Impact of the Number of Passengers in the Vehicle Braking Performances Equipped with Modern Mechatronics Braking System

Shpetim Lajqi, Agron Syla, Naser Lajqi, Gazmend Krasniqi*
University of Prishtina “Hasan Prishtina”, Faculty of Mechanical Engineering, Kosovo
*Corresponding author: gazmendkrasniqi89@gmail.com

Abstract: *Modern vehicle braking systems mainly are based on deceleration of vehicle and tire slip control. Trends in improving vehicle braking performance give rise to a large variety of braking systems and control strategies. An anti-lock braking system is an electronic braking process control system, which greatly increases the ability of the driver and vehicle to avoid road accidents even during difficult braking conditions or circumstances. The load (number of passengers in the vehicle) which is transmitted to the road surface through the vehicle tires is an issue which directly affects the braking efficiency of the vehicle during stopping. The braking efficiency also depends on the material of the road surface, climatic condition, road condition, vehicle speeds and tire condition.*

The purpose of this paper is investigation the impact of the number of passengers in the vehicle during the braking process, respectively to determine the performance of the braking of vehicles equipped with modern mechatronic braking systems such as: Antilock Braking System, Electronic Braking System, Emergency Brake System and Electronic Brake-force Distribution System.

The braking performance of the vehicle was determined experimentally through the XL Meter device which was fixed on the windshield of the VW Polo vehicle. The tests were performed on asphalt roads for different speeds of 40, 60 and 80 km/h. The determination of the center of gravity of the vehicle and the reaction forces in the front and rear axles was performed through the devices in the Motor Vehicle Laboratory of the Faculty of Mechanical Engineering and the developed mathematical model for calculating static and dynamic reactions forces for the respective axes. The obtained results will help the traffic experts in the analysis of road accidents.

Keywords*: DISK BRAKE, ROAD, TIRES, REACTION FORCES, FRICTION COEFFICIENT, DECELERATION, BRAKING DISTANCE.*

1. Introduction

Vehicle safety devices are mainly categorized into two main categories: passive and active safety devices [1-3].

Passive safety devices are intended to minimize damage and reduce the risk of injury during the time of impact. Vehicle passive devices are: seat belts, airbags, and the construction of the vehicle and automatically deploy when the vehicles gets into a crash.

Active safety devices works to prevent a vehicle accident and stay active until drive vehicle by continually work to avoid from getting vehicle into an accident. Most active safety devices are: braking system, steering system and other vehicles systems electronically controlled by a computer.

Because of developments of electronics and mechatronics, active safety systems have been greatly improved. They include traction control, electronic stability control, and braking systems.

In order to increase braking efficiency, maintain the stability of the vehicle during the braking process and the maneuverability of the vehicle, Anti-lock Braking Systems (ABS) have been developed since the 80s.

Trends in improving vehicle braking performance give rise to a large variety of braking systems and control strategies. An anti-lock braking system is an electronic braking process control system, which greatly increases the ability of the driver and vehicle to avoid road accidents even during difficult braking conditions or circumstances [4].

ABS consists of the conventional braking system integrated with the Electronic Control Unit (ECU), the Electronic Brake Control Module (EBCM) and the Wheel Speed Sensors for receiving information about the speed of the wheel (rotation), Figure 1.

Fig. 1 *ABS braking system – Brake rigs*

2. Impact of load on the vehicle braking effectiveness - Case study

The calculation of disc and drum brakes is quite specific. During the calculation, the magnitude of the braking torque which can be realized by the brake must be calculated [5].

2.1. Calculation of the braking system

Calculating the forces and braking torque of the disc brakes is relatively simple. Figure 2 shows the scheme of the disc brake and the forces that acting during the braking process. In the given scheme we can see that the force for activating the brake (F_a) is equal to the reaction force of the disk (N).

