

Evaluation the course of the vehicle braking process in case of hydraulic circuit malfunction

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Abstract. In the paper, the results of the research were discussed, the aim of which was the evaluation of the vehicle braking performance efficiency and the course of this process with regard to the dysfunction which may occur in braking hydraulic circuit. As part of the research, on-road tests were conducted. During the research, the delay of the vehicle when braking was measured with the use of the set of sensors placed in the parallel and the perpendicular axis of the vehicle. All the tests were conducted on the same flat section of asphalt road with wet surface. Conditions of diminished tire-to-road adhesion were chosen in order to force the activity of anti-lock braking system. The research was conducted comparatively for the vehicle with acting anti-lock braking system and subsequently for the vehicle without the system. In both cases, there was a subsequent evaluation of the course of braking with efficient braking system and with the dysfunction of hydraulic circuit.

1. Introduction

Currently, vehicles are equipped with many kinds of devices that assist drivers in emergency situations. Vehicle ride control depends on the vehicle design and also on the condition of the vehicle braking hydraulic circuit components. Modern passenger cars are equipped with anti-lock braking systems (ABS). Anti-lock braking systems are one of the basic construction solutions which have the influence on active safety of the vehicles. The system prevents the wheels from locking during braking. Anti-lock braking systems ensure vehicle steerability even in conditions of emergency stop. The system also attempts to keep the wheel slip within the range where maximum braking force can be generated, thereby optimizing braking performance [6, 10]. From this point of view, their research and functional on-roads testing gain particular significance [3, 4, 9, 10].

We can distinguish three basic units in anti-lock braking systems, namely: wheel speed sensors, vehicle ABS controller and central hydraulics block with valves. When braking, the evaluation of the longitudinal slip is based on the measurement of wheel rotary speed. On the basis of the information on the speed it is possible to control hydraulics valve, which regulates the pressure in braking hydraulic circuit of particular wheels. In anti-lock braking system, vehicle velocity and the rotational speed of each wheel are assumed as input signals constantly sent to the controller, whereas control signal of brake pressure modulator is the output signal from the system. Thanks to this, change of the pressure of the brake fluid in brake caliper pistons of particular wheels is possible. However, what is the exerted value in this system is the pressure on brake pedal, ipso facto pressure in the master cylinder [4,6,8,11].



The operation of the control system of anti-lock braking system can be based on various strategies. The assumed strategy of the division of braking forces on particular wheels decides on the maintenance of steerability and stability of vehicle movement. The issues are the subject of theoretical considerations [1], which constitute the basis for working out the logic of the activity of anti-lock braking system [2,11]. Operation strategies have high significance for the ABS controller's ability to adapt to changing slip-force characteristics of tyres and provide estimates of the magnitude of the effects of different tyre and road operating conditions. Vehicle ABS control algorithm allows to compensate eventual dysfunctions of particular components of the braking system, too. Usually, the algorithms of controlling anti-lock braking system are realized with full efficiency of the remaining part of the braking system. However, during vehicle operation, confounding factors may occur. The obsolescence of brake fluid and the absorption of humidity from the surroundings by it may considerably lower its boiling point. During intensive braking, when the elements of wheel brakes heat considerably, vapour of brake fluid may be created in brake caliper pistons. Likewise, leakiness in the system or its air bubbles in the lines result in the restriction of the pressure possible to obtain in lines, since in such cases the change of compressibility of the brake fluid filling the system occurs. The most unfavourable situation is the significant diversification of braking forces on wheels on the right and left side of the vehicle. In case of the occurrence of the mentioned dysfunctions, the evaluation of the effectiveness of the operation of anti-lock braking system is most reliable in operation conditions, in road tests.

