Increasing efficiency of braking control algorithm for a two-wheeled motorcycle

A S Melnikov[1], V A Kim[1], and A A Melnikov[1]

[1]Belarusian-Russian University, Mogilev, 212000, Republic of Belarus

E-mail: as_mlun@mail.ru

Abstract. The paper presents a new method for improving the efficiency of the braking control algorithm for a two-wheeled motorcycle. The method is based on the use of high quality information sources - direct measurement and analysis of forces in the wheel-road contact. The criterion for generating control signals by actuators is based on the negative sign of derivatives of lateral forces acting on wheels with respect to time. Experimental studies have shown that the negative sign of lateral force derivatives with respect to time determines side slip of wheels relative to the road surface. The consequence of the sideslip is loss of vehicle stability. The algorithm for generating vehicle control signals, which is based on the negative sign of the lateral force derivative with respect to time, is, to some extent, analogous to modern ESP systems (electronic stability control systems), which are currently being actively installed in two-wheeled vehicles (motorcycles).

1. Introduction

The risk of death for motorcyclists in road traffic accidents (RTA) is 29 times higher than that for motorists. This conclusion has been drawn by Ian Savage, Professor of Northwestern University, USA. Having extensively studied the statistics on RTA from 2001 to 2009, he found that the average motorcycle trip distance is 24 km per day throughout the year, and the probability of death for motorcyclists is 1/860.

Mistakes made by motorcyclists result in falling, skidding and running off the road, most often when cornering at high speed. The main cause of these accidents is loss of stability due to sideslip of motorcycle wheel contacts relative to the road surface. It is the side slip of wheel contacts that leads to a decrease of the wheel-road friction coefficient in the lateral direction, and, as a consequence, to loss of motorcycle stability [1-8].

The statistics on road traffic accidents involving motorcycles in Moscow for the year 2013 is presented in Fig. 1. The data in the figure confirm that the issue of development of active safety systems for two-wheeled vehicles is highly relevant.

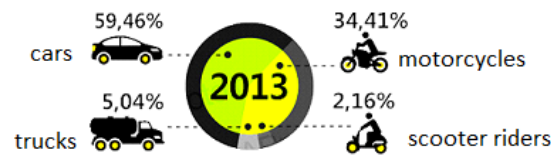Offenders of road traffik assidents with motorcycles

Fig 1. Statistics on road traffic offenders [1]

It is known that modern active safety systems (ASS) are based on measuring and analyzing kinematic parameters (angular velocities and accelerations of wheels, angular velocities and accelerations of vehicle frames), which are necessary for indirect calculation of forces in the wheel-road contact.

Based on indirect calculations, identification of the road surface is performed. Control algorithms become more complicated, and the quality of control is significantly reduced.

In this regard, it is obvious that the solution to the problem of direct measurement and analysis of forces in the wheel-road contact will significantly improve the efficiency of control algorithms for wheeled vehicles under all modes of their movement.

Primarily, ASS solves the problem of maintaining stability and controllability of wheeled vehicles. Modern ESP systems include an anti-lock braking system (ABS) and a traction control system (TCS).

The ABS algorithm is based on tracking a predetermined threshold value of the relative slip ratio of braking wheels, and TCS is based on tracking the difference between threshold values of angular velocities of drive wheels. The specified threshold values are indirect estimates of the grip of wheels on the road surface — these are forces or coefficients of friction between wheels and the road surface.

It should be noted that all ASS systems, without exception, assess the wheel grip in the longitudinal direction of the wheel rolling. In this regard, longitudinal slip of wheel contacts is used for indirect estimation of the friction coefficient in the lateral direction, since stability and controllability of a wheeled vehicle are mostly determined by the friction coefficient in the lateral direction [4 - 8].

For example, if all wheels lock up during braking, but there are no lateral responses, then there is no reason for ABS to engage, as there is no loss of stability. The same can be attributed to the traction mode of motion (TCS).

2. Theory

The aim of the research is to improve the efficiency of the braking control algorithm for a two-wheeled motorcycle by using a high quality informative source — direct measurement and analysis of lateral responses of the road surface.

We have created devices for measuring lateral responses of the road surface for a two-wheeled motorcycle. The results of field tests of the device for measuring lateral forces on various road surfaces (asphalt, wet asphalt, compacted snow cover, ice) at different speeds at the start of motorcycle braking are presented in Fig. 2. The analysis of the results of the motorcycle emergency braking showed that, in the absence of side slide, the derivative of the lateral response R_{σ} with respect to time

t has the positive sign, i.e., $\dfrac{dR_{\sigma}}{dt} > 0$.

