Experimental study of motorcycle trim while braking

S I Hesapchieva[1,3], D Hlebarski[1], G Yanachkov[1], E Dimitrov[1], Z Georgiev[2]

[1] Technical University – Sofia, Department of Combustion Engines, Automobile Engineering and Transport, 8 Kliment Ohridski Blvd., 1000 Sofia, Bulgaria
[2] University "Prof. Dr Asen Zlatarov" - Burgas, 1 Prof. Yakim Yakimov Street, 8010 Burgas, Bulgaria

[3] E-mail: six@tu-sofia.bg

Abstract. The aim of the publication is to study the behavior of the motorcycle suspension in braking mode, to determine its tendency to dive and the pitch motion of the sprung masses through a road experiment. A series of experiments were carried out in which the motorcycle stopped on a dry, flat section of asphalt road. The motorcycle brakes from an initial speed of 40 km/h to a full stop. The experiment was performed in three parts – using only the front, only the rear and braking with both brakes simultaneously. The experimental data were processed in MATLAB software. The results of this study can be used to study the behavior of the motorcycle in different braking method and to calibrate mathematical models to optimize the characteristics of the suspension.

1. Introduction

The term vehicle trim implies the geometric configuration that the motorcycle acquires in different conditions during transient and steady motion, in acceleration and in braking. It depends on the stiffness characteristics of the front and rear suspensions, on the forces acting on the motorcycle, and on the inclination angle of the chain andthe swinging arm [1]. During the accelerating or decelerating of the motorcycle, inertial forces arise from the translation moving and rotating masses. These forces, applied to the drive wheel, create moments of inertia around the three coordinate axles, which have a significant impact on the manoeuvrability and stability of the motorcycle. The longitudinal moment of inertia gives information about the properties of the suspension when passing through a rough road or in the mode of stopping /acceleration, which can also be used as an indicator of driving comfort. It depends on the geometry of the suspension and the characteristics of the elastic elements.

Since the braking force acts in the contact patch of the wheel, on the sprung masses of the vehicles acts a torque, which generates a dive-effect. The magnitude of this effect is proportional to the inertial force and to the height of the vehicle [2]. The action of this moment is accompanied by the inclination of the sprung masses in the longitudinal direction, due to the presence of elastic suspension [3]. This phenomenon leads to a redistribution of normal reactions in the front and rear axles and is most pronounced in the motorcycle, as it is characterized by a short base and a relatively high center of mass. Due to the load redistribution, the normal reaction in the rear wheel is getting smaller and only a small braking torque can be applied to it. Another problem that can occur is the loss of contact between the rear wheel and the road when significant braking forces are reached in the front wheel [4]. This leads to loss of stability, overloading of the front tire, puncture in the front suspension and others.

The purpose of this publication is to conduct a road experiment to determine the deformation of the suspension during braking and to determine the pitch angle as a function of deceleration.

2. Forces acting on the motorcycle during braking and weight redistribution

The forces acting in braking are shown in figure 1. Applying Newton's law, the equations of motion in braking mode can be derived. The resistance forces from the air and from the rolling of the wheels are neglected because the maximum speed in the experiment is only 40 km/h. They represent a certain margin of braking force, but are insignificant at that speed compared to the maximum braking forces developed by the axles [5]:

$$m\ddot{x} = -F_f - F_r, \tag{1}$$

where F_f и F_r are the braking forces in the front and rear wheels respectively. For the dynamic reactions in the wheels the equations are:

$$N_f = mg\frac{b}{p} + F\frac{h}{p}; N_r = mg\frac{(p-b)}{p} - F\frac{h}{p}. \tag{2}$$

From the equations for the dynamic reactions in the wheels it is seen that the load transfer is proportional to the total braking force and the vertical coordinate of the center of gravity (CG) and inversely proportional to the base of the motorcycle.

