ANALYSIS OF USING THE BENCH TESTS ON MOTORCYCLE'S STABILITY

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Summary

Experience shows that stability, which is one of the more important properties of single-track vehicles, defined as its resistance to interference or disturbance and returning the motorbike to ride straight ahead after riding in a turn depends on many factors. Implementation of road tests motorcycle carries a great risks to the rider and used sensors and archive equipment. The existing simple mathematical models do not allow a proper simulation of these forms of movement. An attempt to carry out tests on the bench stand was taken The influence of kinematic parameters of the front unit of the motorcycle on its stability was analyzed on a specially designed drum bench stand. The study included wobble vibrations for different speeds and different angles of the front fork of the motorcycle. The paper contains a description of the issues of vibration occurring in single-track vehicles, description of the bench test and compilation of the results and obtained stability characteristics.

Key words: motorcycle dynamics, stability, bench tests, wobble

1. Introduction

The stability of motorcycle is understood as the resistance to interference at linear motion and returning the motorbike to ride straight ahead after riding in a turn. The most dangerous for the preservation of stability (and the rider) are oscillatory phenomena. They exist in two different forms but they often are complex vibration. They occur suddenly, in some states of motion they are overdamped, in some others underdamped or even self-induced. The motion characteristics of a motorcycle have been marked, inter alia, by Mauro Salvador [1]. The results are shown in Figure 1. The research showed that the occurrence of loss of stability depend on many factors such as speed, tire type, geometric and mass parameters. The tested vehicle unstable form was only a capsize. Theoretical researches set three characteristic form of loss of stability.

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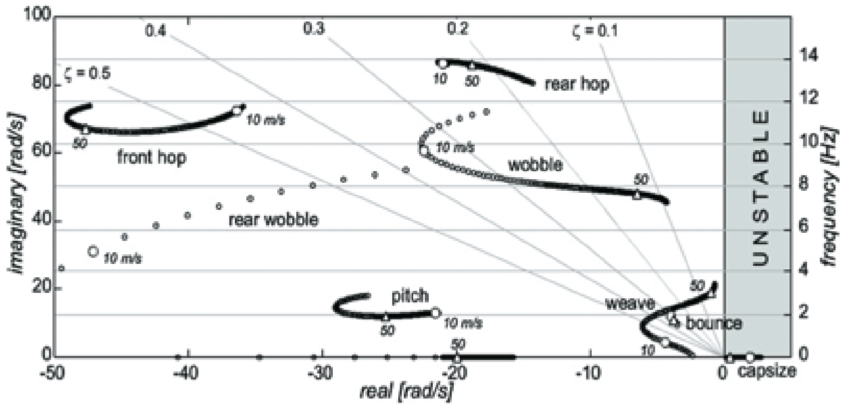

Fig. 1. Stability characteristics of the motorcycle [1]

Capsize

The simplest form of loss of stability. It results in overturn of the vehicle on the side (like a inverted pendulum - the center of mass of the motorcycle is located above the line joining the points of contact with the road). The single-track vehicle which stands or moves at low speed falls over. The capsize movement is normally controlled by rider and used for turning. The parameters influencing the capsize are velocity, gyroscopic effect of the wheels, height of the center of mass of the motorcycle, steering head angle and trail [9].

Wobble

Vibration form of loss of stability. It only occurs when the single-track vehicle is in motion. Wobble oscillations are the vibrations of the front unit (handlebar, front suspension and front wheel) around the control axis. In the rear unit (motorcycle frame, engine, rear suspension, rear wheel) there are no significant displacements. Wobble type vibrations frequencies are in the range of 4 to 10 Hz. Above a certain speed oscillations can be self-induced. The higher the speed the greater the displacement of front unit and higher vibrations energy. When they occurs the rider is rarely possible to overcome them. The motorcycles which are susceptible to the wobble vibration are equipped with torsion dampers (hydraulic or friction).

Weave

The weave vibrations are characterized by movements of the rear unit around the steering head. Vibrations frequencies are in the range of 0,2 to 4 Hz The weave form is unstable at lower speeds. At higher speeds, the risk of occurring of these oscillations decreases but the vibration energy grows so the rider may not be able to control them.

Usually both forms of oscillations occurs at the same time.

