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INFLUENCE OF THE BRAKING SYSTEM THAT IS CONTRARY TO LEGISLATION ON BREAKING CHARACTERISTICS OF PASSENGER CAR

Abstract. There are also the vehicles among the other vehicles in road traffic that have been modified without being authorised by their producer. These also include modifications such as structural modifications in the vehicle break system. Besides a brake system of road motor vehicles is one of the main factors influencing the active safety of vehicles. The design of the brake system, its technical condition and additional intervention in its construction may have a positive as well as negative impact on the braking distance length and the value of the mean braking deceleration achieved. The paper focuses on the influence of the brake disc diameter of the front axle on the achieved value of the mean braking deceleration and the braking distance length, while the braking system has been modified for several times without being approved by car manufacturer. The introductory part of the paper describes the braking distance sections and it also explains the term of mean braking deceleration. The following part of the paper deals with the measurement methodology, measuring equipment and the vehicle used during the measurements as well as procedures employed. The results obtained from the measurements are processed and presented in tables and also in graphs for greater clarity. The final part of the paper summarizes and evaluates the measured results. The importance of the paper lies in quantification of the influence of brake discs with different diameters on the vehicle active safety in the case of a particular vehicle.
Keywords: active safety, brake system, brake disc, braking distance

Tomáš Skrúcaný[1]
[1]University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia; +421 41 513 3518; tomas.skrucany@fpedas.uniza.sk
František Synák[2]
[2]University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia; +421 41 513 3523; frantisek.synak@fpedas.uniza.sk
Štefánia Semanová[3]
[3]University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia; +421 41 513 3535; stefania.semanova@fpedas.uniza.sk

Introduction

If a vehicle cannot move, this represents a problem. However, if it is already in motion and it cannot brake, the problem is much greater. The brake system fundamentally affects the level of vehicle active safety (Lazeet et al. 2016; Oyetubo, Afolabi, Ohida 2018). The design and technical condition of the brake system (Lagel et al. 2016) together with tyres (Selig et al. 2012) and other factors such as road surface (Metz 2016; Paraskevadakis et al. 2016) and slope influence (Mikušová 2017) the vehicle directional stability during braking and the braking distance length (Rievaj et al. 2013). The braking distance represents the distance which is travelled by a vehicle from the moment of pressing the brake pedal till the vehicle stops or till the moment when the driver stops applying the brake pedal (Zamzamzadeh et al. 2016) Fig. 1.

The total braking distance consists of the distance related to the driver perception and reaction time and the braking distance itself (Jammes et al. 2017). Further, the braking distance itself consists of the distance related to the brake system reaction time, initial braking and the distance travelled during full braking application effect (Gunney, Mutlu, Gavretli 2016).

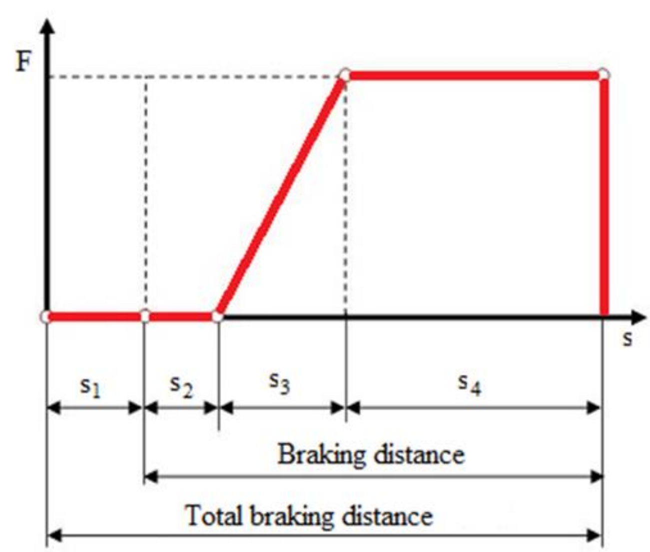

Fig. 1. The braking distance (Ondruš, Hockicko 2015)