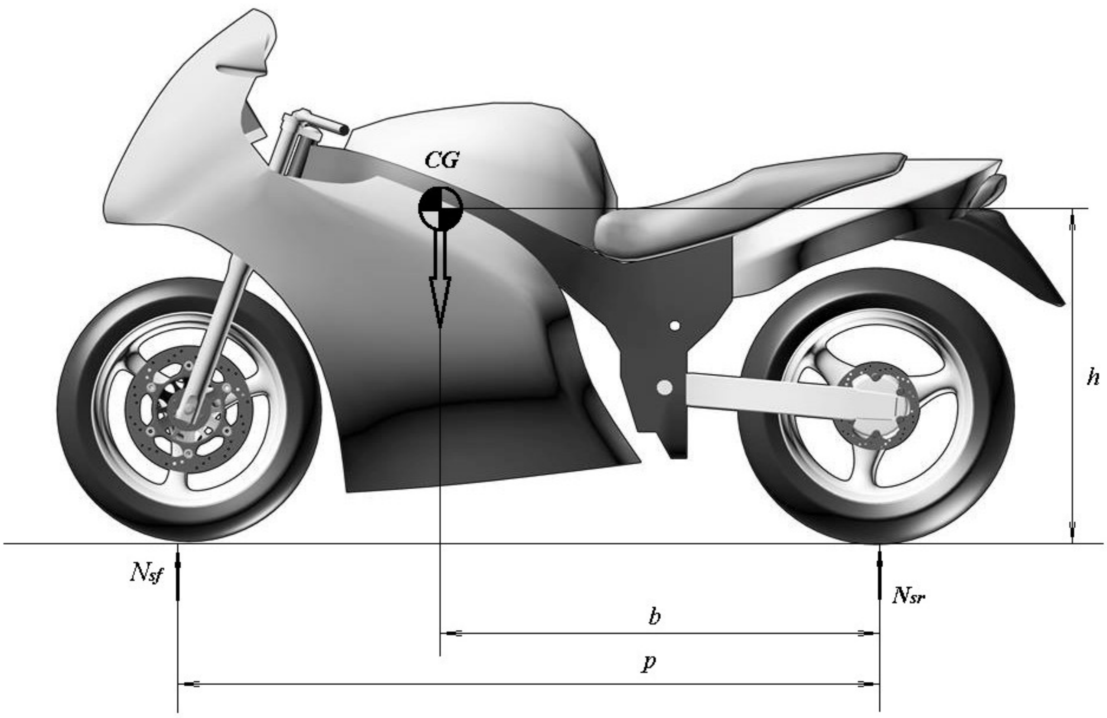

Figure 1. Forces, acting on a motorcycle while braking.

If the longitudinal coordinate of the center of gravity is known, the vertical coordinate can be determined by measuring the load on only one wheel, for example the rear wheel, by raising the front wheel to a predetermined height H [1]:

$$h = \left(\frac{mg\frac{(p-b)}{p}p}{mg} - (p-b) \right) cotg\left[arsin\left(\frac{H}{p}\right)\right] + \frac{R_r + R_f}{2} \tag{3}$$

where R_f and R_r are the radii of the front and rear wheels, respectively. In table 1 are presented the parameters of the experimental motorcycle.

Table 1. Parameters.

Parameter	Definition	Value
Mass of motorcycle, kg	m_m	237
Mass of rider, kg	m_B	75.8
Mass of both motorcycle and rider, kg	m	312.8
Height of gravity center, m	h	0.604
Distance from front axle to the CG, m	a	0.828
Distance from rear axle to the CG, m	b	0.682
Front static load, N	N_{sf}	1386.15
Rear static load, N	N_{sr}	1681.43
Castor angle, °	ε	27
Weight distribution	–	45/55
Wheel lift height	H	110