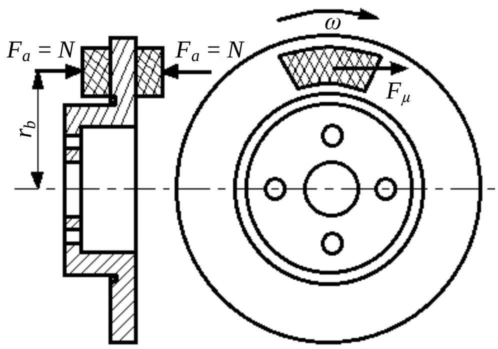

Fig. 2 *Forces acting on the disc brake*

The value of the friction force (F_μ) that acting on both sides of the disc is defined by the expression:

$$F_\mu = 2 \cdot \mu \cdot N = 2 \cdot \mu \cdot F_a \quad (1)$$

The braking torque (T_b) for this case is determined by the expression:

$$T_b = F_\mu \cdot r_b \quad (2)$$

where are:

r_b [m] – radius from the center of disc to the point of action of the frictional force
F_μ [N] – friction force
F_a [N] – braking activating force

This research is focus on the influence of load on the tires and not on the calculation of forces and torques which act on the system.

2.2. Contact between tire and road surface

The contact between the tire and the road surface plays a key role in vehicle dynamics. The interaction between the tire and the road surface can be described by the three forces and three moments as shown in Figure 3.

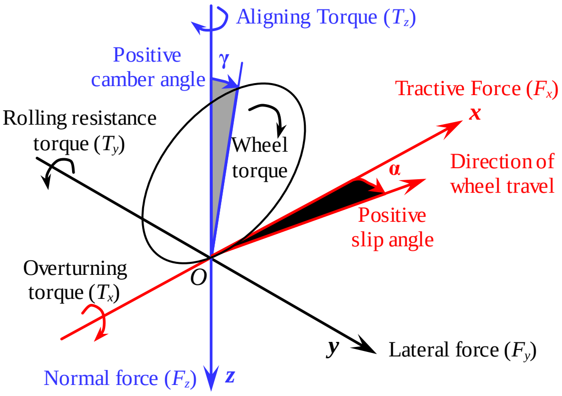

Fig. 3 Tire contact with road surface

Tractive force (F_x) can be expressed as a function of the friction coefficient (μ_x):

$$F_x = \mu_x (\lambda, \alpha, \gamma, F_z) \tag{3}$$

2.3. Calculation of friction coefficient

To determine the friction coefficient is required to know values of normal force (F_z), longitudinal slip (λ), lateral slip angle (α), and wheel slope angle (γ), Figure 3.

Since in our case we are not dealing with lateral slipping to simplify the calculation and to make the impact of the changes easier the angles α and γ are assumed zero ($\alpha = 0$, $\gamma = 0$), so friction remains a function of normal load and longitudinal slip.

On the other hand, the longitudinal slip (λ) is:

$$\lambda = \frac{v - r \cdot \omega}{\max(v,\ r\omega)} = \frac{v - \omega \cdot r}{v} \tag{4}$$

when is:

r [m] - is the dynamic radius of the wheel and its value depends on several factors such as: load, number of wheel rotations, and air pressure in the tires.

Since during the measurements are obtained the deceleration values, it will be calculate the coefficient of friction from the expression for calculating the deceleration, as written in the follow:

$$a = \mu_x \cdot g \Rightarrow \mu_x = \frac{a}{g} \tag{5}$$

2.4. Calculation of forces acting on the vehicle during the braking process

The process of braking the vehicle is influenced by many different factors, from the psycho-motor skills of the driver to the smallest element of the system. In terms of forces that affect the braking process there are a number of different forces such as: normal, longitudinal, inertia, air forces and other forces that appear within the system.

In this paper it's foreseen to compare the impact of loads during braking of the vehicle in its longitudinal direction, therefore is calculate only normal and longitudinal forces.