The aim of the paper was the evaluation of the influence of restricted efficiency of the hydraulic system on the operation of anti-lock braking system during braking. Since the restriction of maximum pressure in brake caliper pistons influences the change of the division of braking forces on particular wheels and extorts the correction of them by anti-lock braking system, road tests were conducted, which evaluated obtained delay in braking on various levels of braking system dysfunction. During braking maneuver, parallel and perpendicular acceleration of the vehicle was recorded with the aim of the evaluation of car body movement dynamics during braking process.

2. Experimental procedure

As part of the research, on-road tests were conducted. During the research, the delay of the vehicle when braking was measured with the use of the set of sensors placed in the parallel and the perpendicular axis of the vehicle. On-road tests were conducted on the vehicle – B Segment in Euro Market Segment car classification with independent suspension. On the front, the vehicle was equipped with multi-link suspension, whereas at the back of the vehicle – trailing-arm suspension. Telescopic shock absorbers were installed both on the front and at the back. All the tests were conducted on the same flat section of asphalt road with wet surface. Conditions of diminished tire-to-road adhesion were chosen in order to force easier activity of anti-lock braking system. The research was conducted comparatively for the vehicle with acting anti-lock braking system and subsequently for the vehicle without the system. Turning off the possibility of the operation of anti-lock braking system was achieved by the removal of a circuit breaker fuse. In both cases, there was a subsequent evaluation of the course of braking with efficient braking system and with the dysfunction of hydraulic circuit. All the tests with the same conditions of their realization were four times repeated. The tests were conducted with air-locked hydraulic system and with fully blocked flow of brake fluid to particular brake calipers. During road research, the acceleration in the parallel and perpendicular axis of the vehicle was measured with the use of acceleration sensors of the company Hottinger Baldwin Messtechnik GmbH of B12/200 type. Measurement sensors were connected to an analog-to digital converter also produced by HBM. The courses of acceleration obtained during test rides were recorded on the computer disc.

3. Results of research

After conducting road tests, the courses of the signals obtained from acceleration sensors were evaluated in the first place. The figure 1 depicts the courses of acceleration in the parallel and perpendicular axis of the vehicle when braking from the speed of 14 m/s, recorded by the set of sensors installed in the vehicle. Obtained courses of acceleration changes illustrate the behaviour of car body during intensive braking. The delay in the perpendicular axis of the vehicle obtained in road conditions, during the test with the efficient braking system and with the operation of anti-lock braking system reached peak values exceeding 8 m s^{-2} - Figure 1.

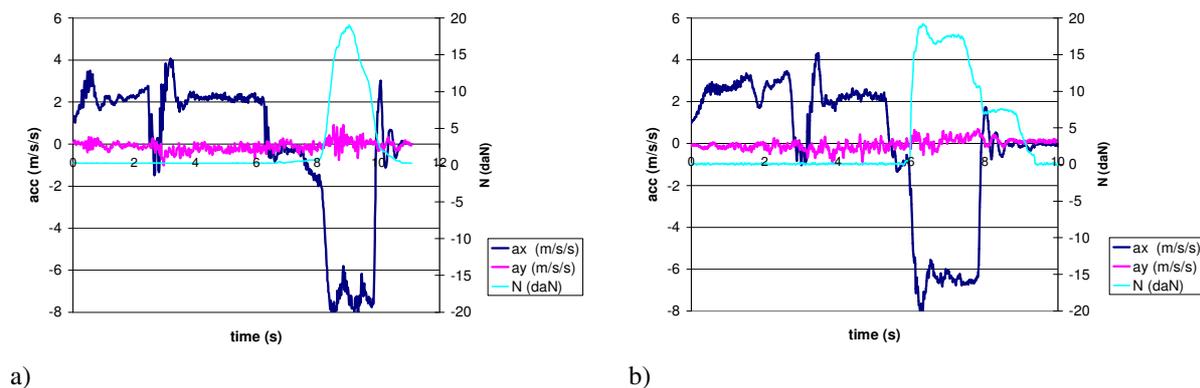
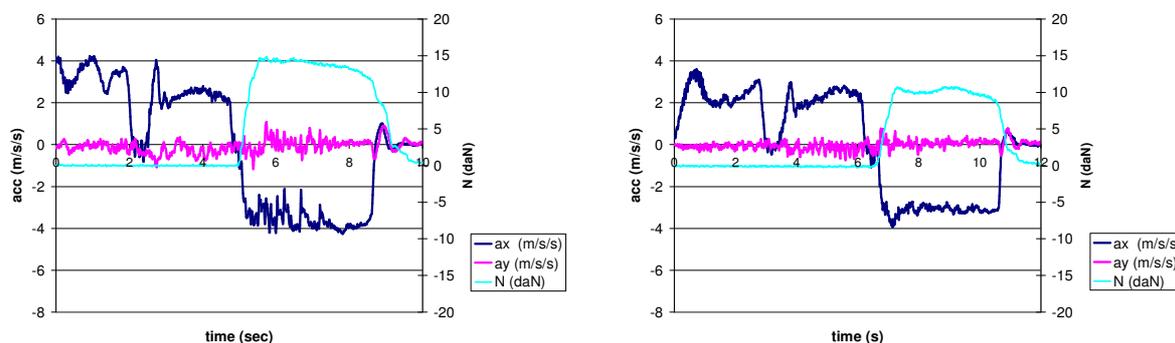


