VEHICLE BRAKING PARAMETERS INFLUENCING FACTORS

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Abstract

In automotive technology attributes of the "driver-vehicle-environment" system are described as "vehicle handling". The driver has control of the vehicle generally by means of directional guidance, acceleration and braking, on the other side different influences as are side wind, road irregularities, road profile, sudden obstructions etc. from the environment affect on the vehicle. The task of research and development in the field of vehicle control is to adjust the vehicle handling to the driving ability of an average driver so that the active safety of the vehicle and passengers maximizes. Some selected vehicle characteristics and relations which influence the vehicle dynamics in braking modes are analysed in the paper. In particular vehicle influencing forces at braking, slip curve of the wheel, velocity course at braking, simplified parameters course, measurement preparation, measurement from the initial velocity v=90 km.h^{-1}, maximum braking deceleration dependence on tire pressure and velocity v_1 on dry surface, maximum braking deceleration dependency on tire pressure and velocity v_1 on wet surface, maximum braking deceleration dependency on velocity v_1 and tire pressure on dry surface, Maximum braking deceleration dependency on velocity v_1 and tire pressure on wet surface are presented in the paper.

Keywords: *vehicle, braking distance, braking deceleration, brakes test, adhesion*

1. Introduction

A braking device consists of all braking systems mounted on the vehicle which function is the decrease in velocity of a moving vehicle or its stop or holding already standing vehicle. The braking systems belong to the most important vehicle devices because of their direct impact on safety of personnel, passengers and other road users too. A lot of requirements is demanded from braking systems. Some of them are:

- suitable quantity of operating forces,

- maximum achievable effects (deceleration, braking distance),
- functionality in complicated operational conditions, durability and reliability,
- driving stability in braking mode and others.

2. Movement braking forces of the wheel vehicle

The vehicle is braked during the driving continuously by the road resistance. This can be lossmaking (passive) and useful – trailer, tools and others. At vehicle drive disconnection (declutching) the total brake resistance will be:

$$F_O = F_f + F_w + F_s + F_{ost}\,, \tag{1}$$

where:
F_f - rolling-resistance force,
F_w - aerodynamic resistance,
F_s - grade resistance,
F_{ost} - others resistances.

The vehicle operation requires so that the vehicle deceleration is personnel-operated and mainly the deceleration is greater than the deceleration caused by road resistance. Therefore it is needed to mount into the vehicle a device that ensures the required deceleration, sustenance of required velocity at downhill grade and parking (vehicle ensuring against self-motion) – this device develops braking force F_B, which works against the vehicle movement. The mentioned braking device can be according to its function and purpose classify into these types of brakes: service, emergency, parking and retarding. Forces applied onto the vehicle at braking are shown in Fig. 1. Inertial force F_i acts in direction of travel and total brake resistance F_O and braking force F_B act against vehicle movement. Then total braking force will be:

$$F_{BC} = F_B + F_O = F_B + F_f + F_w + F_s + F_{ost}\,,$$

$$F_{BC} = G_v \cdot \cos\alpha \cdot \mu + G_v \cdot f \cdot \cos\alpha + \frac{1}{2} \cdot \rho \cdot c_x \cdot S_{č} \cdot v^2 + G_v \cdot \sin\alpha\,, \tag{2}$$

where:
g - gravity acceleration,
f - rolling-resistance coefficient,
ρ - air density,
c_x - coefficient of air resitance,
S_c - cross-sectional area of vehicle,
v - vehicle velocity ($m.s^{-1}$).

3. Basic parameters influencing the braking process

The vehicle braking system is weighted according to the following achieved parameters: braking deceleration, braking distance for the service brakes, and slope angle for the parking brake. The problems of service braking will be written in the following study.

3.1. Tangential force coefficient

The maximum value of total braking force is important from the point of view of road-traffic safety. The braking force F_B developed at the wheels of the vehicle is the crucial part of the total braking force. The maximum value of this force is limited by the adhesion force F_{ad} which represents the maximum force transferred between wheel and road at specific adhesion weight G_{ad}, tire and road surface. The ratio between tangential force and adhesion weight G_{ad} is the tangential force coefficient μ_s.