2.5. Calculation of axles reaction forces

To determine axle's reaction forces it is necessary to determine the Center of Gravity of the vehicle (CG), which can be found experimentally by measuring the vehicle curb weight and weight of rear wheel when the vehicle is horizontal plane [6]. The determination of the CG was done by several measurements performed in the Laboratory of the Faculty of Mechanical Engineering, University of Prishtina "HASAN PRISHTINA".

Figure 4 shows the measured dimensions of the vehicle examined in the Faculty Laboratory.

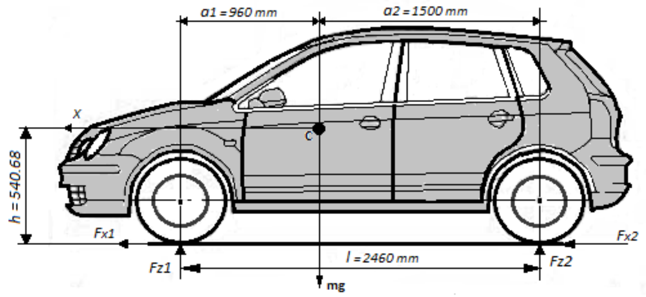

Fig. 4 Geometric dimensions of VW POLO vehicle

After the measurement of the mass of the vehicle through digital weight scales in the wheel of the first and rear axles, can be define:

$$a_1 = \frac{2 \cdot l}{m \cdot g} \cdot F_{z2} = \frac{2 \cdot l}{2 \cdot (F_{z1} + F_{z2})} \cdot F_{z2} = \frac{l \cdot m_2}{m_1 + m_2} \tag{6}$$

$$a_1 = \frac{2460 \cdot 245}{380 + 245} = 960\ mm = 0.96\ m \tag{7}$$

$$a_2 = l - a_1 = 2460 - 960 = 1500\ mm = 1.5\ m \tag{8}$$

where are:

F_{z1}, N – Front axle reaction in horizontal plane
F_{z2}, N – Rear axle reaction in horizontal plane
m, kg – Curb mass of vehicle
m_1, m_2– Mass of the half front and rear axles
a_1, m – Distance between CG behind the front axle
a_2, m – Distance between CG in front the rear axle
l, m – Car wheel base

The height of the center of gravity of the vehicle (h) can be determined by assuming the vehicle is set at a certain angle (assume an angle of 30^0), then we have:

$$h = \left(a_2 - 2 \cdot \frac{F_{z1(\theta)}}{m \cdot g} \cdot l\right) \cdot ctg\theta + r_d \tag{9}$$

$$h = \left(a_2 - \frac{m_1}{m_1 + m_2} \cdot l\right) \cdot ctg\alpha + r_d \tag{10}$$

$$h = \left(1.5 - \frac{343.75}{380 + 245} \cdot 2.46\right) \cdot ctg30^0 + 0.293 \tag{11}$$

$$h = 540.68\,mm = 0.5468\,m \tag{12}$$

where are:

h, m - Height of center of gravity from ground level
R, m - Wheel radius (R = 293 mm = 0.293 m for tire 165/70 R14)

Vehicle axle's reaction forces acting on the vehicle during deceleration (a) in a straight horizontal road are affected by components of the static and dynamic forces [5] and can be defined as follows:

$$F_{z1} = (F_{z1})_{sta} + (F_{z1})_{dyn} \tag{13}$$

$$F_{z2} = (F_{z2})_{sta} + (F_{z2})_{dyn} \tag{14}$$

$$(F_{z1})_{sta} = \frac{1}{2} \cdot m \cdot g \cdot \frac{a_2}{l} \tag{15}$$

$$(F_{z1})_{dyn} = \frac{1}{2} \cdot m \cdot g \cdot \frac{h}{l} \cdot \frac{a}{g} \tag{16}$$

$$(F_{z2})_{sta} = \frac{1}{2} \cdot m \cdot g \cdot \frac{a_1}{l} \tag{17}$$

$$(F_{z2})_{dyn} = -\frac{1}{2} \cdot m \cdot g \cdot \frac{h}{l} \cdot \frac{a}{g} \tag{18}$$

As the vehicle deceleration increases, the normal forces on the front wheels increase while on the rear ones decrease, as we only need the normal forces on the front wheel then only the results of the normal force on the front wheel will be given (F_{z1}).

