Transport and Telecommunication, 2025, volume 26, no. 4, 325-330
Transport and Telecommunication Institute, Lauvas 2, Riga, LV-1019, Latvia
DOI 10.2478/ttj-2025-0024

EXPERIMENTAL DETERMINATION OF THE BRAKING BEHAVIOR OF AN ALTERNATIVE FRONT MULTILINK MOTORCYCLE SUSPENSION

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Abstract braking of the motorcycle is a critical aspect that must be considered when investigating traffic safety, which is an ever-present problem that requires extensive research and alternative solutions. This requires that motorcycles be designed with a certain self stability. One of the methods to increase the stability can be achieved is the development of an alternative suspension. The purpose of this publication is to investigate the behavior of a motorcycle front suspension borrowed from the automotive industry - the "multilink" type. A series of road experiments were conducted where the motorcycle stopped on a dry, level stretch of asphalt pavement. Since the designed suspension is new and under investigation, for safety reasons the experiment was conducted using only the front brake. Also, the initial speed from which the braking begin has been reduced. This does not affect the results, because as known from the theory of the car, the maximum braking deceleration is not a function of the speed, but depends on the realized braking force and the traction coefficient. The motorcycle stops from an initial speed of 20 km/h to a complete stop. Experimentally was determined the deformation in the front and rear suspension, the lateral and vertical acceleration, the. The pitch angle and load transfer - are numerically determined. The experimental data were processed in MATLAB software. The test results can be used for suspension optimization.

Keywords: Motorcycle front suspension, alternative suspension, motorcycle breaking, pitch angle, multilink suspension

1. Introduction

In recent years, scientific research and engineering developments have made a huge contribution to the modernization of motorcycles in order to meet the increasingly strict requirements for efficiency, environmental protection, safety and traffic safety. Modern motorcycles develop very high speeds and in most cases the driver cannot react to disturbances from the road surface and the environment. Increasing the speed of movement, in turn, depends to a large extent on the parameters of the wheel suspension. A suspension with incorrectly selected parameters leads not only to a decrease in the speed of movement, but also to a significant deterioration in the safety of movement, both in a straight line and cornering. The kinetic behaviour of the different types of front suspension and its impact on the basic geometric dimensions of the motorcycle and its stability are presented in Moreno-Ramirez *et al*., 2021, Moreno-Ramirez *et al*., 2018 and Mavroudakis & Eberhard, 2019, and other researches. A comparison of the behavior of different types of alternative suspension is presented in Gadola *et al.*, 2019. Kinematic and dynamic simulations of different types of alternative suspensions - with a hub center and with a double wishbone suspension - were carried out. In order to validate the systems performance, various simulations of situations close to real driving conditions have been carried out. The models are subjected to a series of tests such as lane change, U-turn, braking/acceleration. The significant superiority of the alternative systems over the model equipped with a conventional telescopic fork is noted. The effect of front suspension kinematics on optimal braking is investigated by calculating the value of the front braking torque that minimizes the braking distance for different values of stiffness and damping of the front suspension is investigated in Doria *et al*., 2000. The basic phenomena which occur during braking are highlighted, a strategy for combined braking systems is developed and its implications on motorcycle stability are discussed in Cossalter *et al.,* 2004. Road experiments using alternative front suspension on motorcycles are insufficient. Due to the relevance of the problems related to the stability of the movement of the motorcycle, the purpose of this work is to study a multilink front suspension and conduct an experimental study of its braking behavior. In order to make a real assessment of its advantages and disadvantages, the results are compared with those obtained in Hesapchieva, 2022.

2. Methodology

A series of road experiments were conducted on a horizontal section with a dry pavement in a controlled and safe environment. During the experiment, the displacement in the front and rear suspension, the longitudinal and vertical acceleration were measured. The pitch angle, the redistribution of the normal load on the front and rear running wheels and the variation in the geometric parameters of the motorcycle were determined numerically. The aim of the study was to determine the deformation in the suspension during braking. In this way, the tendency of the suspension to "dive" can be assessed. In order to achieve the aim of the study, it is necessary to perform the following tasks:

- Smoothly pull the motorcycle, accelerated to the selected initial speed, from which braking begins and braking the motorcycle to rest.
- Determine the deformation in the front and rear suspension. It is necessary to use displacement sensors.
- Determination of the horizontal acceleration of the motorcycle's mass center using an accelerometer
- Use of a data acquisition through which the measurements can be recorded on a portable computer.
- Processing of results and analysis.

In order to register the deformation in the front suspension when the motorcycle braking, the displacements. Processing of results and analysis or must be positioned in such a way that it does not impede maneuvering and the driver's access to the controls (clutch or brake). The most suitable option for this design was to mount it parallel to the upright using brackets and plates (Figure 1, pos.1). The sensor that measured the displacement in the rear suspension is placed vertically on the wheel axle using elastic plates (Figure 1, pos.3). The accelerometer is placed in a horizontal position on the tank, as close as possible to the mass center (Figure 1, pos. 2).