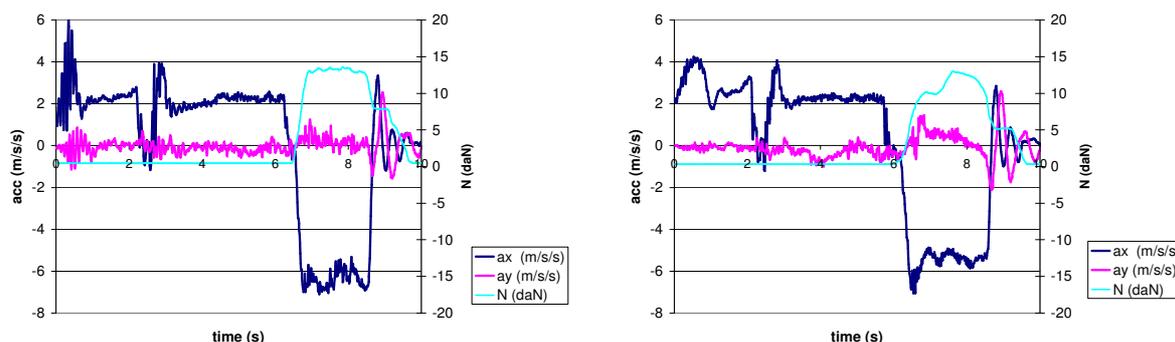
Figure 1. The course of the changes of the delay during braking test in perpendicular (a_x) and parallel (a_y) axis of the vehicle; a – braking with the efficient hydraulic circuit and operating anti-lock braking system, b – braking with the efficient hydraulic circuit without anti-lock braking system.

The introduction of the air into braking system, the consequence of which is the decrease of the pressure of brake fluid in brake caliper piston of the right front wheel with the same pressure force on the brake pedal was the reason why obtained peak values of braking delay were half lower. In such conditions, due to the occurring differences of the developing braking force in the right and left wheel of the vehicle, pressure hydraulic valves were started by anti-lock braking system, what is very clearly visible on the courses presented on figure 2. The constraint of the possibility of increasing pressure in hydraulic caliper cylinder of one of the wheels resulting from the presence of air bubbles was the reason for the occurrence of the tendency of blocking and skidding the second wheel, the anti-lock braking system needed to counteract. However, its consequence was considerable decrease of the obtained braking delay – in maximum values up to 4 m s^{-2} . Analogous relationships can be observed by comparing the courses presented on subsequent figures 1b and 1 d respectively, which illustrate braking attempts for the vehicle without anti-lock braking system. Also in this case, the presence of vapour bubbles of the hydraulic caliper cylinder caused lowering the maximum obtainable braking delay by 50 %, and additionally it can be noticed that in the initial braking phase i.e. in the phase of the increase of longitudinal delay, the increase of the value of parallel acceleration of the vehicle is also recorded. Such a course of parallel acceleration can be explained with the increasing difference of braking forces on the wheels on the right and left side of the vehicle, not corrected by the operation of anti-block system. The changes of the braking force on the vehicle wheels are visible on all acceleration courses recorded by the sensor in parallel axis of the vehicle. The course of their changes when braking during rectilinear vehicle movement and with fully efficient braking system is considerably smaller both during the operation of the anti-lock system and without the system.