The lateral response reaches its maximum value at the point A, and the time derivative of the lateral response with respect to time is zero, i.e., $\dfrac{dR_{b}}{dt} = 0$.

A noticeable decrease in the lateral response is observed on the interval AE, $\dfrac{dRb}{dt} < 0$.

Subsequently, an oscillatory character of the change in the lateral response with a change in the signs of the derivatives is observed on the interval EB.

On the BD interval, the lateral response reaches a constant value.

In addition, it can be seen from the graph of the change in the lateral response (Fig. 2) that the sign of the lateral response derivative changes before the braking wheel locks up.

This means that the change of the sign of the lateral response derivative is a priority criterion for generating control signals, as it makes it possible for braking to occur before wheels lock up, i. e., without sideslip, which improves stability of a two-wheeled motorcycle while maintaining its trajectory.

Thus, a pattern of changes in the lateral response during emergency braking of the wheel has been established.

Experimental studies have shown that the wheel contact slip in the lateral direction can be identified by the negative sign of the derivative of the lateral response with respect to time. Therefore, the negative sign of the lateral force derivative with respect to time can be used as a criterion for generating control signals for brake actuators.
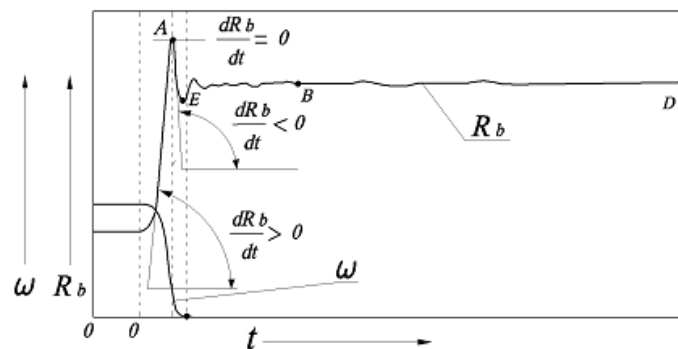

Fig 2. The change in the lateral force acting on the wheel and the change in the force derivative with respect to time during emergency braking of a two-wheeled motorcycle: ω is the angular velocity of the front wheel with the disc brake; R_b is the lateral response (road surface - wet asphalt, speed at the start of braking V = 22 m/s)

The braking control algorithm for a motorcycle, which is based on identification of the negative sign of the time derivative of the lateral force acting on wheels, is presented in Fig. 3. The control algorithm ensures the maximum use of friction coefficients of wheels taking into account conditions of their grip, which ensures stability and controllability of a motorcycle.

The main task of the algorithm is to provide stability control of a motorcycle during braking. Therefore, negative signs of derivatives of lateral responses of motorcycle wheels are proposed as priority criteria for generating control signals in the active safety system algorithm.

The algorithm makes maximum use of the wheel-road friction coefficient by controlling the effort that presses brake pads against the brake disc to bring actual wheel torques to the required values.

The algorithm must ensure the operation of the active safety system taking into account actual magnitudes of the forces arising in the contact patch of both front and rear wheels of a motorcycle and redistribution of road surface responses and braking torques during braking.
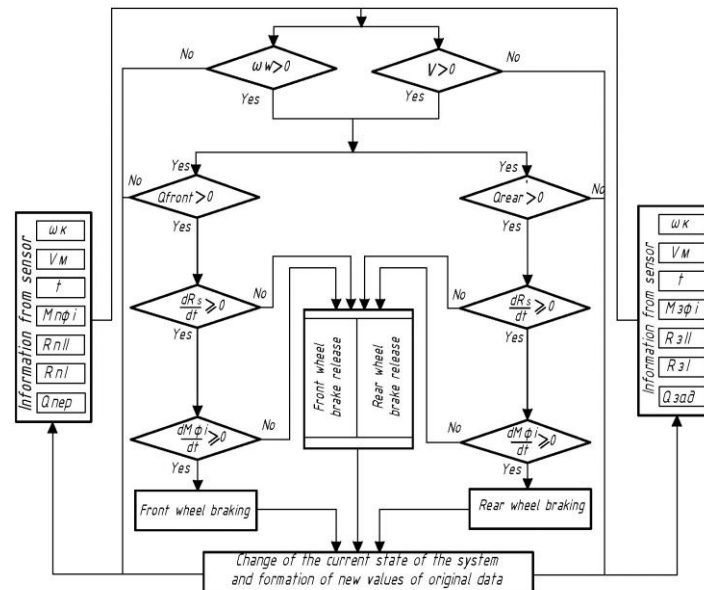
Fig 3. Algorithm of the active safety system of a two-wheeled motorcycle based on the force analysis

In this regard, the problem of complete dissipation of kinetic energy, which takes place in the brake mechanism itself and not in the wheel-road contact, is solved. After each calculation of the brake release force, the signs of the derivatives of the lateral response $dR\delta/dt$ and the braking torque $dM\varphi i/dt$ are checked.

