Rig for testing active safety system for two-wheelers

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Abstract. The paper deals with the measuring equipment used to conduct two-wheeler braking system testing. When in motion, two-wheelers are initially less stable than cars, which necessitates creating more advanced active safety systems (ASS) that take into account the characteristics of their motion. Active safety systems available today operate on the basis of control algorithms that use kinematic parameters as sources of information, which requires performing approximate estimation of the relative slip in the contact patch between the wheel and the road. This leads to more complex control algorithms and increased cost of the entire system. To improve the safety of two-wheelers, an active safety system operating on the basis of control algorithms which use primary information about road conditions as sources of information must be developed. The primary information includes a number of forces, brake power, the magnitude of lateral forces and normal reactions in the contact patch between the wheel and the road. When creating and testing new anti-lock braking systems and their control algorithms, rig and road tests must be performed where testing conditions closely represent the real modes of operation of the active safety systems being developed. To conduct the rig tests under conditions close to real-world scenarios, a specialized rig for two-wheelers must be developed and created.

1. Introduction
The number of two-wheelers in the world is constantly increasing. According to the requirements set out in UN ECE Regulation No. 13 [1] and the laws adopted in 2012, all motorcycles having a cylinder capacity of 125 cm$^3$ and above must be fitted with anti-lock braking systems. Improvement of control algorithms based on kinematic parameters [2] implies a more sophisticated information processing unit, which results in an increased cost of the active safety system to be installed on a two-wheeler. This, in turn, leads to a significant increase in price of motorcycles with a cylinder capacity of 125 cm$^3$ and a decrease in competitive advantages. As an alternative, information sources based on primary factors, such as brake power, the magnitude of lateral forces and normal reactions in the contact patch between the wheel and the road can be developed [2, 4, 5, 6, 7] and the systems operating on the basis of sources of information about forces acting on the wheel should be improved.
In order to confirm the results of the development of active safety systems for two-wheelers, full-scale tests have to be performed.

2. Rig for active safety system testing
Full-scale tests are an integral part of the development, creation, refinement of new systems, components and mechanisms of vehicles. When performing full-scale tests, rig and road tests have to be conducted, and the results of computer simulation, rig and performance tests should be compared.
The small dimensions of two-wheelers make it difficult to install measuring equipment on motorcycles and, as a result, to measure the parameters of the components being tested and the motorcycle controls.

When studying the active safety system, brake system and operating brake mechanisms, a number of parameters have to be measured. During rig tests, the brake torque, the actuating force acting on the brake pads of the brake mechanism being tested or the pressure in the hydraulic drive of the brake mechanism, the temperature of brake linings, the speed of rotation of the brake disc are determined. To identify, measure and detect the parameters of the brake system and the active safety system, the motorcycle and the rig are equipped with a number of sensors.

In order to measure and detect parameters of the motorcycle (lateral forces in the contact patch between the wheel and the road, normal reactions, wheel rotation speed), as well as brake systems and active safety systems of a two-wheeler, the rig is fitted with the following sensors:

- a speed sensor which detects the wheel rotation speed;
- a temperature sensor which detects the temperature of the brake disc during braking;
- a force sensor mounted on the actuator handle and the pedal of the rear brake mechanism; it detects the impact force applied to the actuator of the brake mechanism and the brake torque produced by the braking mechanism;
- two compression force sensors installed in the tubes of the front fork on the wheel rotation axis; they detect changes in the normal forces acting on the fork shock absorber;
- a compression force sensor installed in the shock absorber bracket of the rear swingarm of the motorcycle; it detects the change in the normal forces acting on the rear wheel;
- a steering angle sensor detects the steering angle of the front fork of the motorcycle during curvilinear motion;

Due to the holder fixing the motorcycle frame to the rig, the motorcycle can move, which makes it possible to detect the redistribution of normal loads during the motorcycle braking and acceleration.

Two electric motors connected to the inverter are installed on the rig; their speed is controlled by means of the software developed specifically for this purpose.

The motors can run in different modes: they can operate synchronously and be controlled simultaneously; they can operate and be controlled each in its own preset mode or in a combined mode.
when one motor runs and the other is operated by means of a motorcycle wheel rotating in a power-actuated mode.

The brake power arising on the rig roller during braking as well as the power and the torque acting on the roller, which operates in traction mode, are determined by means of the motor. The motor power is \( N = 4.5 \text{ kW} \), the speed is \( n = 1420 \text{ min}^{-1} \).

![Figure 2. Measuring rig used to test brake systems, mechanisms and active safety systems:
1 – compression force sensor; 2 – bending moment sensor; 3– tilt angle sensor; 4 – actuating force sensor; 5 – guide; 6 – axial force sensor; 7 – frame](image)

The developed rig is equipped with a measuring system for collecting and processing information that transmits the measurement results to a PC; the measuring unit can transmit data over distances of up to 100 m.

The module for collecting and processing information (MCPI) is the main part of the measurement and data processing unit. Its main functions are as follows:

1) to produce voltage levels needed to power the unit modules and sensors;
2) to process sensor readings;
3) to perform sensor reading filtering operations;
4) to implement the data exchange protocol between the MCPI and the PC via the UBS2.0 interface or via a wireless communication protocol based on radio modules.

A simplified block diagram of the MCPI is shown in figure 4.

The module has 16 analog inputs (A In) and 16 digital inputs (D In).