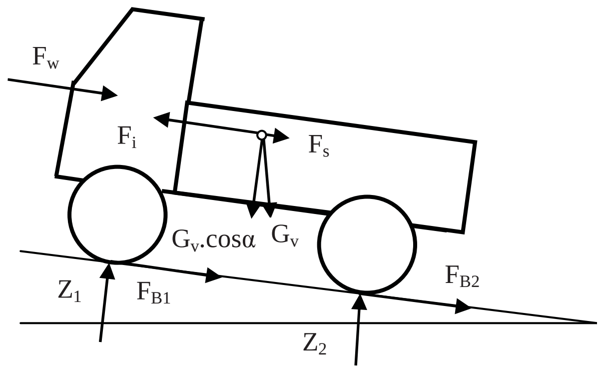

Fig. 1. Vehicle influencing forces at braking

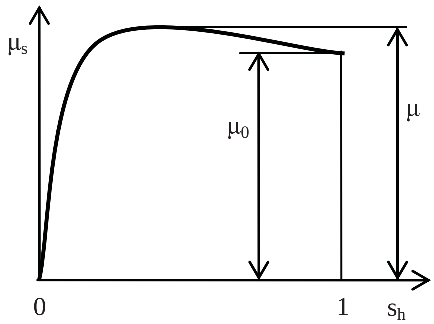

Fig. 2. Slip curve of the wheel

Its value depends on the slip and its curve can be seen in Fig. 2 as a slip curve of the wheel. The maximum value of this coefficient μ is important for the braking, it is called coefficient of adhesion and reached mostly at slip of 15-25 %. The adhesion force is then given by the following relationship:

$$F_{ad} = G_{ad} \cdot \mu \, . \tag{3}$$

3.2. Adhesion weight

The adhesion weight is the second factor which influences the value of braking force F_B. It is given by the sum of loads (radial reactions Z_i) of all braked wheel – see Fig.1.

$$G_{ad} = Z_1 + Z_2 = G_v \cdot \cos\alpha \, . \tag{4}$$

In the optimal case all braked wheels will roll with the slip corresponding to the coefficient of adhesion, i.e. coefficient μ_s will have the maximum value μ and the maximum braking force will be at wheels.

$$F_{B\max} = G_{ad} \cdot \mu = G_v \cdot \cos\alpha \cdot \mu \, . \tag{5}$$

The maximum value of total braking force at vehicle braked wheels (equations 4, 5) will be reached in the case that the braking effect will be distributed to the single wheels in proportion to their radial load together with the optimal slip ($\mu_s = \mu$).

3.3. Theoretical braking deceleration

The motion equation of vehicle at braking for the driving state according to Fig. 1 has the following form:

$$\delta \cdot m_v \cdot b = F_{BC} \, , \tag{6}$$

where:
b - vehicle deceleration,
δ - cofficient taking effect increase of inertial force resulting from rotating mass into account,
m_v - mass of the vehicle,
and then after taking the equation (2) into account the theoretical value of deceleration will be:

$$b_t = \frac{g}{\delta}\left(\cos\alpha \cdot \mu + f \cdot \cos\alpha + \frac{1}{2} \cdot \rho \cdot c_x \cdot \frac{S_c}{G_v} \cdot v^2 + \sin\alpha\right). \quad (7)$$

3.4. Theoretical braking distance

From the theoretical discription of vehicle braking is known that the completed course is in the graph with the coordinate system velocity – time, see Fig. 3, represented by the area under the curve of functional dependence v(t) in the time range dt and the following equation is valid for it:

$$S = \int_{t1}^{t2} v \cdot dt\,. \quad (8)$$

From the equation (6) the following relationship is resulting:

$$b = \frac{F_{BC}}{\delta \cdot m_v} = \frac{dv}{dt} \text{ and from here } dt = \frac{\delta \cdot m_v}{F_{BC}} \cdot dv\,. \quad (9)$$

Theoretical braking distance S_t resulting from the equations (9) and (8) will be:

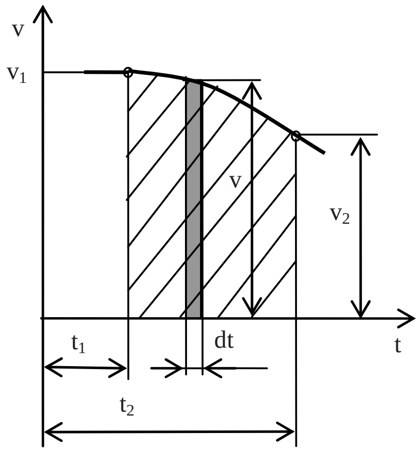

Fig. 3. Velocity course at braking

$$S_t = \int_{v1}^{v2} \frac{\delta \cdot m_v \cdot v \cdot dv}{F_{BC}}\,. \quad (10)$$

Term F_{BC} contains the components dependent on the velocity: aerodynamic resistance, rolling-resistance coefficient f, tangential force coefficient μ. For simplification of solution it is possible to neglect the influence of aerodynamic resistance and coefficients f and μ consider as constant. After substitution for F_{BC} and integration of equation 10, the theoretical braking distance of vehicle will be

$$S_t = \frac{\delta \cdot (v_1^2 - v_2^2)}{2 \cdot g(\mu + f \cdot \cos\alpha + \sin\alpha)}, \quad (11)$$

where:
v_1 and v_2 - are starting and ending velocity.
In the case of braking until vehicle stops it will be $v_2 = 0$.

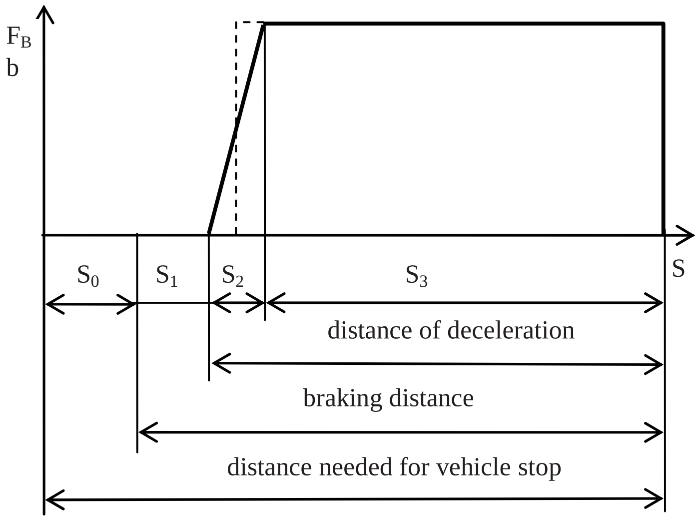

Fig. 4. Simplified parameters course

In practice there is the tendency to simply the braking distance calculation and at the same time get it in the accordance with possibilities of braking distance measurement. Motor Vehicles Traffic Regulations and EEC regulation Nr. 13 consider the brake effect by the braking distance or mean value of maximum braking deceleration. Nevertheless the simplified model of braking course is used as it can be seen in Fig. 4. It is considered with the retardation of control mechanism (distance S_1), linear deceleration increase in the course of braking start (S_2) and with constant value of maximum braking deceleration (S_3). Maximum braking deceleration is considered as deceleration from the ending of braking start to braking end. As this value during the braking is not constant, the mean value of maximum braking deceleration is evaluated. This value cannot be replaced by mean braking deceleration, which is the average value of deceleration for real braking distance.

4. Braking parameters measurement of SUV vehicle

Fig. 5. Measurement preparation

Control measurements on the SUV vehicle were carried out for verification of theoretical outputs. At assumption of correctly designed system from the theory results that the adhesion coefficient μ is the crucial factor that influences the braking deceleration. The others parameters of braking device like processes delays, assistant systems and others can help to decrease the braking distance of the vehicle. In Fig. 6 can be seen the standard test of braking distance from the velocity of 90 km.h^{-1}.