The brake system reaction time represents the time interval elapsed from the moment of pressing the brake pedal until brake torque starts to act on wheels (Vrábel et al. 2017). It is the time during which all resistances are overcome and friction lining comes into the contact with friction surfaces which are friction surfaces of the brake disc in our case (Timur, Kuscu, Toylan 2017). The time interval from that moment till the moment of reaching full braking effect is called the initial braking (Gigan 2017). At the moment of full braking, the vehicle is continuously decelerated by the steady value of braking deceleration until it fully stops (Caban et al. 2016).

$$MFDD = \frac{v_b^2 - v_e^2}{25.92\ (s_e - s_b)}$$

v_b vehicle speed at $0.8 \cdot v_1$ (km·h^{-1})
v_e vehicle speed at $0.1 \cdot v_1$ (km·h^{-1})
s_b distance travelled between v_1 and v_b (m)
s_e distance travelled between v_1 and v_b (m) (Li et al. 2013)

Variable v_1 is considered to be initial vehicle speed i.e. the speed at the moment when the driver starts to act on the brake system controller (Li et al. 2013).

The aim of the paper is the measurement and quantification of the influence of the brake disc diameter on the value of mean braking deceleration as well as the braking distance length. The paper contains the methodology and the results of measurements with brake discs with different diameters of the front axle. The measurements were carried out by driving tests with the vehicle Volkswagen Golf II by using XL metre.

1. Methodology

The purpose of the measurement was to determine the influence of brake disc diameter on the braking distance length and on the achieved value of the mean braking deceleration MFDD. Three sets of front brake discs were used. The first set of brake discs was 239 mm in diameter, the second set contains the brake discs of 256 mm in diameter and the third set includes brake discs of 280 mm in diameter.

Vehicle used for measurements

The Volkswagen Golf II was used for the measurement, Fig. 2. The vehicle is not equipped with ABS system or any other similar electronic safety system. The technical parameters of the vehicle are given in Table 1.

Fig. 2. The vehicle used for measurements

Table 1. Technical parameters of the vehicle

manufacture year	1991
engine displacement	1.6 dm^3
fuel	diesel
body type	hatchback
vehicle dimensions	3 985 mm x 665 mm x 405 mm
vehicle curb weight	915 kg
total vehicle weight	1 465 kg
vehicle weight during the measurement	1 061 kg
construction of rear brakes	disc, 226 mm
tyres	summer, Bridgeston Turanza 195/50 R 15 82 H
front brakes	disc, 239 mm, 256 mm, 280 mm
rear brakes	disc, 226 mm

The vehicle is equipped with a Volkswagen Golf III main brake cylinder and a controller of brake effect of the rear axle.

Measuring equipment

The equipment used for the measurement was XL metre Pro Gamma with recording frequency from 25 Hz up to 200 Hz, Fig. 3. This electronic device is battery-powered and provides the ability to evaluate the data via a PC.

Fig. 3. Device XL metre used during measurements

The basic measuring range in the longitudinal and transverse axe is from -14 $m \cdot s^{-2}$ to +14 $m \cdot s^{-2}$. The device records the following parameters:

1) braking distance S_0 (m),
2) braking time t_{br} (s),
3) initial speed V_0 ($m \cdot s^{-1}$),
4) mean braking deceleration MFDD ($m \cdot s^{-2}$).

Measurement procedure

The proper tyre inflation was checked prior measurements. The measurement procedure was as follows:

1) Heating up the brakes and tyres to the operating temperature.
2) Fixing of XL metre on the windscreen.
3) Calibration of XL metre.
4) Reaching the specified vehicle speed.
5) Full braking of the vehicle after reaching the specified speed.
6) Complete stopping of the vehicle.
7) Saving the measured data.

Each measurement was repeated three times for the following speed ranges: 40 $km \cdot h^{-1}$, 60 $km \cdot h^{-1}$ and 80 $km \cdot h^{-1}$. Subsequently, brake discs of different diameter were mounted and the measurements were repeated.

2. Measured data

The data obtained by measurements are shown in the following tables (Tables 2 – 9). The tables contain the mean braking deceleration MFDD, braking distance length S_0, initial vehicle speed V_0 and braking time t_{BR}. During the measurements at speed of 80 $km \cdot h^{-1}$, significant vehicle directional instability was observed in the case of brake discs with diameter of 239 mm, and therefore the data from this measurement were not evaluated.