The wobble vibrations are difficult to model because of the need to consider the complex nonlinear tire model [2]. Therefore, the solution that could give the proper results are empirical studies. Because of the great danger for the rider it is impossible to make large interference or to make tests at high speeds. Much more safe form of research which might give sufficient compliance are bench testing. The bench tests eliminate the possibility of the capsize of the motorcycle and its rider and the construction provides low simplification. The work aims to capture the real effects of changes in kinematic parameters of the front unit on the vibration phenomenon and to get a material for comparison with road tests which still maintain a safe speed for the driver.

The parameters which are influencing the vibration modes are the subject of many theoretical studies. For example, Vittore Cossalter [3] points on the basis of theoretical analysis that the parameters affecting the oscillation frequency and damping rate are the speed of the single-track vehicle, the sideslip stiffness coefficient of tire, trail, viscous damping coefficient of steering damper, the moment of inertia of the front unit and the angle of the fork.

Mauro Salvador and others in their work [1] using road tests of a small single-track vehicle also analyze occurrence of wobble type vibrations. Figure 2 shows example of waveforms for the steering torque. It is noticeable that the torque amplitude increases (left fig. self-excited vibrations, right fig. force impulse).

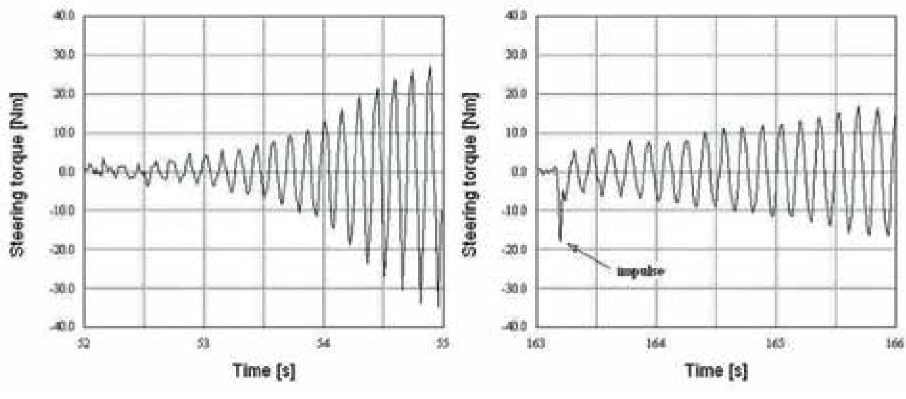

Fig. 2. Results of Mauro Salvador[1]

The influence of these parameters is also shown in work of Verma N. K [4] and others[8].

In the paper [5] written by J. Maryniak and Z. Goraj, the authors carry out the example of the bicycle "Ambassador" stability analysis with numerical calculations. The bike is treated as a system of four masses with nonholonomic constrains. The paper contains the impact analysis of some design parameters, kinematic and pneumatics parameters. Authors point the influence of changing of the angle of the fork and offset of the wheel to a single-track vehicle . The authors describe received ranges of optimal values of these parameters and draw attention to the need for experimental studies to accurately describe the stability of two-wheeled vehicles.

Also R. Andrzejewski and J. Awrejcewicz [6] deal with the nonlinear dynamics of wheeled vehicles. The theoretical considerations in the work includes the front wheel vibration problem of wobble where linear model of the tire is used.

2. Bench tests

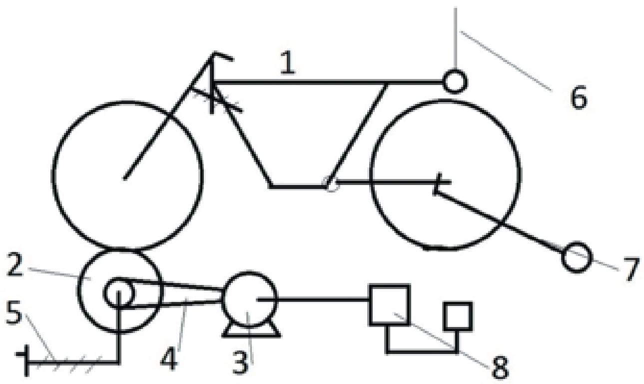

Fig. 3. Scheme: 1 Motorcycle; 2 Ride drum; 3 Motor; 4 Transmission; 5 System of the ride drum moving; 6 Suspension of a motorcycle; 7 Mounting the bike to the vertical position; 8 Inverter and power

