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DIAGNOSTIC TESTS OF VEHICLE SUSPENSION DURING BRAKING

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Summary

This paper describes the influence of shock absorbers' technical condition on the vehicle braking process on two types of surface with the Anti-Lock Braking System activated and deactivated. During each of the road tests the vehicle stopping distance, the braking deceleration, and the force applied on the brake pedal were determined. The test plan includes various road surfaces and technical conditions of shock absorbers. The established characteristics of the stopping distance and the deceleration allow the determination of the relations between the technical condition of the shock absorbers, the road surface, and the efficiency of the braking system. In addition, this paper presents the principle of operation of the Anti-Lock Braking System, which is one of the basic active safety systems.

Keywords: vehicle, Anti-Lock Braking System, suspension, shock absorbers, diagnostics

DIAGNOZOWANIE UKŁADU ZAWIESZENIA W ASPEKCIE PRZEBIEGU PROCESU HAMOWANIA POJAZDU

Streszczenie

W pracy określono wpływ stanu technicznego amortyzatorów na proces hamowania pojazdu na dwóch rodzajach nawierzchni, przy aktywnym oraz zdezaktywowanym układzie ABS. Podczas każdej z prób drogowych określane były droga hamowania pojazdu, opóźnienie hamowania oraz siła nacisku na pedał hamulca. W planie badań uwzględniono różne stany nawierzchnie drogi i stany techniczne amortyzatorów. Wyznaczone charakterystyki drogi hamowania i opóźnienia pozwalające na identyfikację zależności pomiędzy stanem amortyzatorów, nawierzchnią drogi, a skutecznością funkcjonowania układu hamulcowego. W pracy przedstawiono również zasadę działania układu ABS, który jest jednym z podstawowych elementów bezpieczeństwa czynnego.

Słowa kluczowe: pojazd, układ ABS, układ zawieszenia, amortyzatory, diagnozowanie

1. INTRODUCTION

Road accidents cause injuries among vehicle drivers, passengers and vulnerable road users, and cause damage to vehicles, goods and road infrastructure. The removal of the results of accidents and collisions involves significant financial resources. [2, 4]

Active safety refers to the vehicle's parts, components and assemblies which allow the reduction of the risk of accidents. During the last twenty-five years manufacturers have been putting plenty of effort into increasing the active safety of their vehicles [6]. On the other hand, many vehicle owners still believe that an active safety system will ensure the safety of both the driver and the passengers in every situation. Vehicle users frequently forget to maintain the vehicle’s suspension in a correct technical condition, and to periodically check its components. Only maintaining the correct technical condition of all components will ensure the safety of vehicle users.

2. ANTI-LOCK BRAKING SYSTEM — CONSTRUCTION AND PRINCIPLE OF OPERATION

The anti-Lock Braking System is an active safety system used in road vehicles. Its main task is to prevent the wheels from locking up during sudden braking. The adhesion of the vehicle’s wheels to the road surface has a direct impact on the braking process and the stopping distance. The better the adhesion, the higher the braking force and the shorter the stopping distance of the vehicle. Moreover, good adhesion means that the driver can control the vehicle and maintain the correct driving line in a better way. [5, 9].

The Anti-Lock Braking System includes such components as the electronic control unit, hydraulic control unit and the brake pedal position sensor. Each of the wheels has a rotational speed sensor installed. [3, 5]. A detailed view of the system is presented in [12].

If the maximum braking force is applied throughout the entire stopping distance, the maximum efficiency of the vehicle's brakes until the vehicle's complete stop can be calculated from the formulas (1) and (2). The driver's reaction time and the braking force rise time are not taken into consideration.

$$L_H = \frac{m \cdot V_p^2}{2 \cdot F_H} = \frac{m \cdot V_p^2}{2 \cdot \mu \cdot m \cdot g} = \frac{V_p^2}{2 \cdot \mu \cdot g} \quad (1)$$

$$F_H = \mu \cdot m \cdot g\,, \quad (2)$$

where:
m – vehicle's weight,
V_p – vehicle's speed at the start of the braking,
V_p – vehicle's speed at the finish of the braking,
F_H – braking force,
L_H – stopping distance.

The difference between the stopping distance with the Anti-Lock Braking System activated and deactivated can be calculated from this formula:

$$\Delta L_H = L_{H(ABS)} - L_{H(T)} \quad (3)$$

where:
$L_{H(T)}$ – stopping distance without the Anti-Lock Braking System,
$L_{H(ABS)}$ – stopping distance with the Anti-Lock Braking System.