Table 2. Measurement with brake discs 256 mm at speed 40 $km \cdot h^{-1}$

	MFDD ($m \cdot s^{-2}$)	S_0 (m)	V_0 ($km \cdot h^{-1}$)	t_{BR} (s)
1	5.39	12.81	39.43	2.23
2	5.48	13.66	40.80	2.31
3	5.28	13.58	40.08	2.33
average	5.38	13.35	40.10	2,29

Table 3. Measurement with brake discs 256 mm at speed 40 $km \cdot h^{-1}$

	MFDD ($m \cdot s^{-2}$)	S_0 (m)	V_0 ($km \cdot h^{-1}$)	t_{BR} (s)
1	5.85	12.65	39.84	2.19
2	6.13	11.86	40.40	2.00
3	5.79	12.76	40.30	2.08
average	5.92	12.42	40.18	2.09

Table 4. Measurement with brake discs 280 mm at speed 40 $km \cdot h^{-1}$

	MFDD ($m \cdot s^{-2}$)	S_0 (m)	V_0 ($km \cdot h^{-1}$)	t_{BR} (s)
1	8.54	9.11	39.29	1.51
2	7.90	10.44	39.89	1.67
3	8.26	8.89	40.31	1.50
average	8.23	9.48	39.83	1.56

Table 5. Measurement with brake discs 239 mm at speed 60 $km \cdot h^{-1}$

	MFDD ($m \cdot s^{-2}$)	S_0 (m)	V_0 ($km \cdot h^{-1}$)	t_{BR} (s)
1	5.03	31.17	59.25	3.54
2	4.93	39.49	59.39	4.16
3	5.51	32.41	59.71	3.56
average	5.16	34.36	59.45	3.75

Table 6. Measurement with brake discs 256 mm at speed 60 $km \cdot h^{-1}$

	MFDD ($m \cdot s^{-2}$)	S_0 (m)	V_0 ($km \cdot h^{-1}$)	t_{BR} (s)
1	6.78	24.45	59.02	3.42
2	6.31	29.94	59.30	3.48
3	7.31	22.39	59.55	2.44
average	6.80	25.59	59.29	3.11

Table 7. Measurement with brake discs 280 mm at speed 60 $km \cdot h^{-1}$

	MFDD ($m \cdot s^{-2}$)	S_0 (m)	V_0 ($km \cdot h^{-1}$)	t_{BR} (s)
1	7.92	24.60	60.48	2.66
2	6.85	28.39	61.09	2.95
3	6.73	23.96	59.25	2.75
average	7.17	25.65	60.27	2.79

Table 8. Measurement with brake discs 256 mm at speed 80 $km \cdot h^{-1}$

	MFDD ($m \cdot s^{-2}$)	S_0 (m)	V_0 ($km \cdot h^{-1}$)	t_{BR} (s)
1	6.80	48.83	78.93	4.10
2	6.53	45.12	79.15	4.23
3	6.73	43.82	80.37	3.78
average	6.69	45.92	79.48	4.04

Table 9. Measurement with brake discs 280 mm at speed 80 $km \cdot h^{-1}$

	MFDD ($m \cdot s^{-2}$)	S_0 (m)	V_0 ($km \cdot h^{-1}$)	t_{BR} (s)
1	6.91	47.26	78.34	3.98
2	6.20	68.16	80.77	5.04
3	6.51	43.86	80.17	3.94
average	6.54	53.09	79.76	4.32

The results obtained from the measurements are processed also in graphs for greater clarity, Fig. 4 and Fig. 5. The graphs provide information about MFDD and braking distance length depending on the initial vehicle speed and brake disc diameter used.

