Article citation info:
Gajek A. Proposed method of checking the braking efficiency coefficient for motor vehicles with hydraulic braking systems. The Archives of Automotive Engineering – Archiwum Motoryzacji. 2016; 73(3): 19-30, http://dx.doi.org/10.14669/AM.VOL73.ART2

PROPOSED METHOD OF CHECKING THE BRAKING EFFICIENCY COEFFICIENT FOR MOTOR VEHICLES WITH HYDRAULIC BRAKING SYSTEMS

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Summary

The article presents a modified method of evaluating the braking efficiency of a motor vehicle when examined on a roller brake tester with a load lower than the vehicle load capacity. For vehicles having no pressure sensor in the braking system, a modification to the existing method of extrapolation of measurement results has been proposed. For vehicles with an ESP system, provided with a pressure sensor incorporated in the hydraulic braking system, and for electrohydraulic brakes, a new calculation procedure has been proposed for checking the braking efficiency coefficient. This procedure consists in simultaneous measurements of pressure in the hydraulic system and braking forces on the roller brake tester, followed by calculation of the pressure that would generate the braking forces corresponding to the required braking efficiency. Finally, a check is made to see if the hydraulic system generates the calculated pressure when a force applied to the brake pedal not exceeds the acceptable value.

Keywords: brakes, braking efficiency coefficient, roller brake tester, brake examinations on test stands

1. Introduction

Pursuant to legal requirements, the motor vehicle braking efficiency is determined by measuring the braking forces in test stand conditions and by measuring the braking deceleration in road test conditions [1]. For motor vehicles of the M1 category (passenger cars) registered for the first time from 28 July 2010, the braking efficiency coefficient should not be lower than 58 %. This value considerably exceeds the previously required level of 50 %.

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This indicator is calculated in relation to the vehicle weight defined by the maximum authorized mass (MAM):

$$z = \frac{\sum F_h}{G_c} \cdot 100\% \tag{1}$$

where:

$\sum F_h$ – sum of the maximum values of the braking forces measured on the test stand;
G_c – vehicle weight defined by the maximum authorized mass (MAM).

The testing of a fully laden vehicle during the periodic motor vehicle inspection poses a serious problem for the diagnostic engineer. In the normal diagnostic practice, such tests are carried out for unladen vehicles. In such conditions, the tests result in wheel lockup on the test stand even at low braking forces. In consequence, many new passenger cars fail to meet the requirement of 58 % braking efficiency [2][2]. In such a case, the determining of a "computational" braking efficiency coefficient is allowed by the regulations, which has the form as follows for hydraulic braking systems:

$$z' = z \cdot \frac{P_d}{P_z} \tag{2}$$

where:

z – braking efficiency coefficient value calculated from the braking forces having been measured;
P_d – maximum acceptable value of the force applied to the service brake pedal
P_z – actual force applied to the service brake pedal, measured during the test.

This is a procedure of extrapolation of the experimentally determined dependence of wheel braking forces on the brake pedal force, based on the maximum acceptable pedal force value P_d (for passenger cars, P_d = 50 daN, according to [1]). Such a procedure is required by the Regulation currently effective [1]. For power-assisted brakes, however, it gives physically absurd results, unobtainable in real braking conditions because the maximum possible braking forces, defined by the tyre-to-road adhesion, are achieved when the brake pedal force is much lower than the permissible maximum. It should also be noticed that for braking systems provided with braking force regulators acting by limiting the brake fluid pressure, the said dependence is non-linear. In electrohydraulic brakes, there is no direct relation between the brake pedal force and the brake fluid pressure with the resulting wheel braking moment. The required values of brake fluid pressure in wheel brake cylinders are calculated by a computer program and implemented by controller-operated hydraulic valves.

A correct method of checking, on a test stand, whether a vehicle meets the braking efficiency requirements defined by formula (1) would be testing the vehicle loaded to the maximum authorized mass (MAM). This would make the diagnostic engineer's work more difficult and lengthen the test time.