The roll stand at which the test was performed allows to speed up the front wheel of a motorcycle, while keeping it vertically and not taking him completely the possibility of roll. The position of the vehicle is held vertically by two pre-tensioned springs. Preload of springs is chosen experimentally. The longitudinal movement of the motorcycle (in the plane of the wheels) is blocked by using a subframe rigidly attached to the rear swing arm. Such fixing coincides with the Mozzi axis. The Mozzi axis is a concept set by Vittore Cossalter for a description of displacements of a single-track vehicle when riding on curves. The movement of the motorcycle can be mathematically described as a movement around this axis. The results of experimental studies give evidence to determine the suitability of Mozzi axis theory to the analysis of other maneuvers. The ride drum is driven by the electric motor controlled by the inverter. The drive is transmitted to the ride drum with the releasing belt drive. The inverter characteristic allows smooth change of the riding speed in the range of 0 to 30 m/s (0 to 110 km/h). Whole stand is showed in Figure 4.

Fig. 4. Motorcycle on the test stand

3. The vehicle

Special modify of the serial motorcycle MZ ETZ 150 was used in tests. A front suspension of a motorcycle consists a telescopic fork with a stroke of 185 mm with hydraulic damping. Tubed motorcycle tires 3.00 R18 on front wheel and on rear wheel 3.50 R16. The modification consisted of mounting the system which allows to change the angle of the steering head. This system consists of a hinge around which fork makes flips, screw allowing smooth adjustment of the angle of steering head and screw system for locking in any position. The modification is showed in Figure 5.

Fig. 5. System changing the angle of steering axis

4. Instrumentation

During the tests two inertial accelerometers HBM type B12/200 were used. One was placed one on the handlebar of a motorcycle, and the other on the frame of the motorcycle (Figure 6). For data recording a track consisting a measuring card Spider 8 connected to a archiving computer was used. The speed of the front wheel was also checked by Correvit head.

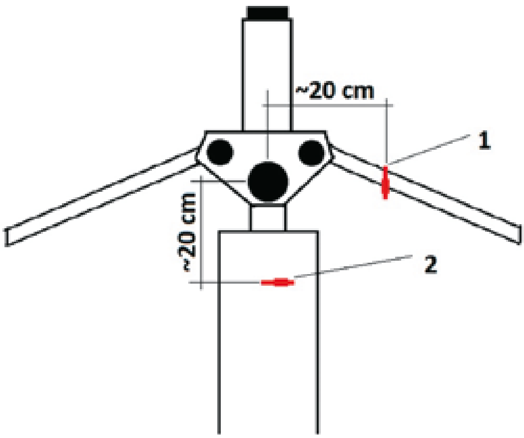

Fig. 6. Sensor mounting points

5. Sample test result

With a fixed speed the rider took his hands off the handlebar. The front unit was free to rotate around the steering axis. The rider pushed the handlebar with one hand and took it off. Then he waited for disappearing vibrations or stopping the handlebar when the amplitude were increasing continuously. For different angle of the steering head and different speeds, the following curves are received. The damping characteristics and vibration frequency are determined.