Figure 1 presents diagrams showing the differences between braking with and without the Anti-Lock Braking System.

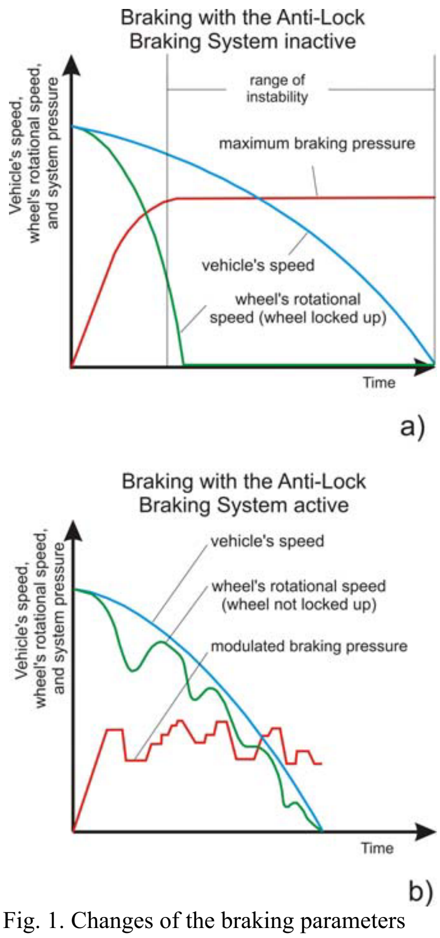

Fig. 1. Changes of the braking parameters a) without the Anti-Lock Braking System and b) with the Anti-Lock Braking System [authors' own elaboration on the basis of 12]

During emergency braking of a vehicle not equipped with the Anti-Lock Braking System the driver must not only maximise the braking force (by applying the maximum force on the braking pedal), but also try to maintain the vehicle on track. When the wheels lock up, the driver has little control over the vehicle's direction of travel. Thus, during emergency braking the driver must make attempts to maximally utilise the adhesion while not allowing the locking up of the steered wheels in order to maintain control over the vehicle's direction of travel.

If the vehicle is equipped with the Anti-Lock Braking System, the most effective technique is to immediately depress the brake pedal with the maximum force [4, 8]. During emergency braking the system follows the driver's action but does so in a quicker and more precise way. The braking force is maximised within a very short time, and when the system detects that the wheels have locked up, it decreases the braking force on the wheels until they start spinning again. At this time manoeuvrability is regained and so is the pressure in the braking system — the braking force is increased until the wheels lock up again [1, 7]. Thus the adhesion factor is similar to the value of the adhesion limit.

Until now no tests had been carried out to determine the influence of shock absorbers' condition, or the type and condition of the road surface on stopping distance. The test results can facilitate the determination of road safety and raise the awareness of vehicle users on the requirement to check the technical condition of the suspension and other components during the vehicle's operation.

3. TEST METHODS

This paper describes the influence of shock absorbers' technical condition on the vehicle braking on two types of surface with Anti-Lock Braking System activated and deactivated.

The object of the test was an Audi 100 car (fig. 2). This selection was based on the ease of deactivation of the Anti-Lock Braking System. This allowed the analysis of the braking process with the Anti-Lock Braking System activated and deactivated. The tests were carried out on two types of asphalt surfaces and two different conditions of shock absorbers.

The friction coefficient for porous asphalt is significantly higher than in the case of mastic asphalt (approximately 1.3 and 1.0, respectively) [13, 14].

The characteristics of the test section surface conditions are presented in table 1.

Table 1 Road surface characteristics

Designation	N1	N2
Asphalt type per PN	PN-EN-13108-6 – mastic asphalt	PN-EN 13108-7 – porous asphalt
Surface characteristics	mineral and asphalt mixture with a very small number of free spaces with an asphalt binder in which the amount of the filler and the binder exceeds the volume of the free spaces in the mineral mixture.	mineral and asphalt mixture with a very high number of interconnected free spaces to allow for free water and air flow to ensure correct drainage.
Technical condition of the surface	The surface was free of rough parts and defects, and had never been subject to repairs.	The surface had many longitudinal and cross-wise bumps and defects, and had been subject to repairs.