2.6. Calculation of braking forces

The braking forces acting on the wheels of the vehicle are a function of the normal reaction forces and the coefficient of friction of the wheels and is given by the expression:

$$F_{x1} = F_{z1} \cdot \mu_x \tag{19}$$

where is:

μ_x - Coefficient of friction between tires and road surface

3. Methodology for Evaluation of the Vehicle Braking Performances

The place where the tests were performed is located around of the city of Pristina. For evaluation of braking performance is used professional XL Meter ™ Gamma Pro device which measure acceleration/deceleration in two direction (longitudinal and transverse site).

The ECE R13 regulation is mandatory for measuring braking efficiency. According to this "The efficiency of the braking system is determined by the braking distance or the average deceleration during braking".

The braking distance (S_f) is calculated from the double integration of the acceleration data in the braking interval. The Successful evaluation gives the following results:

– Distance in the time of braking (S_f[m]),
– Initial vehicle speed at the time of braking (V_0 [km/h]),
– Time from the start till the end of braking (T_{br} [s]), and
– Averaged maximal vehicle deceleration ($MFDD$ [m/s^2]).

The vehicle deceleration ($MFDD = a_2$) is estimated as the average deceleration of the vehicle motion distance in the range from speed V_b to speed V_e as written in the follow:

$$MFDD = \frac{V_b^2 - V_e^2}{25.92 \cdot (S_e - S_b)} \tag{20}$$

In Figure 5 are presented equipment and type of road surface (old and new asphalt) for measuring vehicle braking performance.

Fig. 5 Equipment and testing polygon for measuring vehicle braking performance [7]

4. Measuring results from test drive

Type of the vehicle used to test braking performance has been VW Polo, 2002 model year, with ABS braking system. Test drives have been performed in the testing polygon with different loads and road surfaces (old asphalt and new asphalt), Figure 5.

The evaluation of the braking performance has been carried out with a professional devices called "XL Meter" where in each testing cases on the board of vehicle was one and four passengers [8-9].

In Table 1 are presented vehicle technical data in order to known performance of braking system for VW Polo.

***Table 1** Technical vehicle data for VW Polo*

Characteristics		Data
Year of production:		*2002*
ABS (ON/OFF) :		*ON*
Tire dimension:		*165/70 R14*
Weather temperature:		*22 [°C]*
Road surface:		*Dry asphalt with significant roughness*
Seat numbers:		*5*
Vehicle geometry	length:	*3897 [mm]*
	width:	*1650 [mm]*
	height:	*1465 [mm]*
Engine	Fuel:	*Petrol*
	Volume:	*1198 [cm^3]*
	Power:	*54 [HP]*
	Torque:	*106 [Nm]*
Capacity of reservoir:		*45 [l]*
Total weight:		*1530 [kg]*

The investigation on the vehicle braking performance was done with the vehicle VW Polo, manufactured in 2002 and equipped with ABS system. Testing was performed on roads with old and new asphalt through the XL Meter device. The obtained results are presented through diagrams and tables.

Figure 6 shows the braking efficiency parameters for the initial braking speed V_0 ~ 60 [km/h] when there were driver + 3 passengers and when there was only the driver.