This article shows a modified method of checking the braking efficiency coefficient, applicable in the case that an unladen vehicle examined on a roller brake tester fails to meet

[2] The survey carried out by a German organization FSD revealed that only 42 % of new passenger cars met the required criterion of 58 % braking efficiency coefficient when tested in unladen condition at Vehicle Inspection Stations.

the requirements; this method reflects the development of vehicle brakes as mechatronic systems, which make it possible to examine the vehicle on a test stand with taking into account the information obtainable from the on-board vehicle diagnostic system.

2. Measurement principle

The proposed measurement and calculation procedure intended for motor vehicles with braking systems having no brake fluid pressure sensor and braking force regulator [3] is run as follows:

1. The front wheel braking forces F_{hp} on the roller brake tester and the force applied to the service brake pedal are measured and recorded until the front wheels are locked up.

2. The rear wheel braking forces F_{ht} and the brake pedal force are measured and recorded until the rear wheels are locked up or the force applied to the service brake pedal reaches its maximum acceptable value.

3. The front and rear wheel braking forces (F_{hp} and F_{ht}, respectively) corresponding to the brake pedal force P_{z1} at which the front wheels get locked up, are totalled, Fig. 1a (in most cases, the rear wheels get locked up at a higher brake pedal force or are not locked up at all):

$$F_{hp}(P_{z1}) + F_{ht}(P_{z1}) = F_{h1}(P_{z1}) \tag{3}$$

4. The sum of the front and rear braking forces, F_{hwym}, necessary to achieve the required braking efficiency z_{wym} for the vehicle when fully laden, is calculated as follows or read from the table of reference data for the vehicle under test:

$$F_{hwym} = 0.01 \cdot z_{wym} \cdot G_c \tag{4}$$

5. The force that should be applied to the service brake pedal P_{zwym} (Fig. 1a) for the total braking force F_{hwym} to be obtained is calculated:

$$P_{zwym} = F_{hwym} \frac{P_{z1}}{F_{h1}} = 0.01 \cdot z_{wym} \cdot G_c \cdot \frac{P_{z1}}{F_{h1}} \tag{5}$$

6. A check is made to see whether the required force P_{zwym} can be applied to the service brake pedal and does not exceed the maximum acceptable value P_d = 50 daN. Affirmative answers to both questions have the meaning that the system under test is capable to achieve the required braking efficiency value z_{wym}.

This procedure will be valid if the relation between the brake pedal force P_z and brake fluid pressure p and, simultaneously, the performance curve of the brake booster system are linear.

The other checks, i.e. inspection of the resistance of non-braked wheels to motion, side deformation (runout) of brake discs or ovality of brake drums, differences between braking

[3] The braking systems meant here are provided with an ABS (Anti-lock Braking System) featuring the EBD (Electronic Brake-force Distribution) function, without an ESP (Electronic Stability Program) system.

forces on wheels of individual axles under test, are carried out on the grounds of braking force measurement results.

The method of linear extrapolation outside of the range under test is inappropriate for vehicles with mechanical braking force regulators. The pressure-operated regulators cause a breakpoint to appear in the wheel braking force vs. brake pedal force (F_h (P_z)) curve and the inertial or load-dependent regulators assume their static positions during tests carried out on test stands. For such vehicles, the braking forces may only be checked if the vehicle is fully laden.

For vehicles with an ESP (Electronic Stability Program) system, provided with a pressure sensor incorporated in the hydraulic braking system, and for vehicles with electrohydraulic brakes (EHB)[4], a new calculation procedure has been proposed to check the braking efficiency for conformity with requirements. In this procedure, the fluid pressure in the master brake cylinder (or in the hydraulic system of the vehicles with EHB or SBC (Sensotronic Brake Control) brakes) is measured simultaneously with the braking force F_h measurements carried out on a roller brake tester.

The inspection procedure is run as follows:

1. The front wheel braking forces F_{hp} are measured and recorded on the roller brake tester and the fluid pressure p in the vehicle's hydraulic system is measured and recorded with the use of a tester connected to the on-board diagnostic link until the front wheels are locked up.

2. The rear wheel braking forces F_{ht} and the fluid pressure p in the vehicle's hydraulic system are measured and recorded until the rear wheels are locked up or the force applied to the service brake pedal reaches its maximum acceptable value.