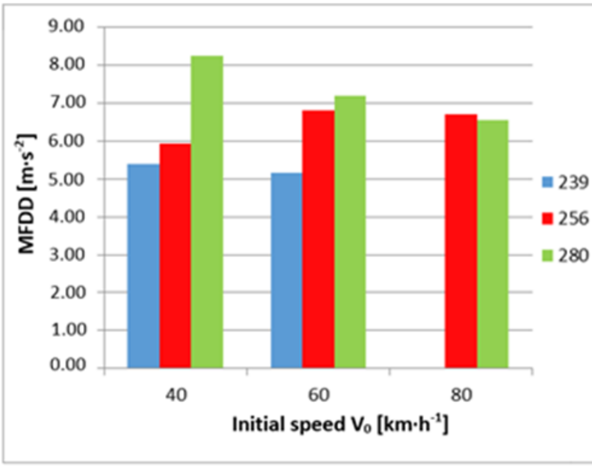

Fig. 4. MFDD depending on the initial vehicle speed and brake disc diameter used

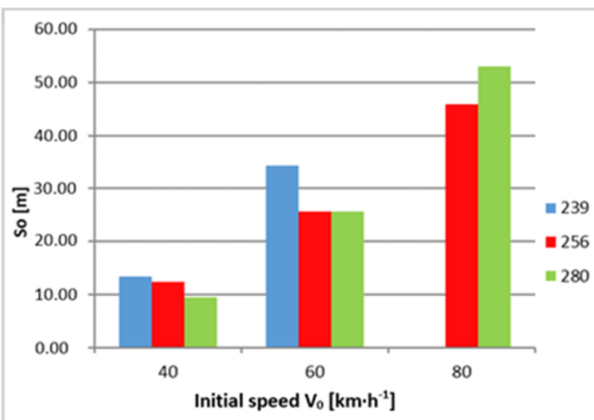

Fig. 5. S_0 depending on the initial vehicle speed and brake disc diameter used

3. Results

As it can be seen in previous tables and graphs, the brake disc diameter plays a significant role in achieved value of the mean braking deceleration as well as the braking distance length. In case of the replacement of the brake discs of 239 mm in diameter with the brake discs of 256 mm in diameter, no significant changes were observed. However, the largest changes in MFDD and S_0 were measured when changing the 256 mm brake disc diameter with 280 mm brake disc diameter. At speed 40 km·h^{-1}, this brake disc change caused an increase in MFDD by 2.31 m·s^{-2} which resulted in braking distance reduction by 2.94 m. In the case of replacement of the brake discs of 256 mm in diameter with the brake discs of 280 mm in diameter, the braking distance was reduced by 23 % at the mentioned speed. During measurements of braking from higher initial speed 60 km·h^{-1} and 80 km·h^{-1} respectively, the measured differences were significantly smaller. For instance at speed of 80 km·h^{-1}, the brake disc of smaller diameter (256 mm) caused the higher measured value of MFDD in comparison with the brake disc of 280 mm in diameter. This fact can be explained that there probably was not sufficient long time period between two measurements and thus the brake disc diameter of 280 mm was overheated and it was not cooled down to the operating temperature (Rievaj, Mokričková, Synák 2017). Brake discs with a diameter of 239 mm can be evaluated as inappropriate because locking of the rear axle wheels and vehicle directional instability were observed while braking from the initial speed of 80 km·h^{-1}. The vehicle with these brake discs mounted did not achieve the MFDD value stipulated by legislation i.e. the value of 5.8 m·s^{-2}.

Conclusion

Many factors have an impact on the course of braking, the braking distance length and the mean braking deceleration value. Based on the results presented in the paper, one of these factors is also a brake disc diameter. The diameter of brake discs may have an influence on the traffic accident occurrence or accident consequences. When interpreting the measurement results, it is necessary to take into account two facts which affected these results. The first one is the absence of electronic safety systems in the vehicle used for measurements. If the vehicle was equipped with an anti-lock wheel system, the locking of rear axle wheels would not occur and thus the resultant values would be different (Haugland 2013). Although, the vehicle was equipped with a rear axle load regulator compared to the serial vehicle, the locking of rear axle wheels occurred when using the brake disc of 239 mm in diameter. The second fact represents the additional mounting of the disc brakes on the rear axle instead of the origin manufacturer solution with drum brakes. In conjunction with the absence of the anti-lock system (Zhao 2014), this fact caused the locking of rear axle wheels while using brake disc diameter of 239 mm and this results in a negative impact on active vehicle safety. In terms of legislation, the results confirm the eligibility of the prohibition to carry out such interventions in the vehicle design which is not approved by the manufacturer.

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