Analog input processing is performed by a precision high-speed and high-resolution analog-to-digital converter (ADC). To match the signal coming from the analog sensor to the ADC, a level matching module is used. The channel to be processed is selected by means of a high-speed analog multiplexer.

To process the digital sensor data, the built-in peripherals of the microcontroller are used. The data from all 16 digital inputs are processed by a high-speed multiplexer matrix.

The microcontroller program is based on a real-time operating system. Consequently, the microcontroller can perform data collection, processing, filtering and transmission operations simultaneously.

The data can be transferred via a high-speed USB2.0 interface (in FullSpeed or Hi-Speed mode) or via a wireless interface using a radio module. When using the radio module in an open area, the transmission range is 100 m.

The unit is powered from mains with voltage of 220 V/50 Hz, or, if it is not available, from a 12 V autonomous power supply.
Figure 3. Block diagram of the measurement and data processing unit.
Figure 4. Simplified block diagram of the module for collecting and processing information.

The main purpose of the power supply module is to produce the voltage levels needed to supply power to the sensors and modules of the unit. Besides, the module monitors the state-of-charge levels of the autonomous power supply.

Tensiometers and piezometers are used as sources of information about the magnitude of lateral forces and normal reactions.

Table 1. Compression sensor characteristics

| Parameter                                      | Unit of measurement | Value       |
|------------------------------------------------|---------------------|-------------|
| Measurement range                              | N                   | Up to 2000  |
| Nominal output signal (n. s.)                   | mV/V                | 2           |
| Nonlinearity (of n. s.)                        | %                   | 0.15        |
| Hysteresis (of n. s.)                          | %                   | 0.1         |
| Null balance (of n. s.)                        | %                   | ± 2         |
| Output signal temperature coefficient (of n. r./10 °C) | %                   | 0.1         |
| Null balance temperature drift (of n. s./10 °C) | %                   | 0.05        |
| Operating temperature range                    | °C                  | -10...+80   |
| Permissible overload (of n. r.)                 | %                   | 150         |
| Recommended power supply                       | V                   | 5           |
| Protection class                                | IP 67               |             |
Table 2. Bending moment sensor characteristics

| Parameter                        | Unit of measurement | Value   |
|----------------------------------|---------------------|---------|
| Measurement range                | N·m                 | 0-1500  |
| Accuracy class                   | %                   | 0.5     |
| Protection class                 |                     | IP 67   |
| Refresh rate                     | Hz                  | 150     |
| Operating temperature range      | °C                  | -10…+80 |
| Recommended power supply         | V                   | 5       |

Modern anti-lock braking systems installed on motorcycles are sets of devices with complex control units and hydraulic brake system components. Rising material cost and advanced technologies used for their manufacture lead to a significant increase in the cost of the vehicles on which they are installed.

The high cost of control units used in active safety systems are caused by the use of complex computing devices operating on the basis of algorithms using kinematic parameters.

Application in control algorithms of sources of information about forces arising in the contact patch between the wheel and the road [4, 5, 6], namely the magnitude of lateral forces in the contact patch, normal reactions, actual torque can increase the speed of the control algorithm due to the use of primary sources of information that help improve the accuracy of decision-making of the generated control actions.

The rig used to test the motorcycle active safety systems is shown in figure 5.

Figure 5. Rig used to test active safety systems of the “MINSK” CX200 motorcycle: 1 – “MINSK” CX200 motorcycle; 2 – rig frame; 3 – roller; 4 – guide; 5 – MCPI data transmission cable; 6 - inverter control unit; 7 – MCPI data collection and processing unit; 8 – laptop; 9 – power supply; 10 – electric motor control inverter.
Figure 6. “Minsk” street motorcycle during brake dynamics testing with force measurement sensors placed on the rig: 1 – steering wheel angle sensor; 2 – front wheel-road contact patch normal load sensor; 3 – rear wheel-road contact patch normal load sensor; 4 – wheel-road contact patch lateral force magnitude sensor

The rig for active safety system testing is designed to measure the forces arising in the contact patch between the wheel and the road. The rig helps monitor a number of kinematic parameters, such as the wheel rotation speed, the roller speed, which provides accurate control of the moment when sliding occurs in the contact patch between the wheel and the road; the brake disc surface temperature, which helps control the efficiency of brake mechanisms and the temperature at the moment when the developed brake power is measured; the value of the force acting on the controls and the start of braking, which makes it possible to determine and measure the response time of the brake actuator of the system and evaluate the performance of brake actuators of various designs; forces that arise in the contact patch between the wheel and the road, such as brake power, the magnitude of lateral forces and normal reactions, due to which the wheel-road friction coefficient in the longitudinal and transverse directions can be calculated.

Figure 7. Lateral force graph obtained in “MINSK” CX200 motorcycle tests conducted for rectilinear and curvilinear motion: a – rectilinear motion; b – curvilinear motion with side slipping.
A rig that can be used to study and test active safety systems, braking systems and mechanisms of two-wheelers has been developed, which makes it possible to carry out tests and trials of braking systems and adaptive mechanisms for anti-lock braking systems.

3. Conclusion

1. The developed measuring system for collecting and processing information allows the data to be transmitted over distances of up to 100 meters, which in turn makes it possible to conduct road trials.
2. The developed rig can be used to conduct tests under conditions close to real road and traffic scenarios.
3. The rig can be used to test existing and new active safety systems.

References

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