a) b)
Figure 2. The course of the changes of the delay during braking test in perpendicular (a_x) and parallel (a_y) axis of the vehicle; a – braking with air-locked braking wires and operating anti-lock braking system, b – braking with air-locked braking wires and without the anti-lock braking system.

The figures 3a and 3b present exemplary results obtained during braking test conducted with the fully blocked flow of brake fluid to brake caliper cylinder to the right back wheel of the vehicle. In such case, the obtained values of perpendicular delay decreased by about 9% in comparison to the values obtained with correct functioning brake calipers of all the wheels of the vehicle. The lack of the possibility of correcting braking forces on the remaining wheels after turning off anti-lock braking system was the reason for even larger decrease of the obtained perpendicular delays. This was when the difference exceeded 10 %. Higher values of maximum parallel acceleration can also be observed during these tests. The recorded values of parallel acceleration were more than 50 % higher. Fully blocked flow of brake fluid to the brake caliper cylinder of the right front wheel of the vehicle caused even larger difficulties with the maintenance of the track of vehicle movement. Exemplary results obtained during such a test were presented on figure 4. We can observe here very high values of parallel acceleration, particularly with turned off anti-lock braking system. Average values obtained from the courses of acceleration of 5 subsequent ride tests were presented on figure 5.



a) b)
Figure 3. The course of the changes of the delay during braking test in perpendicular (a_x) and parallel (a_y) axis of the vehicle; a – braking with the blocked brake caliper cylinder of the right back wheel and with operating anti-lock braking system, b – braking with the blocked brake caliper cylinder of the right back wheel and without anti-lock braking system

The average values of delay obtained in the same road conditions in the vehicle with the diminished braking force, resulting from the air pocket of brake caliper piston, reached similar values both in case of the operation of anti-lock system and with the lack of it. However, anti-lock braking system influences the restriction of the acceleration fluctuations registered in the parallel axis of the

vehicle. This is because, it allows for more profitable division of braking forces on both sides of the vehicle. During rectilinear braking with fully efficient braking system, maximum acceleration registered in parallel axis reached 1.5 m/s^{-2} , whereas in case of the lack of anti-lock system it was 20% higher. Also in case of fully blocked brake caliper cylinder of one of the wheels of the vehicle, anti-lock braking system can considerably influence the course of parallel acceleration of car body.