3. The front and rear wheel braking forces (F_{hp} and F_{ht}, respectively) corresponding to the fluid pressure p_1 at which the front wheels get locked up, are totalled, Fig. 1b (in most cases, the rear wheels get locked up at a higher fluid pressure or are not locked up at all):

$$F_{hp}(p_1) + F_{ht}(p_1) = F_{h1}(p_1) \tag{6}$$

   The braking systems provided with an ESP system do not include a braking force regulator, whose function is performed by the EBD[5] system. Therefore, the relation between the brake fluid pressure in wheel brake cylinders and the brake pedal force during measurements carried out on a test stand is identical for the front and rear wheels. This makes it possible to add up the values of the front and rear wheel braking forces as functions of the fluid pressure and reflects the actual growth in these forces.

4. The sum of the front and rear braking forces, F_{hwym}, necessary to achieve the required braking efficiency z_{wym} for the vehicle when fully laden, is calculated from equation (4) or read from the table of reference data for the vehicle under test.

[4] Such vehicles have no braking force regulators.

[5] EBD stands for Electronic Brake-force Distribution.

5. The fluid pressure p_{wym} required for the total braking force F_{hwym} to be obtained is calculated according to the following equation:

$$p_{wym} = F_{hwym}\frac{p_1}{F_{h1}} = 0.01 \cdot z_{wym} \cdot G_c \cdot \frac{p_1}{F_{h1}} \tag{7}$$

or determined from the graph presented in Fig. 1b:

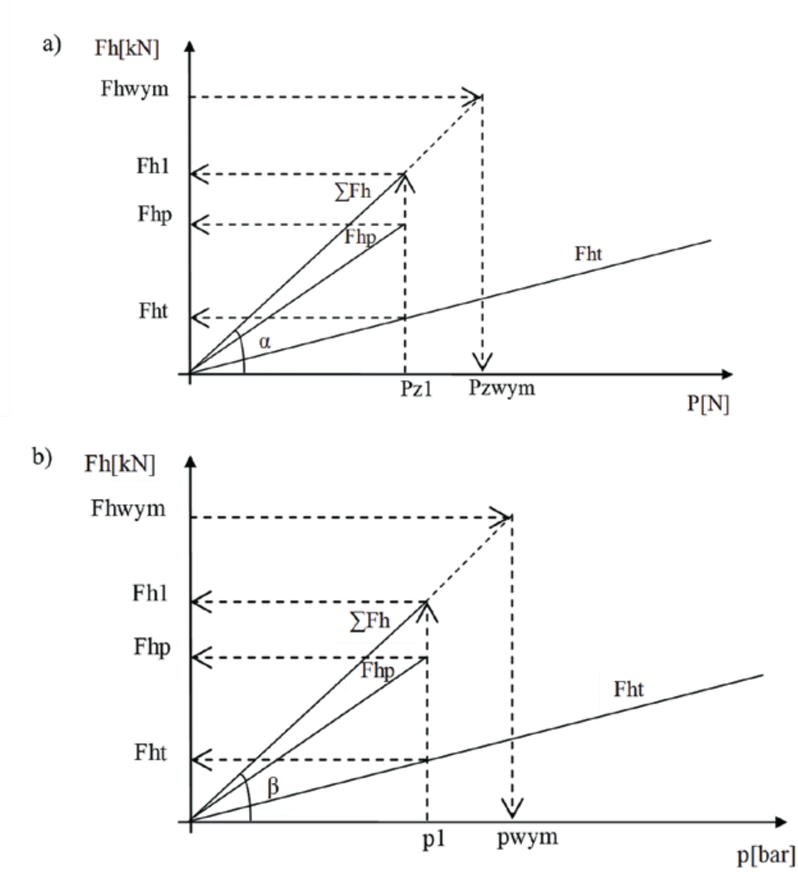

Fig. 1. Schematic diagrams showing the procedure of determining the force that should be applied to the brake pedal, or the brake fluid pressure that should be generated in the system, for the required braking efficiency coefficient to be achieved: a) for a braking system without a fluid pressure sensor; b) for a braking system with a fluid pressure sensor; for the notation used, see the text

6. A check is made to see whether a pressure $p > p_{wym}$ is generated in the system when a force not exceeding the maximum acceptable value P_d = 50 daN is applied to the brake pedal. An affirmative answer to this question has the meaning that the system under test is capable to achieve the required braking efficiency value z_{wym}.

