Comparative analysis of the braking behaviour of a single track vehicle with different types of front suspensions

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Abstract:*. Modal simulations comparing the behaviour of different types of motorcycle suspension in specific conditions are found in the literature. However, there is a lack of sufficient field experiments that can be used both to calibrate the models and to realistically assess the advantages and disadvantages of alternative designs. The aim of this publication is to evaluate the behavior of the authors' alternative front suspension of a motorcycle in braking mode. To achieve this goal, a series of road tests were conducted on the same motorcycle equipped with a different type of front suspension. Both experiments were conducted with the same equipment using the same methodology. The results were processed in the Matlab environment. The obtained results can be used both to evaluate the designed suspension and to validate simulation models and optimize the suspension according to the same methodology. The results were processed in the Matlab environment. The obtained results can be used to validate simulation models and optimize the suspension*

Keywords*: MOTORCYCLE FRONT SUSPENSION, TELESCOPIC FORK, MULTILINK SUSPENSION, MOTORCYCLE BRAKING, ROAD EXPERIMENT*

1. Introduction

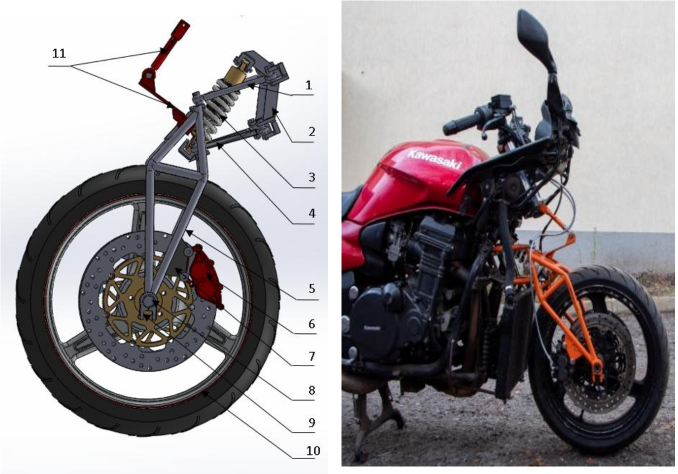
Modal comparison of the behaviour of different types of alternative suspension is presented in [1]. Kinematic and dynamic simulations of different types of alternative suspensions - with a central hub and with a double wishbone suspension - were carried out. In order to validate the systems performance, various simulations of situations close to real driving conditions have been carried out. The significant superiority of the alternative systems over the model equipped with a conventional telescopic fork is noted. Authors in [2] develop a modal study of the dynamic behaviour of the alternative front suspensions – Girder fork and Hossack's suspension, which is a prototype of the modern Duolever suspension, was compared with the conventional telescopic suspension. In order to evaluate the influence of the suspension parameters, experiments were made with three of its configurations - a parallelogram, where the levers are parallel and the angle between them is equal to zero, a configuration where the suspension is designed so that the trajectory of the front wheel to be similar to that using a telescopic fork and a configuration where the trail is kept constant throughout the suspension range. In [3, 4] the development of motorcycle suspension over the years is described, and the advantages and disadvantages of the fork as a front suspension system vs alternative constructions are explained. In studies such as [5-9] and many others, various models of alternative front suspension are presented. Each of the considered designs has advantages and disadvantages. The choice of a kinematic scheme is inevitably associated with a number of compromises - in terms of the mass of the unsprung masses, complexity of the construction, stability and controllability. From the review of theoretical and experimental studies related to the impact of different front suspension structures in the scientific space, the following conclusions can be drawn:

1. Despite alternative front suspension systems, the telescopic fork still remains the most common type of motorcycle front suspension, despite its disadvantages. It also means that these series of research and innovations have not fundamentally solved all the problems of the front suspension.
2. When using a link suspension, the trajectory of the wheel during deformation in the suspension is curvilinear.
3. When using a link suspension, with deformation in the suspension, the main geometric characteristics change significantly less, compared to the telescopic fork. In this way, greater stability is achieved.
4. Using a link suspension achieves a greater anti-dive effect when braking.
5. There is a lack of sufficient road experiments with alternative front suspensions studying their impact in different driving modes to validate the mathematical models.

The purpose of this study is to make a comparative analysis of the results obtained from road experiments with a motorcycle equipped with different front suspension systems while braking. In the first case, the test machine was equipped with the standard serial suspension, which is a simple telescopic fork. In the second case, it is equipped with a MULTILINK suspension designed and manufactured by the authors.