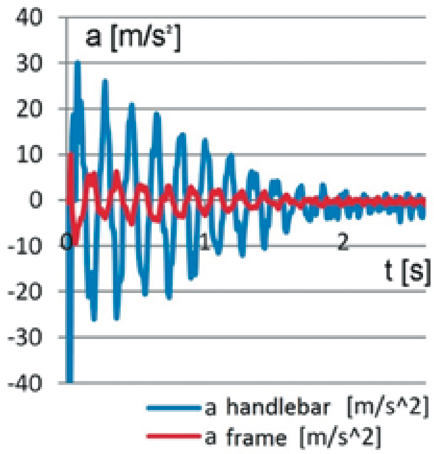

Fig. 7. Example of wobble time evolution, speed 90 km/h, $\varepsilon = 61^0$

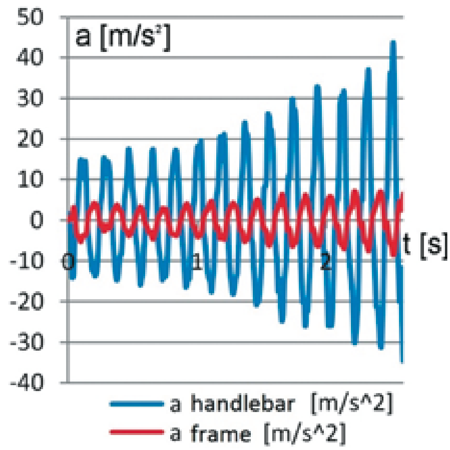

Fig. 8. Example of wobble time evolution, speed 100 km/h, $\varepsilon = 68^0$

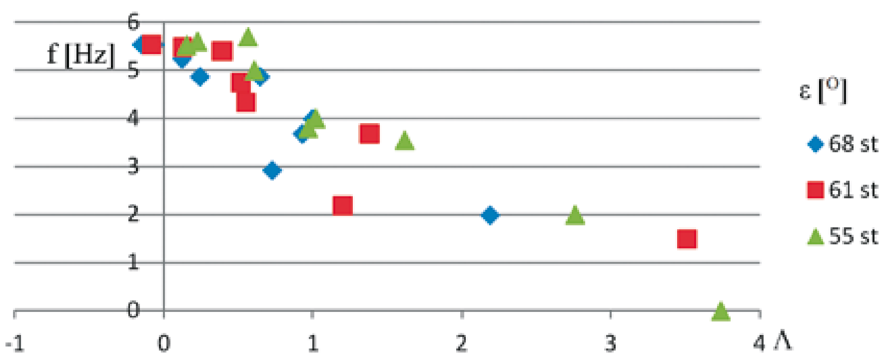

Fig. 9. Stability characteristics

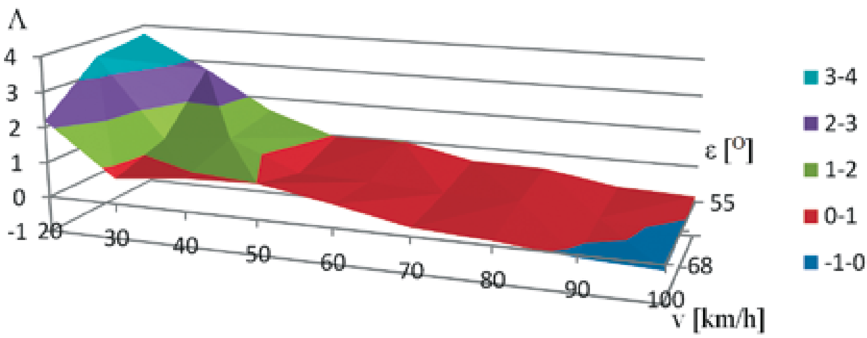

Fig. 10. Damping ratio velocity characteristics

On Figures 7 and 8 curves show the waveforms of the front unit and motorcycle frame acceleration. The oscillation amplitudes after force impulse at speed of 90 km/h and ε = 61° are decreasing. Increase of the amplitudes is clearly seen at speed 100 km/h and ε = 68°.

The study was performed at different speeds and angles of control axis. On Figure 9 points which are lying on the left of ordinate axis represent the unstable vibration of wobble . The area where the damping decrement has negative value on Figure 10 is an area in which the vibration did not extinguished. Vibration type of wobble in this area are self-inducted vibrations.

6. Conclusion

The trends received during the tests are in line with the theoretical considerations of V. Cossalter. Changing the angle of the steering head has a large impact on the value of the dynamic damping. Changing the angle of the steering head of 13° shifts the stability speed limit of tested motorcycle by more than 20 km/h However, this change is non-linear (like a characteristic of the damping). At low speeds the tendency to fall into the wobble type vibration is minimal. When constructing a single track vehicle the right balance between the trail, the moment of inertia of the front unit and viscous damping coefficient of steering damper must be kept. All these parameters have a significant impact on the stability and maneuverability of the motorcycle.

To use this bench tests studies to value the motorcycle there is need to take road tests of similar scope and compare the results. If the results of road tests show similar trends suitable design of the testing stand will be confirmed. This stand test can also be used to study the influence of other parameters such as tire pressure, wheel size, tire type, etc., on the vehicle stability as V. Cossalter [2] and M. Salvador [1] point in their works.

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