Figure 1. Kawasaki GPZ 1100 equipped with sensors and computer

To measure the displacement in the suspension, the same inductive sensors for linear displacement HBM type WA-L with a nominal range of 0-300 mm with a built-in amplifier, which are available at the department, were used. The sensors operate with an input voltage of 12 V provided by external batteries, and the output signal is in the range 0.5-10 V. The realized braking delay (deceleration) is recorded using a three-axis accelerometer MEAS 4030 with a range of ± 2g. The receivers are connected to a four-channel HBM DAQ401 and through it the oscillograms are recorded on a portable computer (Figure 2).

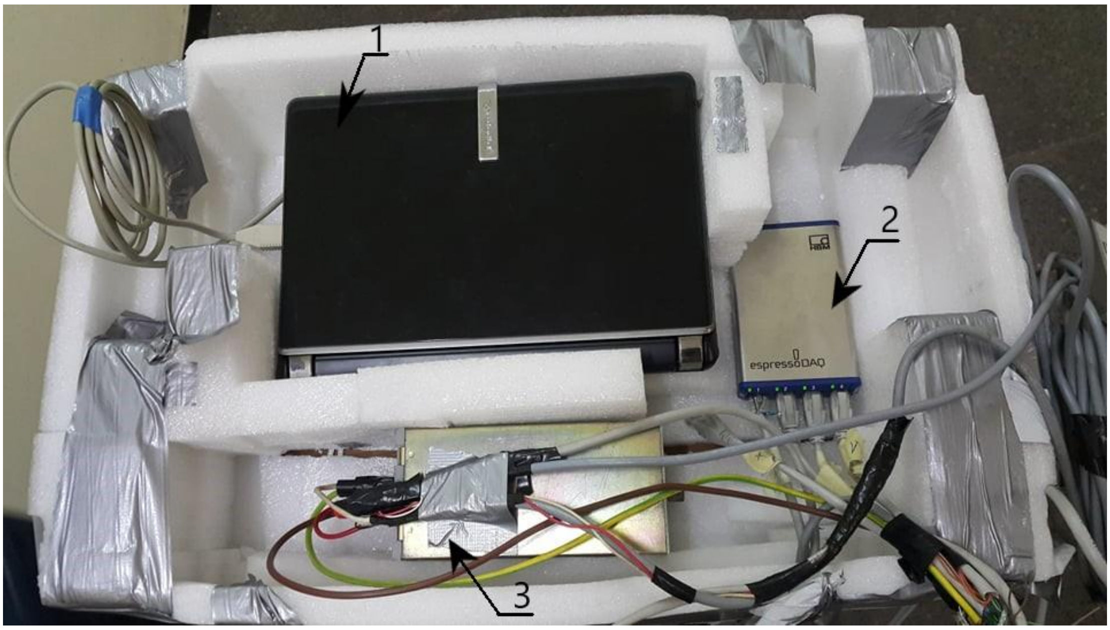

Figure 2. Layout of the measuring system: 1 – PC,2 – DAQ module, 3 – charge amplifiers.
The parameters of motorcycle are presented in Table 1

Table 1. Parameters of motorcycle

Parameter	Definition	Value
Mass of motorcycle, kg	m_m	250
Mass of rider, kg	m_r	75.8
Mass of both motorcycle and rider, kg	m	325.8
Height of gravity center, m	h	0.604
Distance from front axle to the CG, m	a	0.740
Distance from rear axle to the CG, m	b	0.770
Front static load, N	N_{sf}	1579.41
Rear static load, N	N_{sr}	1616.68
Castor angle, º	ε	27
Weight distribution	–	49/51

3. Experimental results

The measurement starts when the motorcycle is stopped with first gear engaged and starts a few seconds. Then the motorcycle accelerates to 20 km/h, immediately after that it begins to brake to a standstill. The measurement is stopped a few seconds later. The results were processed in the Matlab environment. Figure 3 presents the experimental results obtained from the suspension displacement sensors when stop using front brake only. The deformation in the front suspension is represent with Δ_1, and in the rear respectively with Δ_2. Braking begins after the eighth second, where the acceleration line $\ddot{x}$ crosses the abscissa axis and the acceleration becomes negative (braking delay). It is noted that the variation in the deformation of the front suspension is proportional to the negative acceleration – when the motorcycle accelerates to the selected speed from which braking begins, a slight relaxation of the front suspension is observed, and when the braking delay increases, due to the unloading of the rear wheel and the additional loading of the front wheel, compression is observed. For the rear suspension, the trend is opposite. The maximum value of compression in the front suspension is slightly over 12 mm, recorded when a braking delay $\ddot{x}$ of about 6 m/s^2 is realized.