Performed tests on the vehicle are for the following conditions:

- three values of tire pressure (160, 220, 320 kPa),
- two road surfaces (dry rough road asphalt, wet rough road asphalt – rain),
- road slope (upgrade) 2.5°-3°.

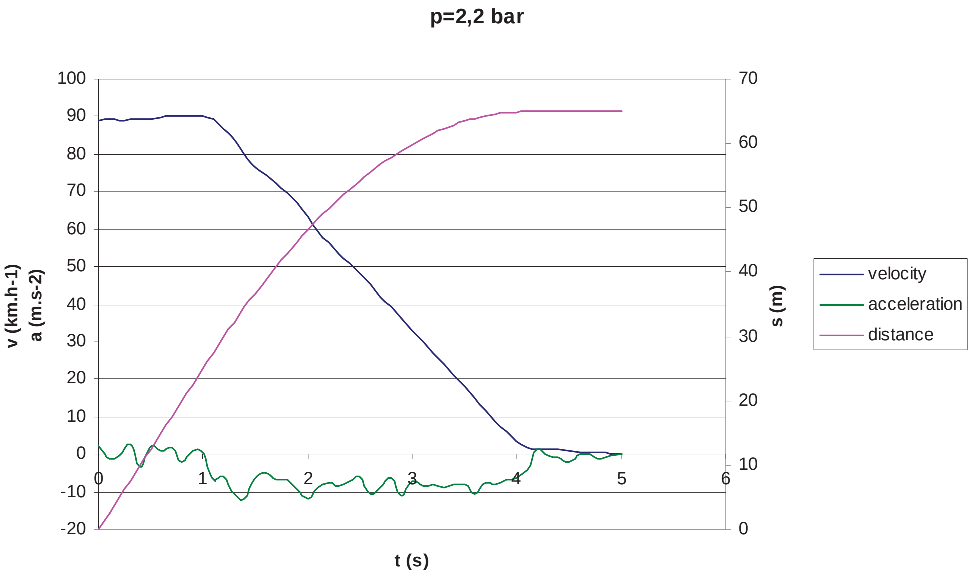

Fig. 6. Measurement from the initial velocity v=90 km.h^{-1}

The vehicle is fitted with the ABS system and then it can be considered as fulfilled the assumptions used at creating the equations for calculation of theoretical values of deceleration (7) and braking distance (11). So the braking is carried out at utilization of maximum value of tangential force coefficient μ and maximum utilization of vehicle adhesion weight G_{ad}.

According to the equations (7), (11) it is evident that the values of parameters b_t and S_t are proportional to the coefficient μ and their courses are identical with the course of coefficient μ. From the performed analysis it results that the value of maximum braking deceleration is the most suitable parameter for considering of real braking ability of the vehicle on the specific surface. Measured outputs – initial braking velocity – maximum braking deceleration characteristics, tire pressure – maximum braking deceleration characteristics and road surface – maximum braking deceleration characteristics are shown in the following Figs.

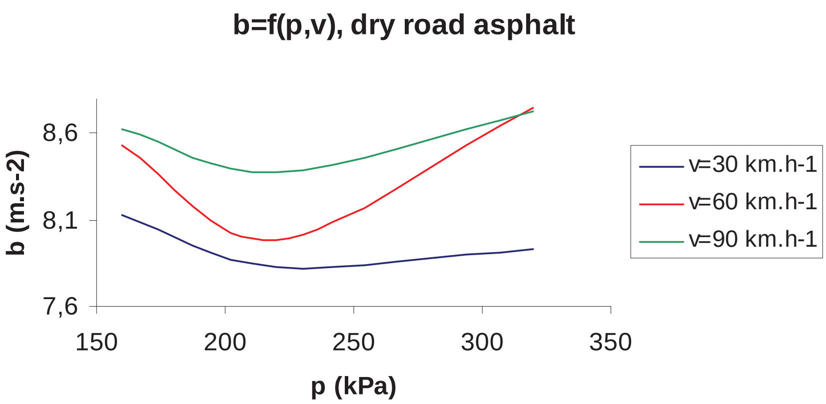

Fig. 7. Maximum braking deceleration dependence on tire pressure and velocity v_1 on dry surface