The distribution of braking forces to the front and rear axles can be calculated as well, based on measurements of the wheel braking forces at the same fluid pressure in the braking system.

The procedure described above requires that a diagnostic tester should be linked to the vehicle's OBD (On-Board Diagnostic) connector and to the controller of the roller brake tester. This will make it possible to record the values of the fluid pressure in the hydraulic system simultaneously with the braking forces and afterwards to automatize the calculation cycle and assessment of test results.

The uncertainty of this method arises from the assumption of linearity of the relation between the wheel braking forces and the fluid pressure in the hydraulic system or the brake pedal force, while the test results are approximated outside of the range under test (the part of the $\sum F_h$ curve plotted in Figs. 1a and 1b with a broken line). On the other hand, it is a good point that the approximation range is limited to the values necessary for the achieving of the required braking efficiency coefficient and in many cases, it only applies to the curve representing the front wheel braking forces.

3. Test results

The method described above was experimentally verified for hydraulic brakes with an ESP system. The only load of the vehicles under test was a diagnostic engineer. The tests were carried out on a roller brake tester at a tangential velocity of vehicle wheels equal to 5 km/h [5]. The software of the test facility makes it possible to record the wheel braking forces and the brake pedal force as functions of the test time. The brake fluid pressure, generated by the master brake cylinder, was measured by pressure sensors installed in the vehicles as elements of the ESP system; it was recorded by a CDiF3 diagnostic tester. Example results of measurements of the wheel braking forces as functions of the fluid pressure in the hydraulic braking system have been presented in Fig. 2. Fig. 3 shows results of measurements of the wheel braking forces as functions of the brake pedal force.

The front wheel braking forces were measured until the wheels were locked up; for the rear wheels, the braking forces were measured until the brake pedal force value became about twice as high as the maximum pedal force value reached at the front axle brakes test.

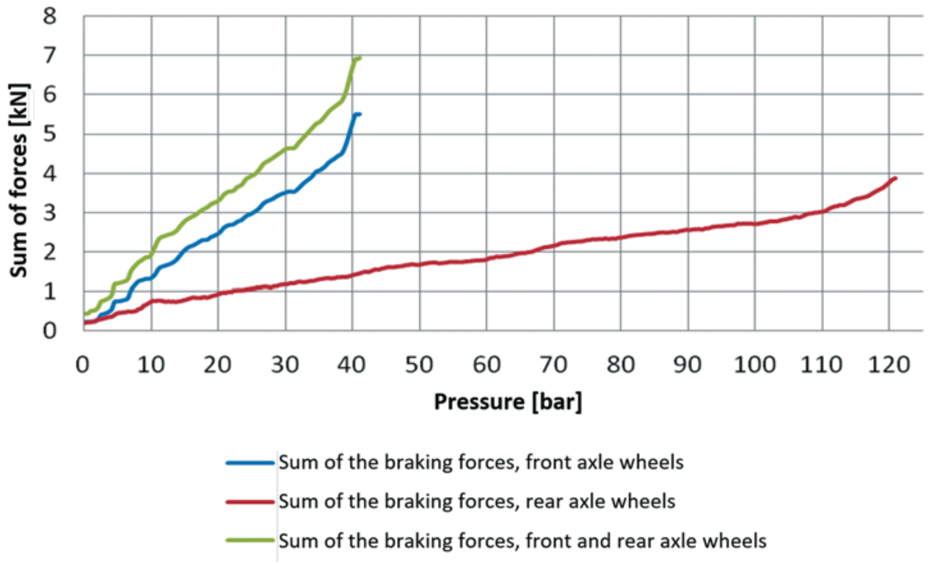

Fig. 2. Front and rear wheel braking forces vs. fluid pressure in the hydraulic braking system (hydraulic brakes with an ESP system)