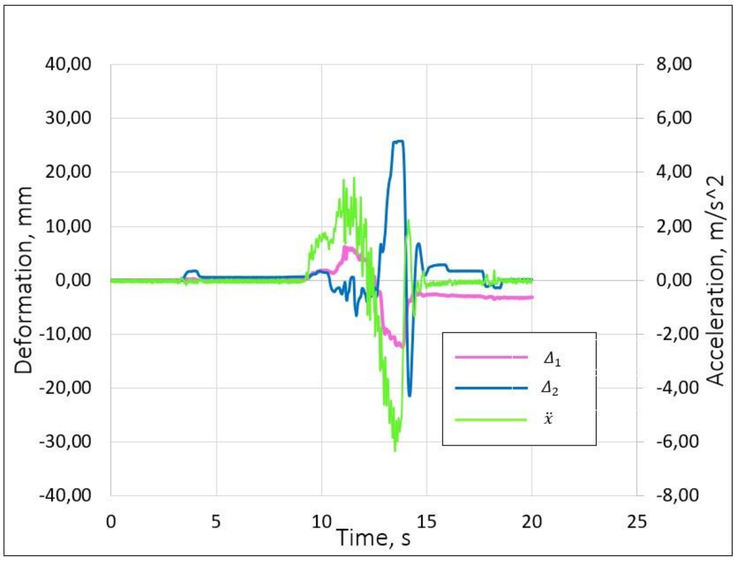

Figure 3. Deformation in suspension

When braking, in addition to the static normal load, the front suspension is subjected to two additional forces: the front braking force and the weight redistribution generated by the total braking force. The load transfer is proportional to the total braking force and the vertical coordinate of the mass center and inversely proportional to the wheelbase of the motorcycle. Having obtained the deformations of the front and rear suspension, the angle at which the sprung masses of the motorcycle rotate is numerically determined. The maximum recorded value of the trim when braking with the designed multi-link arm suspension is 1.37° (Figure 4). The rate of variation of the pitch is also directly proportional to the acceleration of the motorcycle.

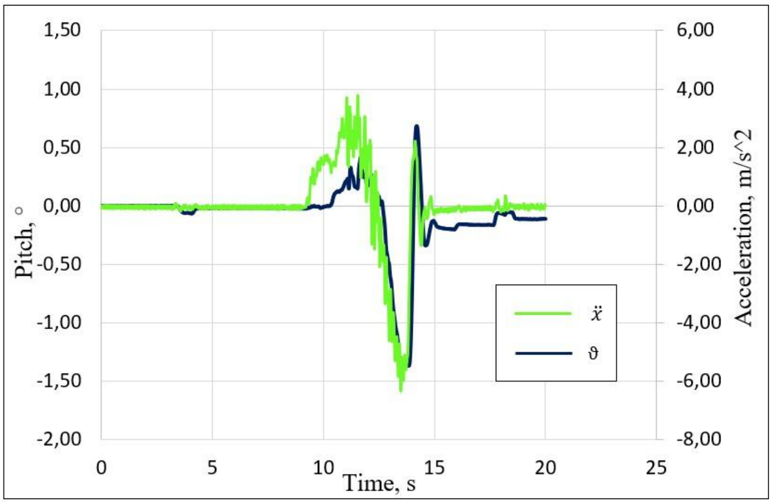

Figure 4. Variation in pitch angle

The variation in the front and rear wheel load when conducting the road experiment when braking using only the front brake is presented in Figure 5 and Figure 6. With N_f is the load in the front wheel, with N_r in the rear wheel, with $\ddot{x}$ the acceleration. The redistribution of load in the front wheel is proportional to the applied braking force, and the nature of the load change in the rear wheel is inversely proportional. When the maximum braking delay is reached, the normal load on the front running wheel increases by 63%.

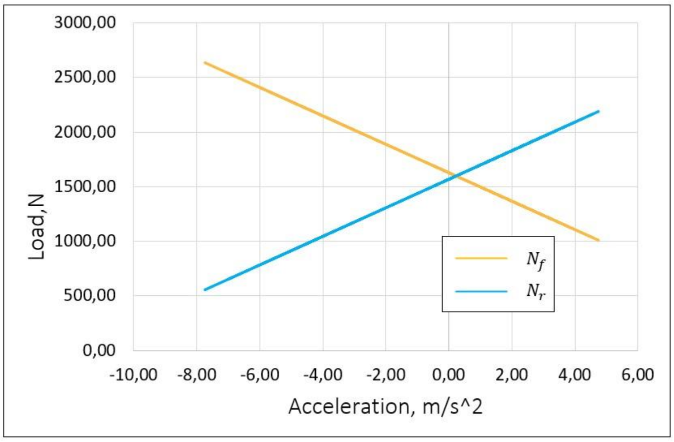

Figure 5. Load transfer as a function of acceleration when braking with the front brake

