsko.pl