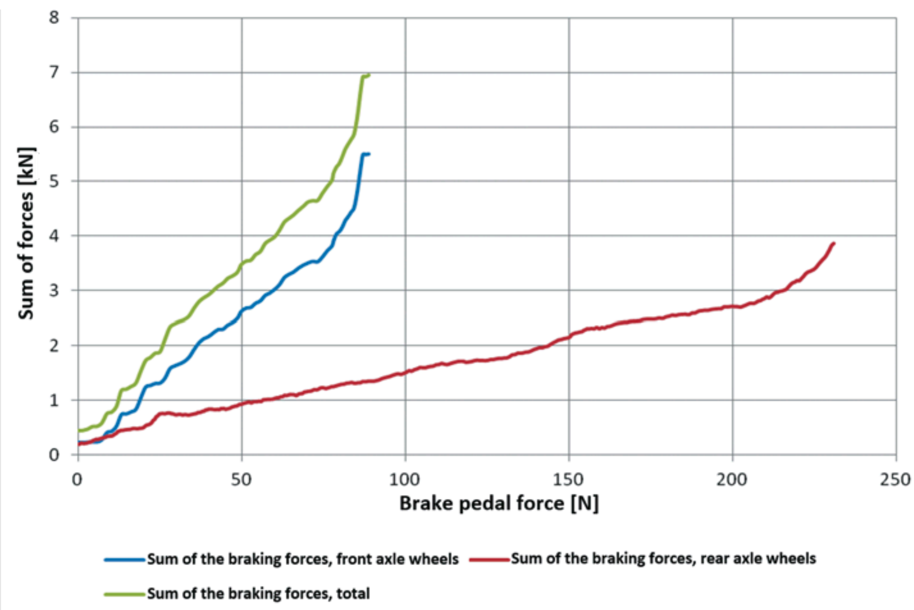

Fig. 3. Front and rear wheel braking forces vs. brake pedal force

In the relations between the wheel braking forces and the brake fluid pressure and brake pedal force, a non-linearity can be observed, which is particularly well visible when the front wheel braking forces approach their maximum values, see Fig. 2. In this phase, the rotational velocity of the front wheels declined due to increasing tyre slip until the wheels stopped (i.e. until they were locked up). Author's research [3] has shown that a decline in the rotational velocity of vehicle wheels, i.e. a decrease in the friction velocity in the brake friction pair, caused an increase in the value of the coefficient of friction between brake pads and brake discs at a constant brake pedal force (see Fig. 4). This phenomenon resulted in a non-linearity of the $F_h\,(p)$ curve. In the conditions of actual vehicle braking on a road, this manifests itself in an increase in the braking deceleration immediately before the vehicle comes to a stop. For the rear wheels, which were not locked up, the non-linearities of the relations between the braking forces and the fluid pressure are not so strong.

The course of the process of vehicle braking on a roller brake tester was analysed in the works described in publications [3, 4].

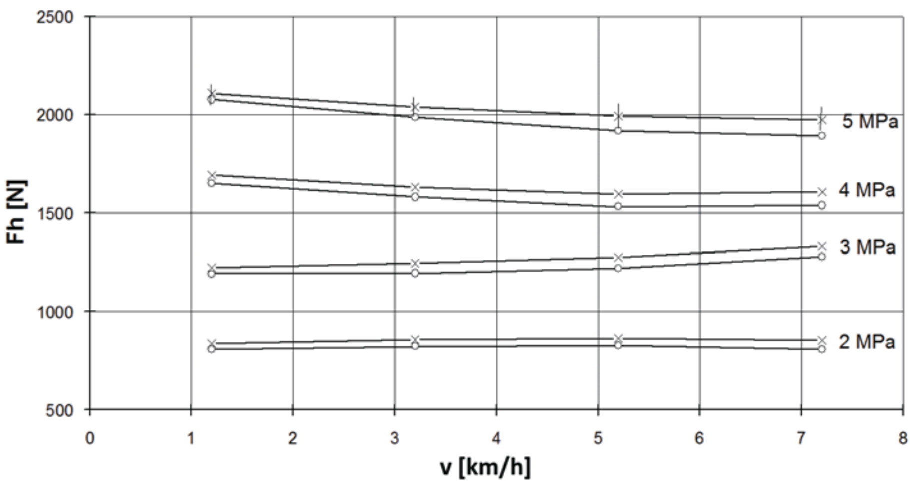

Fig. 4. Relation between the braking force F_h and the vehicle wheel velocity on a test stand: ○ – measured immediately after stabilization of the brake fluid pressure; × – measured 1 min after start of the braking process (disc brake)