2. Alternative front MULTILINK suspension

MULTILINK suspension (Fig.1) is a type of independent suspension with three or more longitudinal links. It is common used in the automotive industry, mostly for luxury and sports cars. A 3D model was developed in a SolidWorks environment to physically investigate how the suspension would perform in 3D space and to check the geometric constraints. In developing this process, the tubular structure that represents the suspension upright is first modeled. The bike's handling was developed similar to some existing designs, using Hossack's suspension kinematics as a prototype. By turning the handlebars of the motorcycle, a moment is transmitted to the upper arm, from which the steering scissor is formed through the triples. Holes are drilled at both ends to allow it to be mounted to the lower triple. The test bike originally had a tubular steel frame. At one end, the suspension levers are hinged to the designed tubular structure. At their other end, they need to be hinged to the frame of the motorcycle. For this purpose, a model of a suspension element was developed to be welded to the frame. 4 p-shaped plates are modeled, in which the four levers are mounted, located at the specified vertical and horizontal distance. In order to increase the movement of the links, conical bushings are located on both sides of the hinge. Ohlins TTX22M Universal was selected for the elastic and damping element of the suspension. This is an adjustable shock absorber with twin tube technology. This technology (TTX) is based on the principle of creating a damping force by increasing oil pressure on one side of the piston and having gas pressure on the other side. A common problem with monotube shock absorbers is a reduction in pressure on one side of the piston, leading to cavitation. This problem is solved by keeping the oil and gas pressure constant. In order to make the results between the standard and the design suspension comparable, the spring was chosen with approximately the same spring rate as the conventional. To allow for comparison of results, the spring rate was chosen to be approximately the same as that of the original suspension.



a) b)

Fig.1. *Assembled suspension type MULTILINK a – prototype, b – real type of suspension.*
1- upper levers of the suspension, 2 - attachment to the frame of the motorcycle, 3- elastic and damping element, 4- lower levers of the suspension, 5- upright, 6 - brake callipers, 7 - attachment of the brake callipers, 8- axis, 9 – hub, 10-wheel, 11 – handling arms.

According to the kinematic scheme, the place of the shock absorber is also determined. One of the main requirements for the suspension was its minimum cost. With the exception of the elastic and damping element, one of the main goals was minimal costs for the suspension materials, technological processes and treatments for its manufacture. Maximum recycled materials available in the department were used. When creating the MULTILINK suspension, maximum preservation of the main geometric dimensions of the motorcycle - trail, castor angle, wheelbase of the motorcycle was ensured. When producing the suspension, the mass of the unsprung masses was invariably increased. This also leads to a redistribution of the weight of the motorcycle along the axes and a change in the horizontal coordinates of the mass center.

3. Methodic of the measurement

A series of road tests were conducted on a horizontal section with dry asphalt concrete pavement in a controlled and safe environment. During the experiment, the displacements in the front and rear suspension, the longitudinal and vertical accelerations were measured. The angle of the trim, the redistribution of the normal load on the front and rear running wheels and the change in the geometric parameters of the motorcycle were determined using a numerical method. The purpose of the study is to determine the deformation in the suspension during braking. In this way, the tendency of the suspension to "dive" can be assessed.

To achieve the aim of the research, it is necessary to perform the following tasks:

1. Smooth start of the motorcycle, acceleration to the selected speed, from which braking begins, and braking of the motorcycle using only the front brake;
2. Determine the displacement in the front and rear suspension. It is necessary to use displacement sensors;
3. Determine the horizontal acceleration of the motorcycle's mass center using an accelerometer';
4. Use a data acquisition;
5. Processing of results and analysis.

The measurements are carried out on Kawasaki GPZ 1100 motorcycle,year of manufacture 1997 (ZX 1100 D), with a maximum power of 108 kW which is not factory-equipped with ABS system.The wheels are equipped with new Continental ContiMotion tires 120/60 R17 at the front and 170/60 R17 at the rear. The internal air pressure in the tires before the start of the experiment (cold tires) is 2.2 bar. The road experiments are carried out on the same section of the roadway in both directions. The measurement equipment used was the same in both experiments. The only necessary change was the change in the location of the sensor that detects the deformation in the front suspension. When using a telescopic fork, it is located parallel to the fork tubes. In the second experiment, it was mounted parallel to the upright using clamps and brackets near the wheel axis. 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 begins has been reduced. This does not affect the results, because as is known from the theory of the car, the maximum braking delay is not a function of the speed of movement, but depends on the realized braking force and the coefficient of traction. The average duration of each trial is about 20 s. In some of them, the braked wheel locks. Details of the methodology and measuring equipment, as well as the results of experiments with telescopic suspension are presented in [10-11]. Fig. 2 shows the location of the sensors during the motorcycle test. Since the suspension design is new and under investigation, for safety reasons the experiment was conducted using only the front brake. Also, the initial speed at which braking begins was reduced, compared to the telescopic fork. This did not affect the results because, as is known from automobile theory, the maximum braking delay is not a function of the speed of travel, but depends on the realized braking force and the coefficient of adhesion. In order to experimentally determine the deformations of the front and rear suspension, as well as the differential, a series of experiments were conducted using the front brake from an initial speed of about 5.71 m/s (20 km/h) to full stop.