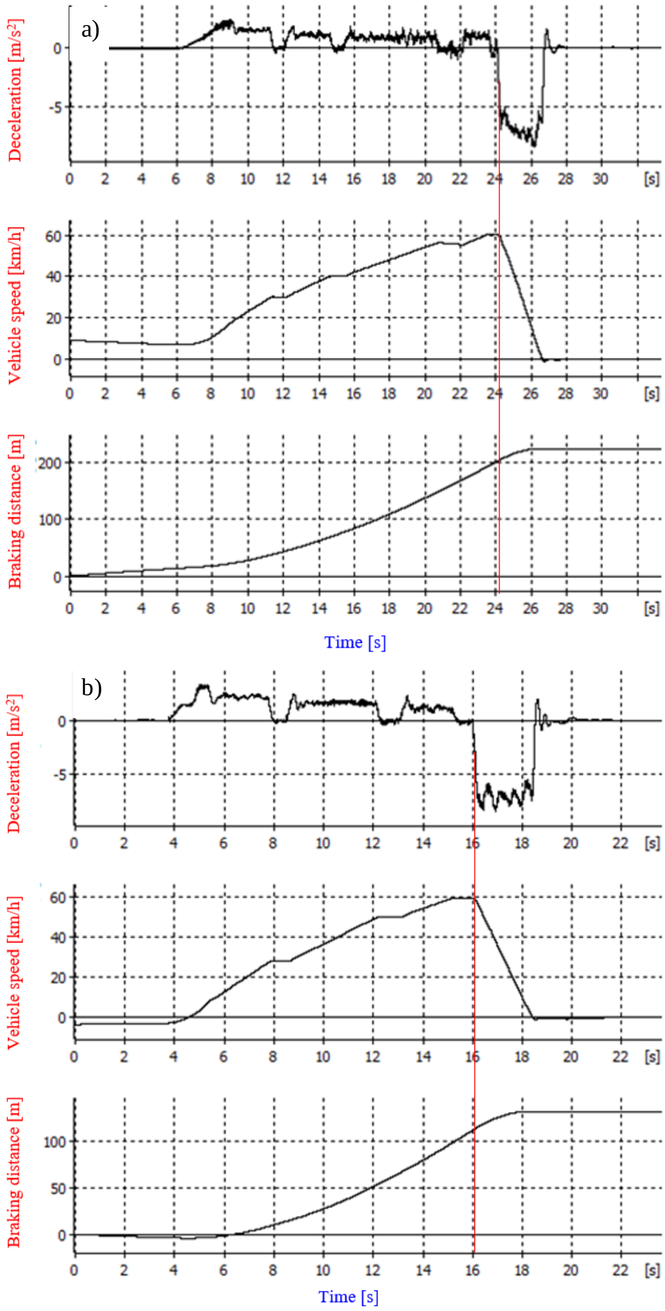

Fig. 6 *Braking parameters for the initial braking speed V_0 ~ 60 [km/h] for the case when in the vehicle board were: a) driver + 3 passengers and b) driver*

In Table 2 are presented the main braking parameters for VW POLO obtained by measuring during the vehicle braking process on the road with old asphalt for two cases when in the vehicle board were: driver + 3 passengers and only the driver. Test was done when during braking process driver has pressed clutch and initial braking speed was 60 and 80 [km/h].

Table 2 *Obtained braking parameters for the initial braking speed of 60 & 80 [km/h] when in the vehicle board were: driver+3 passengers and only driver*

Characteristics	Driver + 3 passengers		Driver		Differences [%]	
V_0 [km/h]	61.28	80.49	60.57	81.65	~60.00	~ 80.00
S_f [m]	22.98	37.62	20.87	39.65	10.11	5.12
T_{br} [s]	2.62	3.37	2.48	3.50	5.65	3.71
MFDD [m/s^2]	7.12	6.92	7.13	6.59	0.14	5.01
Z (MFDD) [%]	72.50	70.60	72.70	68.90	0.28	2.47
$\mu_x = MFDD/g$	0.72	0.70	0.73	0.67	1.37	4.48
F_{z1} [N]	6231.11	6191.11	6058.15	5971.43	2.86	3.68
$F_{x1} = F_{z1} \cdot \mu_x$ [N]	4486.40	4333.78	4422.45	4011.39	1.45	8.04

In Table 3 are presented the main braking parameters for VW POLO obtained by measuring during the vehicle braking process on the road with old and new asphalt for case when in vehicle board was only driver. Test was done when during braking process driver has pressed clutch and initial braking speed was 40 and 60 [km/h].