4. Analysis of the results

In the method proposed, the braking force curves are extrapolated outside of the range under test (the broken line in Figs. 5 and 6), with assuming an approximation of the actual curve to a linear relation between the wheel braking forces and the brake fluid pressure or brake pedal force. According to experiments carried out, the wheel braking forces increase non-linearly in the phase of growing tyre slip and stopping of the wheels.

The extrapolation with assuming a regression function calculated from only the maximum values of individual wheel braking forces[6] would generate an error in relation to the results that could be obtained with taking as a basis a regression function calculated for the whole set of measurement results. Therefore, a regression function calculated for the sum of all the wheel braking forces of the vehicle under test from the results of measurements covering the whole measuring range has been used in the method proposed (see Figs. 5 and 6).

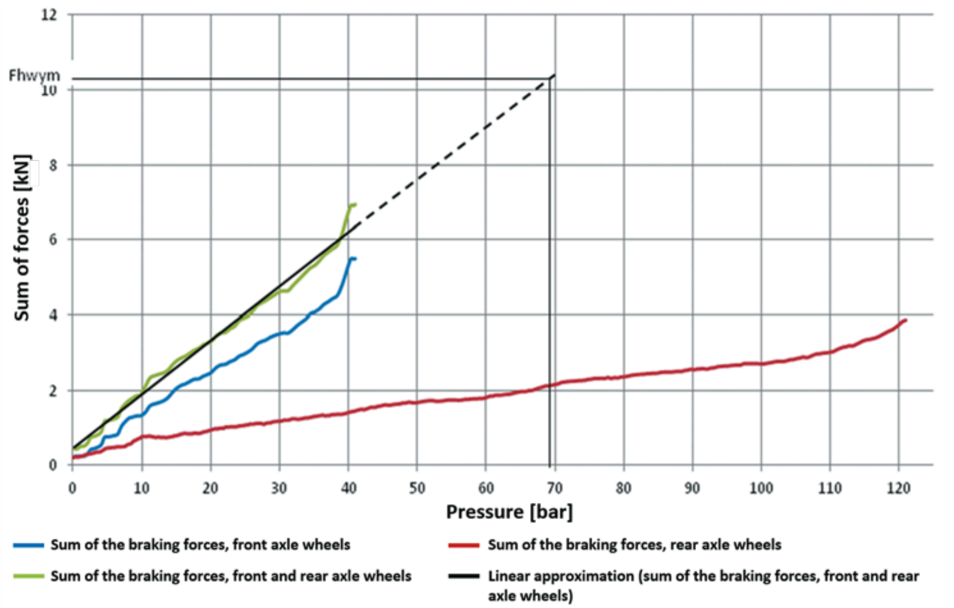

Fig. 5. Results of measurements of wheel braking forces as functions of fluid pressure in the hydraulic braking system; regression function; fluid pressure value necessary to achieve the braking efficiency required

The braking force sum F_{wym} that would give the braking efficiency required (58 % in this case) may be calculated from equation (4). Based on test results and equation (7), the fluid pressure in the hydraulic braking system may be calculated at which the wheel braking forces required can be obtained (Fig. 5). As an example: for a vehicle under test with 1 800 kg maximum authorized mass (MAM), the required value of force F_{wym} is 10.24 kN and the pressure necessary to obtain this force is p_{wym} = 69 bar (Fig. 5). Such a pressure or even higher could actually be achieved. Based on this conclusion of the tests, a statement could be made that the braking system under test met the braking efficiency requirements. Instead, the calculation of the braking efficiency coefficient directly from the braking force measurement results would give a coefficient value of 52 %.

[6] Such a procedure is required by the existing regulations.