3. Methodic of the measurement

The road experiment is carried out on a Kawasaki GPZ 1100 motorcycle, which is not equipped with anti-lock braking system (ABS), therefore the braking delays realized by the rider are not maximal, due to his consideration not to reach the limit of wheel traction, blocking the wheels and crash. Front suspension is traditional telescopic fork and the rear suspension is swingarm. The measurements are performed on a straight section of smooth, dry asphalt pavement at an ambient temperature of 30 ° C. The air temperature was 27 ° C. To solve the tasks, a series of experiments were performed involving the use of front, rear and both brakes simultaneously from the initial speed of 11.11 m/s (40 km/h) until complete stop. To measure the deformation in the suspension, inductive sensors for linear displacement HBM type WA-L with a nominal range of 0-300 mm with a built-in amplifier are used. The receiver measuring the displacement in the front suspension, the receiver is mounted parallel to the telescopic fork by means of brackets and plates (figure 2, position 1, figure 3a). It must be installed in such a way that it does not impede both maneuvering and the driver's access to the controls (clutch or brake). It is also necessary to ensure alignment between the cylindrical body and the piston to prevent distortion of the latter or jamming. The displacement sensor, which detects the displacement in the rear suspension, is mounted vertically on the axis of the wheel with plates (figure 2, position 3, figure 3c). The sensors work with an input voltage of 12 V, provided by batteries, and the output signal is in the range of 0.5-10 V. The realized braking decceleration is recorded by means of a triaxial accelerometer MEAS 4030, mounted in a horizontal position on the tank (figure 2, position 2, figure 3b). The receivers are connected to a four-channel HBM DAQ401 and through it the oscillograms are recorded in a computer (figure 4). The suspension is equipped with new tires – 120/60R17 at the front and 170/60R17 at the rear. The air pressure in the tires is 2.2 bar.

Figure 2. Kawasaki GPZ 1100 equipped with sensors and computer.

a) b) c)

Figure 3. Mounting of the sensors on the motorcycle.

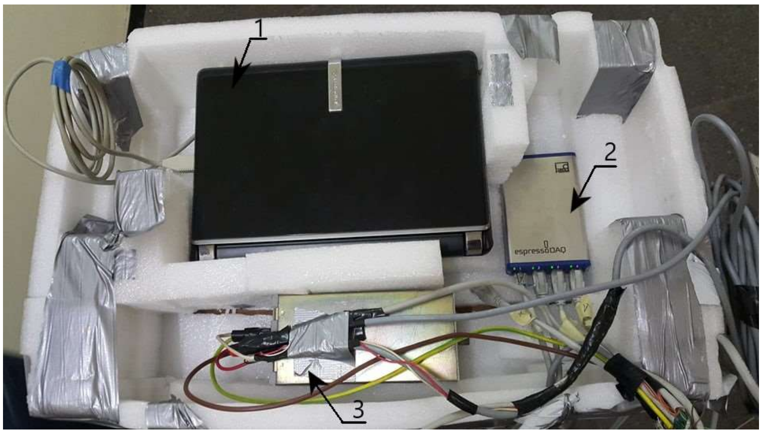

Figure 4. Layout of the measuring system: 1 – DAQ DC module, 2 – PC, 3 – charge amplifiers.

4. Experimental results

The measurement starts when the motorcycle is stopped with first gear engaged and starts a few seconds. Then the motorcycle accelerates to 40 km/h, immediately after that it begins to brake to a standstill. The measurement is stopped a few seconds later.

In figure 5 and 6 are presented the experimental results when braking with the front brake only. Braking begins shortly after 10 seconds, where the acceleration line intersects the abscissa. As seen, the deceleration increases smoothly to his maximum, where the load transfer is the largest. In this section there is the greatest deformation in the suspension and pitch of the sprung masses. The maximum value of the compression in the front suspension is over 56 mm with a braking delay of close to 6 m/s^2. The maximum value of the pitch angle is 3.01 °.

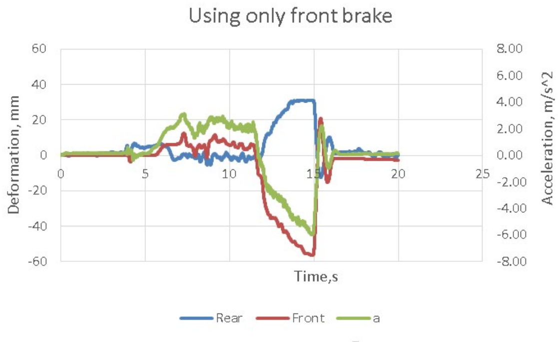

Figure 5. Acceleration and deformation in front and rear suspension when using only front brake.