Fig.2. *Kawasaki motorcycle equipped measuring equipment, 1-front suspension sensor, 2- accelerometer, 3 rear suspension displacement sensor*

4. Impressions of the driver when riding the motorcycle with MULTILINK suspension.

The described features of the behavior of the MULTILINK suspension are entirely subjective impressions of the motorcycle rider, both during the experiment and during free riding without restrictions and equipment:

1. Difficult turning of the steering wheel, at higher speeds the negative effect disappears.
2. Weaker stabilizing effect (self-stabilization of the front wheel). Need to adjust the angle of rotation of the wheel.
3. Perceptibly less dive when braking.
4. Better braking.
5. Fast stabilization and recovery after front tire lockup when braking. The effect has been observed several times.

As a result of the test drive, the conducted experiments and the processing of the results, the following conclusions can be drawn:

With the MULTILINK suspension, the dive of the motorcycle is 50% less.

The trail, normal trail, and wheelbase are kept nearly constant throughout the suspension's compression/rebound range of operation.

5. Results obtained from the road experiment with telescopic front suspension and MULTILINK suspension

In order to make a real evaluation of the designed MULTILINK suspension and to determine its advantages and disadvantages in braking mode compared to the telescopic suspension, a comparison of the obtained results of the road experiments was made.

Fig.3 compares the pitch angle at which the sprung masses of the motorcycle rotate when braking with only the front brake using different kinematics of the front suspension. ϑ_1 presents the results obtained for a motorcycle with a MULTILINK front suspension, and ϑ_2 – for a telescopic fork suspension. In both experiments, the initial speed from which the braking process begins is different. With a telescopic fork suspension, the braking process is longer, but the realized braking force, respectively braking delay, is the same. The nature of the change in the studied quantity is the same. The pitch angle when using a MULTILINK front suspension is half as small. This is due to the resistance against "diving", set as a goal when designing the suspension.

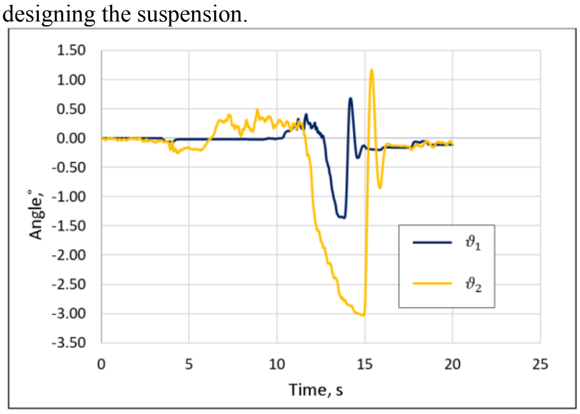


Fig.3 *Comparison between the pitch angle of a MULTILINK and a telescopic suspension motorcycle while braking using front brake only*

Fig. 4 compares the results obtained by the sensor measuring the displacement in the front suspension when braking with the two types of suspension. F_1 represents the displacement in the MULTILINK front suspension, and with F_2 respectively in the telescopic one. When accelerating to the selected speed from which to start the braking process, extention is noticed in both cases. When the maximum braking delay is achieved, the maximum displacement in the suspension is obtained. When using a MULTILINK suspension, the maximum compression in the suspension is reduced by nearly 50%. This is due to the twice smaller pitch angle. When braking with a telescopic fork, a significant damping vibration occurs at the end of the braking process. With the MULTILINK, this process is absent due to the greater resistance in the shock absorber.

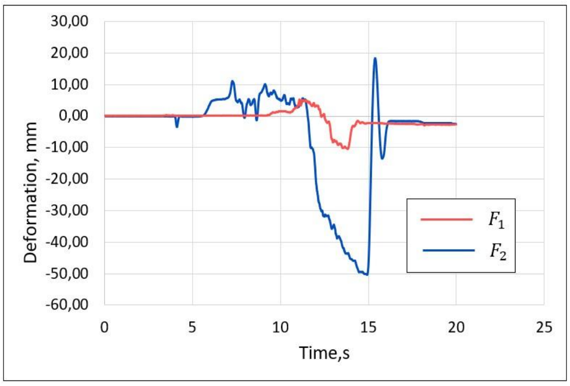


Fig.4 *Comparison of Front Suspension Deformation when braking with MULTILINK and Telescopic Suspension Motorcycle*

Fig. 5 compares the results obtained from the road tests with the two types of suspension. R_1 shows the displacement in the rear suspension of a motorcycle with the designed multi-link suspension, and R_2 presents the rear suspension when using the standard telescopic. The deformation measured in both experiments has the same nature. When stopping the motorcycle, as a result of the load transfer, the rear wheel is unloaded and the suspension is extended accordingly. When using a MULTILINK suspension, the deformation is slightly less compared to a telescopic suspension.