At the measurements carried out with using a brake pedal force sensor, the pedal force necessary to achieve the wheel braking forces required was about 15.5 daN and such a force was possible to be applied (Fig. 6). If the extrapolation procedure were run in pursuance of the regulations in force, then it might be calculated that, based on equation (2) and with assuming the wheel braking forces corresponding to the brake pedal force at which the front wheel were locked up, the computational braking efficiency coefficient z' would be 216 % (!).

It should be noted that the relation between the brake pedal force and the force applied by the brake booster system to the master cylinder piston remains linear until the full vacuum value or the full compressed-air pressure value (in vacuum-operated or pneumatic brake booster systems, respectively) is used. When the brake pedal force is further increased, the relation between the brake pedal force and the brake fluid pressure P_z (p) rapidly changes and the extrapolation for the brake pedal force P_d = 50 daN based on the F_h (P_z) function becomes no longer valid.

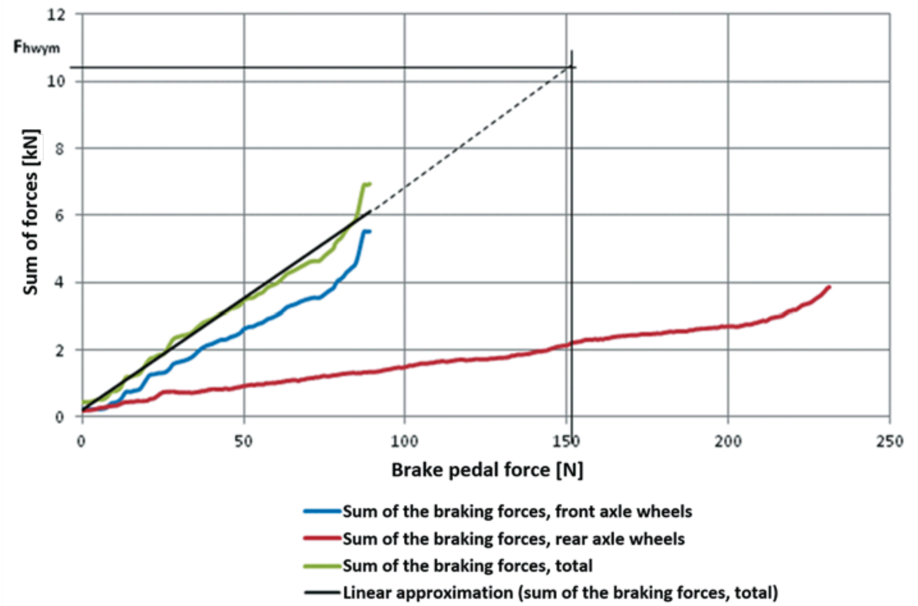

Fig. 6. Results of measurements of wheel braking forces as functions of brake pedal force; regression function; brake pedal force value necessary to achieve the braking efficiency required

The tests carried out showed that the scatter in the results of measurements of wheel braking forces was smaller when the forces were determined as functions of the fluid pressure in the hydraulic braking system rather than the brake pedal force. The assessment of system conformity with the braking efficiency requirement will be more accurate if the brake fluid pressure is measured instead of the brake pedal force.

5. Conclusions

1. The measurement procedure proposed is applicable when a vehicle with a mass lower than the maximum authorized mass (MAM) is subjected to the tests and fails to meet the braking efficiency requirement. Such a procedure may be carried out whether the vehicle under test has or has not a fluid pressure sensor in the hydraulic braking system.

2. For vehicles provided with a brake fluid pressure sensor, the procedure proposed requires the use of a diagnostic tester. For calculation automation purposes, the pressure measurement results should be sent from the tester to a computer program in the controller of the roller brake tester and recorded simultaneously with the braking forces.

3. The measurement procedure proposed makes it possible to calculate the dependence of the wheel braking forces on the force applied to the brake pedal or on the fluid pressure in the hydraulic braking system, within a range achievable in real braking conditions. The regression function calculated on the grounds of all the measurement results rather than of only the figures that correspond to the maximum braking forces measured provides a more reliable basis for the extrapolation of test results outside of the range under test.

The full text of the Article is available in Polish online on the website:
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