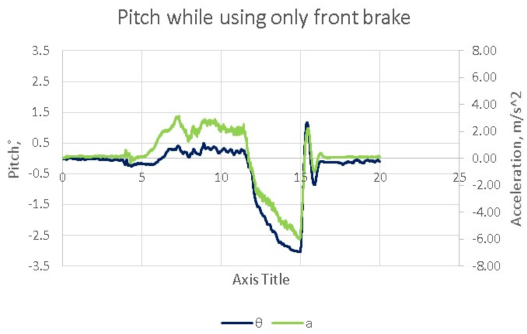

Figure 6. Acceleration and pitch angle when using only front brake.

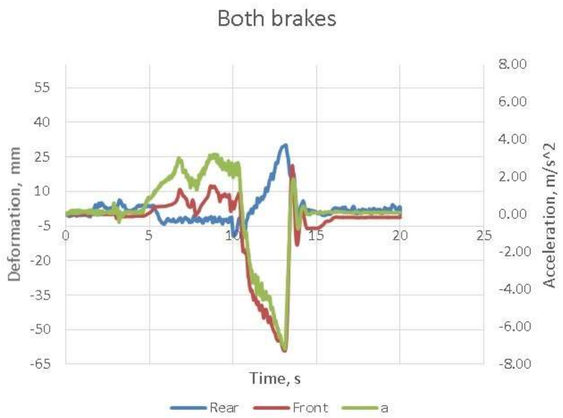

Figure 7. Acceleration and deformation in front and rear suspension when using both brakes.

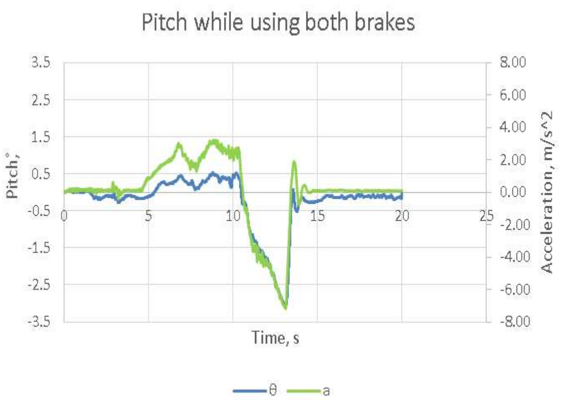

Figure 8. Acceleration and pitch when using both brakes.

Figure 7 and 8 show the results of braking using both brakes. In this case, the maximum braking delay is realized. The suspension behavior is similar to the experiment, where is used only the front brakes. As the braking delay increases, the front suspension compress and the rear suspension extend. The values of the deformations are almost the same compared to braking with the front brake only. Although significantly less percentage of the braking force is produced by the rear brake, the pitch angle is smaller than the previous case. That is because of the specific kinematic of the rear suspension that gives some anti-dive effect.

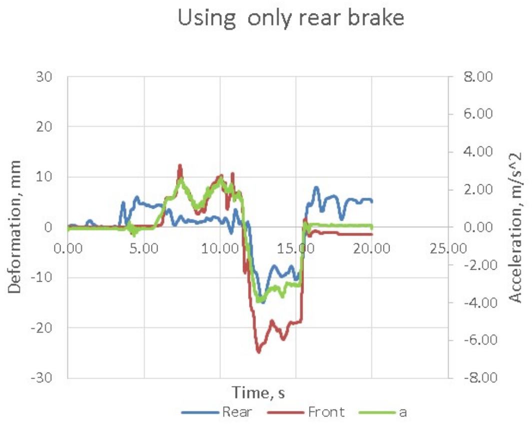

Figure 9. Acceleration and deformation in front and rear suspension when using only rear brake.