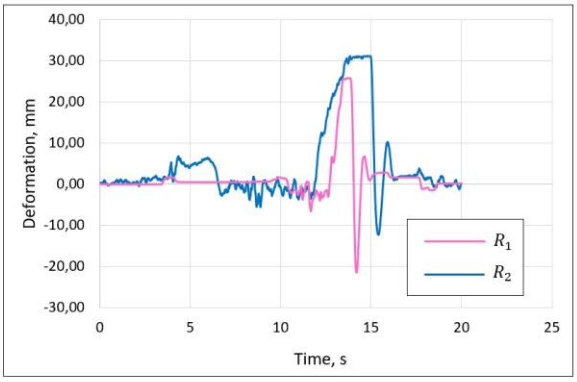


Fig.5 *Comparison of deformation in the rear suspension when braking a motorcycle with MULTILINK suspension and with Telescopic suspension*

Fig. 6. presents the results obtained for the horizontal acceleration of the motorcycle during the road experiments with both types of suspension. $\ddot{x}_1$ represents the acceleration during test with the MULTILINK front suspension, and $\ddot{x}_2$ – with the standard telescopic fork suspension. The variation in the studied quantities was the same nature. When using the designed suspension, the speed to which the motorcycle accelerates is lower and, accordingly, the braking period is shorter. However, the applied braking force and, accordingly, the resulting braking delays in both cases are almost the same. In the braking process, in addition to the normal load, the front suspension is subjected to two additional forces: the front braking force and the weight transfer generated by the total braking force. In both experiments, the applied braking force is the same.

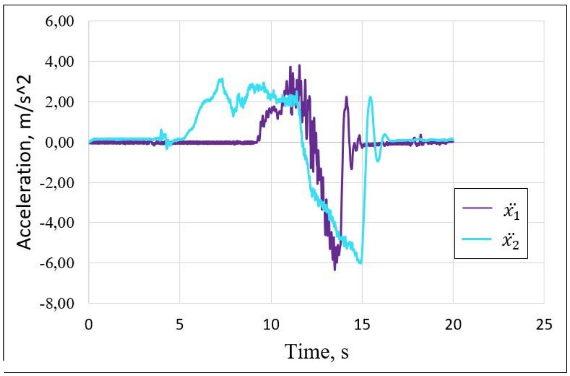


Fig.6. *Comparison in horizontal acceleration of a motorcycle with MULTILINK front suspension and with telescopic fork front suspension*

As a result of the test drive, the experiments carried out and the processing of the results, the following advantages and disadvantages can be deduced:

Advantages of MULTILINK suspension

1. Separation of suspension and steering functions.

2. Possibility of predetermining the trajectory of the center of the contact spot depending on the turning angle by changing the location and length of the levers.

3. When braking, the pitch of a motorcycle with MULTILINK suspension is about 50% less than with a standard telescopic fork suspension.

4. Deformation in the front suspension while braking is significantly less with the MULTILINK suspension than with the telescopic fork.

5. The trail maintains its dimentions throughout the suspension travel.

6. Better braking. Less energy from the brakes is not wasted on compressing the suspension and is used for clean braking.

7. Quick stabilization and recovery after front tire lockup when braking. (More experimental data are needed, but in a tightly controlled environment).

Disadvantages of MULRILINK suspension

1. Complication of the construction, the presence of many elements, more complex production and requirements for the accuracy of individual details.

2. Increase in unsprung masses, which can be compensated by the use of lighter materials.

3. Less suspension travel.

5. More difficult to assemble, the links are located where the coolant and oil radiators are usually located.

6. Conclusions

Road experiments were conducted with a motorcycle with different types of front suspension while braking with front brake. The variation in the front and rear suspension are measured and the longitudinal acceleration of the mass centre. The variation in the pitch angle were determined numerically. Since the safety of traffic and the security of the driver and the equipment used are of primary importance, the repeatability of the experiments is limited. In order to make a more complete assessment of a real prototype of an untested and alternative design, it is necessary to conduct additional tests in a strictly controlled environment under different modes - under different methods of braking, maneuvering, acceleration. However, the obtained experimental data give a real insight into the behaviour of the multilink suspension, the advantages it achieves over the conventional suspension and the problems that are yet to be solved.

The results obtained can be used in dynamic models studying the behaviour of the suspension, and for studying the behaviour of the motorcycle during braking.

The results obtained can be used to compare the influence of different types of front suspension on the geometric parameters of the motorcycle during suspension deformation, and from there to create out-of-plane dynamic models for studying the stability of motion.

Based on the results obtained, suspension optimization can be made.

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