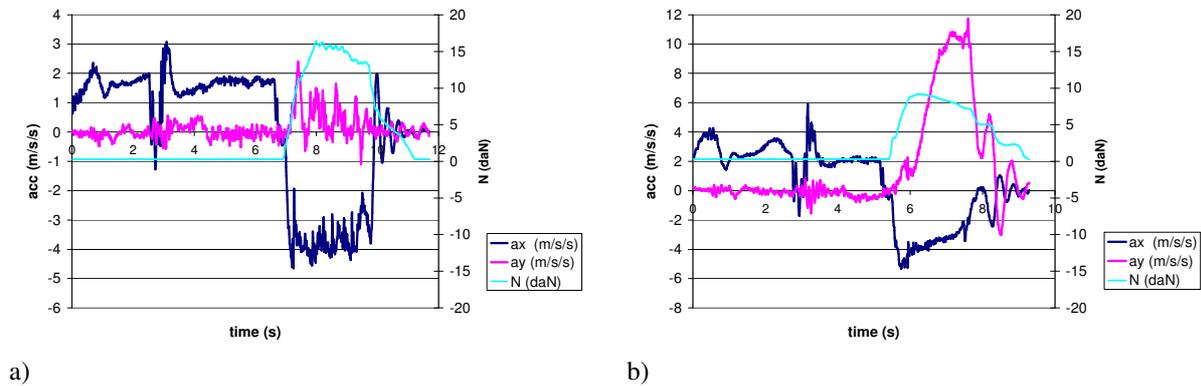


Figure 4. The course of the changes of the delay during braking test in perpendicular (a_x) and parallel (a_y) axis of the vehicle; a - braking with the blocked brake caliper cylinder of the right front wheel and with operating anti-lock braking system, b – braking with the blocked brake caliper cylinder of the right front wheel and without anti-lock braking system.

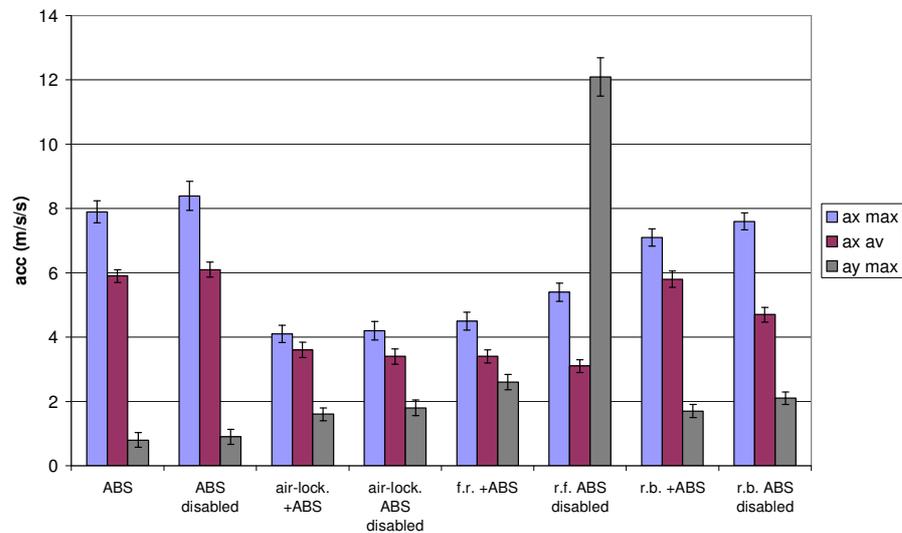


Figure 5. The juxtaposition of average acceleration values in perpendicular and parallel axis of the vehicle obtained during braking tests.

4. Conclusions

Anti-lock braking systems are one of the basic applied constructional solutions which have the influence on vehicle active safety. Conducted road tests of the course of the vehicle braking process allowed to compare the efficiency of their operation with the disturbances occurring in functioning in hydraulic circuit. The measurement of the acceleration in the parallel and perpendicular axis of the vehicle, applied during the tests gave the possibility of the evaluation of the changes of dynamics movement as a result of occurring disturbances.

On the basis of the conducted research we can draw particularly the following conclusions:

1. The change of the compressibility of the brake fluid caused by the presence of vapour bubbles in hydraulic braking system, the consequence of which is the decrease of the brake fluid pressure in brake caliper piston, can lead to lowering the maximum obtainable braking delay by 50 %;
2. The initial braking phase, the phase of increasing pressure constitutes the neuralgic part of the process – recorded parallel acceleration reach the highest values in this phase;
3. With the lack of anti-lock braking system, when braking during straight drive, the parallel acceleration is several times larger than with the operation of the system;
4. The anti-lock braking system is able to correct the dysfunctions of the hydraulic system. Even in case of blocking the flow of brake fluid into the brake caliper cylinder at one of the wheels, anti-lock braking system gives the possibility of the revision of braking course.

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