Table 3 *Obtained braking parameters for initial braking speed of 40 & 60 [km/h] when in the vehicle was only driver on road with old and new asphalts*

Characteristics	Old asphalt		New asphalt		Differences [%]	
V_0 [km/h]	40.17	60.57	39.99	59.14	~40.00	~60.00
S_f [m]	9.99	20.87	9.22	17.75	8.35	17.58
T_{br} [s]	1.76	2.48	1.64	2.09	7.32	18.66
MFDD [m/s^2]	6.68	7.13	7.07	8.36	5.51	14.71
Z (MFDD) [%]	68.1	72.70	72.10	85.20	5.55	14.67
$\mu_x = MFDD/g$	0.68	0.73	0.72	0.85	5.56	15.29
F_{z1} [N]	5989.22	6058.15	6058.63	6284.21	1.45	3.60
$F_{x1} = F_{z1} \cdot \mu_x$ [N]	4072.67	4422.45	4362.21	5341.57	6.64	17.20

5. Conclusions

Based on the performed tests and the calculations done, it can be seen that in cases of loading the vehicle with different loads, the forces acting on the vehicle tires, as well as the coefficient of friction, will change by affects the overall performance of the braking system.

From the performed tests it is noticed that the braking efficiency for the case when in the vehicle is only driver is about 10% higher than in the case when except driver are 3 passengers in the vehicle. It has been proven that the braking distance is shorter in the case when driver during braking press clutch pedal.

For different road surfaces, the coefficient of friction between tire and road surface has different values and plays a major role in braking efficiency. Different loads and vehicle speeds takes different values of coefficient of friction. The measurement confirmed that the braking distance is 17.58% less for new asphalt compared with old asphalt at initial braking speed 60 [km/h].

6. References

[1] Shpetim Lajqi, Stansilav Pehan. *Designs and Optimizations of Active and Semi-Active Non-linear Suspension Systems for a Terrain Vehicle*. Strojniški vestnik - Journal of Mechanical Engineering, pp. 732-743, 58(12), 2012.

[2] Sh. Lajqi, J. Gugler, N. Lajqi, A. Shala, R. Lika. *Possible Experimental Method to Determine the Suspension Parameters in a Simplified Model of a Passenger Car*. International Journal of Automotive Technology, pp. 615-621, 13(4), 2012,

[3] Shpetim Lajqi. *Mechatronic of Vehicle*. Dispense for students. University of Prishtina, Faculty of Mechanical Engineering, Prishtina, 2020.

[4] Agron Syla. *Examination of Advanced braking systems of the vehicles and their effectiveness on the braking*. *Master Thesis*. University of Prishtina "HASAN PRISHTINA", Faculty of Mechanical Engineering, Prishtina, 2020.

[5] Heset Cakolli. Methods for calculation of motor vehicles. Dispense for students. University of Prishtina, Faculty of Mechanical Engineering, Prishtina, 2015.

[6] Naser Lajqi. *Exploitation and Maintenance of Vehicle*. Dispense for students. University of Prishtina, Faculty of Mechanical Engineering, Prishtina, 2010.

[7] XL Meter ™ Gamma Pro / http://www.nehodar.cz/docs/xlmdatasheet.pdf (access 15.01.2021).

[8] Ramadan Mazrekaj, Naser Lajqi, Egzon Tofaj. *Influence of Tires Age on Vehicle's Braking Performance: a Case Study*. International Review of Mechanical Engineering, Volume 14, No 10 (2020), pp. 646-657, DOI: https://doi.org/10.15866/ireme.v14i10.20235.

[9] Ramadan Mazrekaj, Shpetim Lajqi, Fevzi Mema, Naser Lajqi. *The Influence of the Vehicle Shock Absorber Wearing on the Performance of the Braking System – A Case Study*. International Journal on Engineering Applications, Volume 9, No 3 (2021), pp. 137-147, DOI: https://doi.org/10.15866/irea.v9i3.20493