The principle of generating motorcycle braking control signals can be used in traction control systems. The joint operation of the braking control algorithm and the traction control algorithm will ensure the operation of the automatic dynamics control system of motorcycles.

A diagram of a two-wheeled motorcycle control system during braking, which uses the principle of control based on tracking the negative sign of the derivative of the lateral response arising in the wheel-road contact, is shown in Fig. 3.

The developed system can be adapted for use in mechanical disk brakes.

The system involves coordinated control of braking torques on the front wheel (1) and the rear wheel (12) of a motorcycle depending on the value of the lateral responses detected by the sensors (2) and (16), as well as the magnitude of the actual braking torque on the front wheel detected by the sensor (18) and on the rear wheel detected by the sensor (17), redistribution of road responses between the front wheel (1) and the rear wheel (12) detected by the sensors (2) located in left and right tubes of the front fork, as well as in the bottom supporting elements of the rear wheel shock absorbers (16). When the brake lever (5) and the rear brake pedal (7) are operated, the brake mechanism (9) of the front wheel (1) and the brake mechanism (13) of the rear wheel (12) generate brake torques.
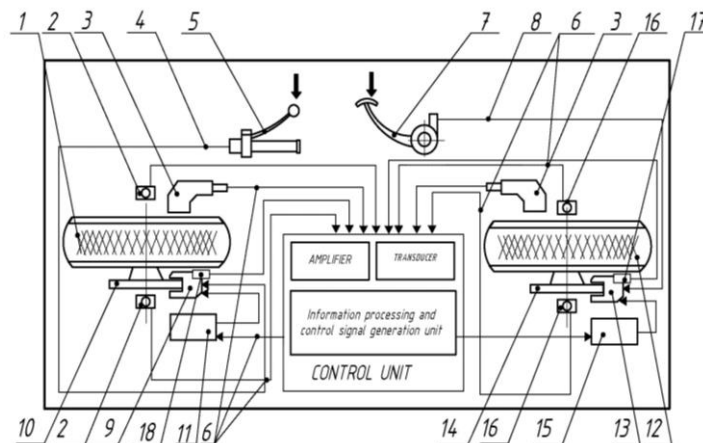
Fig 4. Schematic of the braking control system for a two-wheeled motorcycle: 1 - front wheel; 2 – supporting element for the front fork with a lateral force-measuring sensor; 3 – front wheel RPM sensor; 4 – cable drive of the front wheel brake; 5 – front wheel brake lever; 6 – transmission channels; 7 – rear wheel brake pedal; 8 – cable drive of the rear wheel brake; 9 – front wheel brake; 10 – front wheel brake disc; 11 – actuator – tractive electromagnet of the front brake; 12 – rear wheel; 13 – rear wheel brake; 14 – rear wheel brake disc; 15 – actuator – tractive electromagnet of the rear brake; 16 – bottom supporting element for rear wheel shock absorbers with a lateral force-measuring sensor; 17 – sensor of the actual braking torque of the rear brake; 18 – sensor of the actual braking torque of the front brake.

   The control unit handles the information about values of the braking torques on the front wheel (1) and the rear wheel (12) and the magnitudes of the lateral responses on the front and rear wheels, performs redistribution of the road responses between the front and rear wheels and their RPM. In addition, it is responsible for simulation of control action directed at the actuator (in this system it is a tractive electromagnet), at the brake release of the front or rear wheels in the case of the negative sign of the derivative of the lateral forces and braking torques of the front and rear wheels of a motorcycle. Redistribution of road responses for control signal generation is taken into account as well.

   The developed braking control system for a two-wheeled motorcycle, which is based on the principle of analysis of lateral forces arising in the wheel-road contact, makes it possible to ensure stability of a two-wheeled motorcycle and improve its braking efficiency.

3. Conclusion

1 Wheel slip relative to the road surface can be monitored by identifying the negative sign of the derivative of forces in the wheel-road contact with respect to time.

   2 The experimental studies have shown that the negative sign of the force derivative with respect to time is associated with a decrease in the wheel friction coefficients when the wheel contact is slipping in the longitudinal or lateral direction.

   3 The algorithm for generating control signals for actuators of wheeled vehicles, which is based on identification of the negative sign of the force derivative in the wheel-road contact, can be used in the active safety system of any wheeled vehicle.

   4 The results of tests of braking torque measurement devices show that they can be used to improve brake mechanisms and as sources of information for onboard diagnostic systems for monitoring braking performance of wheeled vehicles.

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