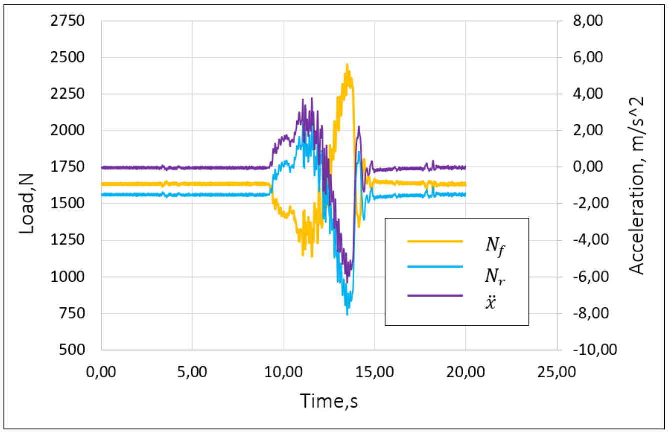

Figure 6. Load transfer as a function of time when braking with the front brake

4. Conclusions

- In order to reduce road accidents, the requirements for modern vehicles related to traffic safety are increasing and are subject to constant regulations and research. This is always an adjective topic and to an even greater extent for two-wheeled vehicles, as they belong to the "vulnerable" group of road users. The stability of movement of two-wheeled vehicles during acceleration and braking is of critical importance for the safety of the rider. The transitions between these modes are particularly critical, as they lead to a sharp redistribution of weight between the front and rear wheels, changing the traction and dynamic characteristics of the system. This emphasizes the need to accumulate knowledge and experience regarding the influence of steering geometry on the dynamic behavior of the motorcycle and road experiments in different modes. As an attempt to expand the possibilities for implementing an alternative front suspension and its advantages and disadvantages, a motorcycle with an original and adjustable front suspension was designed. The focus is on eliminating dive during braking, resulting in a significant reduction in stability parameters.The most important advantage of the designed multi-link suspension is the separation of the motorcycle's suspension and steering functions. Designed Multilink suspension system provides an anti-dive effect due to tyre's contact patch curvilinear trajectory. This allows the suspension to be fully operative on braking. The suspension allows to pre-determine the trajectory of contact patch by changing the length of the links. The deformation of the front suspension is significantly less with a MULTILINK suspension than with a suspension with a telescopic fork, significantly improve in stabilization after braking. Disadvantages include: complexity of the structure, presence of many elements, more complex manufacturing and requirements for the accuracy of individual parts, increase in unsprung masses, less suspension travel, typical of link suspension, more difficult to assemble. It is necessary to note that this is the first prototype of the suspension, which requires various experiments to further clarify some of its advantages and disadvantages in order to optimize the design and properties of the suspension.

- A motorcycle road experiment was conducted in which the motorcycle's horizontal acceleration and suspension behaviour were measured when using only the front brake. As has been proven in other experiments, with this method of braking, the longitudinal rotation of the sprung masses is the greatest and is the most used method of stopping. Through the results obtained from the road test, the rotation of the sprung masses and the variation in the load on the front and rear axles were numerically determined. In this way, it is possible to assess the anti-dive properties of the design suspension, the variation in the parameters characterizing the stability of movement. The results of the suspension measurements show that the change in the studied quantities is similar to the use of conventional suspension and prove a significant reduction in the compression of the front suspension during braking and, accordingly, the preservation of the value of trail. There are no significant differences in load distribution compared to conventional suspension. Here, the load is slightly higher at the front end due to the increase in unsprung masses.
- When accelerating the motorcycle to the selected speed from which braking begins, a slight increase in the studied parameters is noticed. This is due to the load transfer and the elasticity of the suspension. When the maximum braking delay value is reached, the largest deformation in the suspension occurs, and therefore the largest rotation of the sprung masses. After that, a rapid decay of the studied quantities is observed.
- When braking, the trail, normal trail, castor angle, the base of the motorcycle remains almost unchanged. This is due to the anti-dive effect assumed in the design of the suspension.
- The obtained results can be used in dynamic models studying the behaviour of the suspension and to study the behaviour of the motorcycle when braking.
- The obtained results can be used to compare the influence of different types of front suspension on the geometric parameters of the motorcycle under deformation in the suspension and through them to create out-of-plane dynamic models considering the stability of motion.
- The suspension can be optimized based on the results obtained

Acknowledgements

The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

Declaration of Generative AI and AI-assisted technologies in the writing process:

- During the preparation of this manuscript the authors did not used Generative AI and AI-assisted technologies and take full responsibility for this declaration.

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