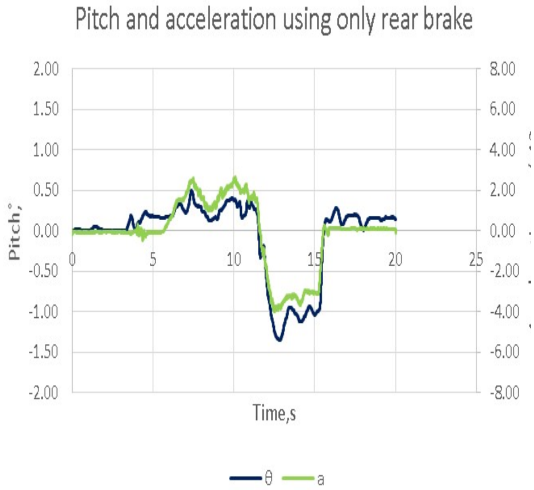

Figure 10. Acceleration and pitch angle when using only rear brake.

Figure 9 and 10 show the results of the experimental braking with rear brake only. In this case braking delays are much smaller due to the lower load on the rear tire, caused by the load transfer. Because of this the tire quickly reaches it is traction limit and no greater brake force can be applied. Unlike other braking methods, there is a compression in both the front and rear suspension. The compression in the front suspension is because of the load distribution, and in the rear is because of the anti-dive effect. In this case the lowest values for the pitch angle are reached.

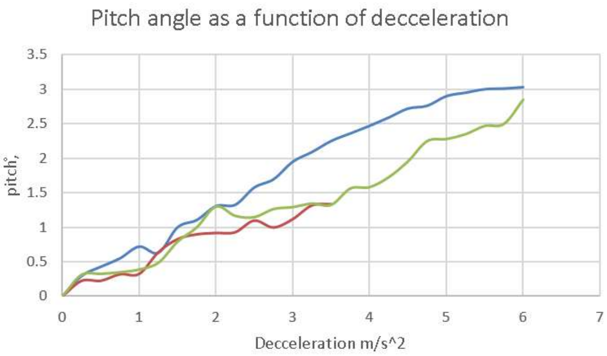

Figure 11. Pitch angles at different types of braking as a function of deceleration.

Figure 11 shows the pitch angle for the different braking methods as a function of the braking delay. It is noticed that the dependence is linear for all three modes and with increasing delay the angle increases also. When using only the front brake, the greatest rotation occurs and the greatest dive of the front. This is due to overloading the front wheel and unloading in the rear. In the case of using only the rear brake, significantly less delay and significantly less pitch of the sprung masses can be achieved. This type of braking can be used for service braking at low speeds or in preparation for cornering, but in most cases it is necessary to use both brakes at the same time. When applying brake force on both wheels at the same time, the greatest delays are achieved.

5. Conclusions

- When braking with both or the front brakes only, approximately the same braking delays are achieved, while when braking with the rear brakes only, the traction limit for the rear wheel is quickly reached and the braking delay is significantly less.

- When braking with the rear brake only, the inclination of the motorcycle is the smallest. This is due to the anti-dive effect of its construction. Only in this braking mode is there a compression of the rear suspension.
- When braking with the front brake only, the angle of inclination of the motorcycle is the largest.
- When braking simultaneously with both brakes, the motorcycle does not dive so much due to the above-mentioned kinematic features of the rear suspension.
- In the zone with high deceleration the pitch angle with front braking and with both (front and rear) braking are similar because the load and the brake force in the rear wheel decreases, respectively the anti-dive effect from the rear suspension.
- The authors recommend using both brakes in every day (not racing) situations.

References

[1] Cossalter V 2006 *Motorcycle Dynamics* 2nd ed. (Lulu: London)

[2] Pavlov N 2019 Reducing pitch angle and suspension jounces of a truck when braking on railway crossing by control of semi-active suspension *Int. J. of Mechanical Engineering and Technology* **10**(3) pp 1584–92

[3] Pavlov N 2017 Numerical study of the motorcycle braking taking into account the suspension deformation *Transport, Ecology – Sustainable Development Proc. of the Technical and Sci. Conf. ECO Varna (Varna, Bulgaria)* **24** pp 215–23 (In Bulgarian)

[4] Cossalter V, Doria A and Lot R 2000 Optimum suspension design for motorcycle braking *Vehicle System Dynamics* **34** pp 175–98

[5] Dimitrov S and Kunchev L 2016 *Motor Vehicle Theory* (TU – Sofia, Bulgaria) (In Bulgarian)