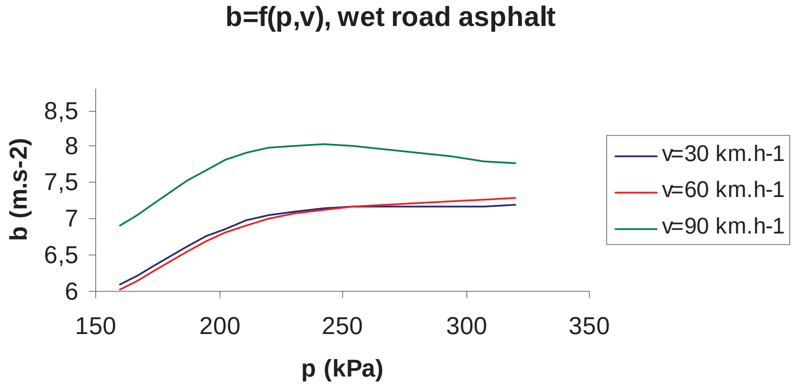

Fig. 8. Maximum braking deceleration dependency on tire pressure and velocity v_1 on wet surface

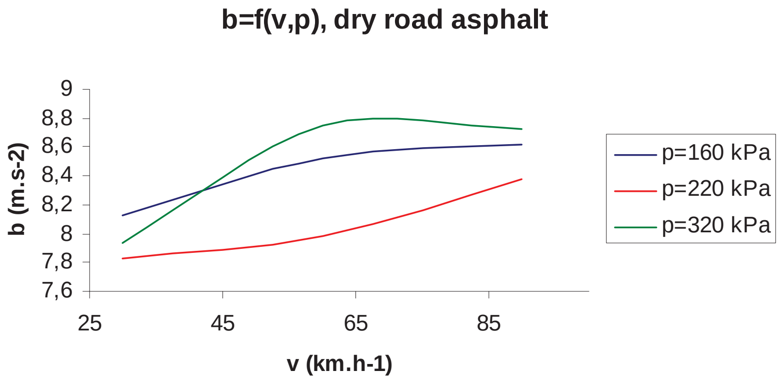

Fig. 9. Maximum braking deceleration dependency on velocity v_1 and tire pressure on dry surface

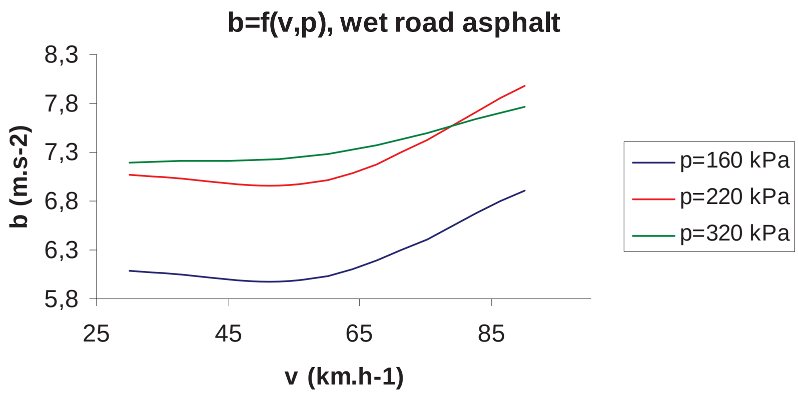

Fig. 10. Maximum braking deceleration dependency on velocity v_1 and tire pressure on wet surface

5. Conclusion

Questions regarding braking parameters of vehicles are discussed in the paper. On one side there are requirements from legislative, which needs simple interpretation in the theoretical form, but mainly easy executable controls in the testing rooms in large scale. On the other side researcher, design engineer, producer needs to know detail dependencies among single parameters of the whole process for his work.

The results of measurement correspond very well to theory in the case of measurement on the wet road asphalt (rain). In the case of measurement on the dry road asphalt the differences between theory and measurement results can be caused by the tire temperature, test driver etc.

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