Fig. 2. The test object on the test section with N1 surface

The test plan is presented below:

1. preparation of the car for tests,
2. measurement of the efficiency of the shock absorbers on the Beissbarth STL7000 diagnostic line (fig. 3) equipped with a Micro-Swing 6200 module for determining the shock absorbers' damping efficiency by means of the EUSAMA method,
3. carrying out the braking tests of a vehicle with worn shock absorbers on both the N1 and the N2 surfaces of good quality with the Anti-Lock Braking System activated and deactivated.
4. replacement of the worn shock absorbers with new, high quality ones,
5. carrying out the tests on the vehicle with suspension systems operating correctly as per points 1 to 3.

Fig. 3. Beissbarth STL7000 diagnostic line

The following parameters were determined during the braking tests:

– braking deceleration and force exerted on the brake pedal – by means of the AMX 520 inertial decelometer (fig. 4a),
– the vehicle's stopping distance – by means of the Trumeter 5500 road measuring wheel (fig. 4b),
– change of the vehicle's direction of travel during braking – by means of a laser distance meter.

Each braking test was repeated three times.

Fig. 4. Measuring instruments a) AMX 520 decelometer and b) Trumeter 5500 road measuring wheel

During the braking tests the driver, after entering the test section at the speed of 50 km/h, pressed the brake pedal with the maximum force and kept it depressed until the vehicle stopped. During all measurements the force exerted on the brake pedal was similar (from 520 N to 540 N). The length of the braking marks, stopping distance and change of the vehicle's direction of travel during braking were measured. The braking tests were carried out in the same atmospheric conditions (on a dry surface).

4. TEST RESULTS

The shock absorbers' damping efficiency are presented in table 2.

Table 2 Vehicle suspension measurement results on the diagnostic line

Shock absorber conditions	Front axle (worn shock absorbers)		Front axle (new shock absorbers)		Rear axle		Allowable value as per [15,16,17]
	Left side	Right side	Left side	Right side	Left side	Right side	
Measured adhesion [%]	42	0	74	75	53	52	above 20
Adhesion difference [%]	42		1		1		below 30
Axle load [kg]	880				710		-
Vehicle weight [kg]	1590						-

Based on the results before the replacement of the front axle shock absorbers, the damping factor of the front right shock absorber was 0%, which shows that the vehicle's wheels were not in constant contact with the surface. In the case of the front left wheel the damping factor was 42%, which shows its significant wear. On the other hand, the damping efficiency of the rear axle shock absorbers indicate their good technical condition.

After the technical condition of the shock absorbers was determined, the road tests were carried out. The test results of the vehicle with worn shock absorbers carried out on two asphalt surface types with the Anti-Lock Braking System activated and deactivated are presented in table 3.

Table 3 The measurement results of the vehicle equipped with worn shock absorbers on two surface types with the Anti-Lock Braking System activated and deactivated

		Braking on the N1 surface		Braking on the N2 surface	
		Stopping distance [m]	Registered maximum braking deceleration [m/s²]	Stopping distance [m]	Maximum braking deceleration recorded [m/s²]
Anti-Lock Braking System activated	I attempt	12.70	9.6	9.97	8.3
	II attempt	12.07	7.5	10.04	8.4
	III attempt	11.92	8.1	10.16	9.5
	Mean value	12.23	8.40	10.06	8.73
Anti-Lock Braking System deactivated	I attempt	15.71	6.1	12.53	7.2
	II attempt	14.88	6.3	9.26	7.3
	III attempt	14.53	6.6	11.59	7.6
	Mean value	15.04	6.33	11.13	7.37

In the case of the road tests with the Anti-Lock Braking System deactivated the stopping distance increased in comparison with the tests carried out with the Anti-Lock Braking System active; on the road with a good surface the difference of stopping distances was nearly three metres, and the measured braking deceleration decreased by more than 2 m/s2.

Figure 5 presents the braking deceleration changes during tests with the Anti-Lock Braking System active and inactive on the road with a good surface.

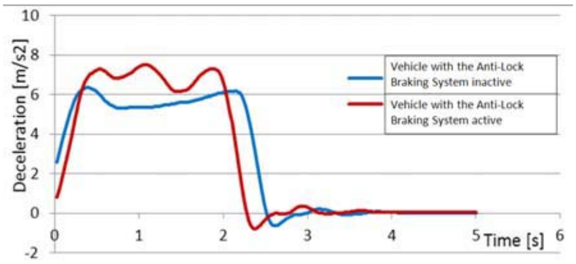

Fig. 5. Diagrams presenting the braking deceleration differences in the case of the vehicle with worn shock absorbers on the N1 surface

The above figure indicates higher deceleration values during braking with the Anti-Lock Braking System active.

When comparing the results achieved on the roads with poor and good surfaces, the tests carried out with the Anti-Lock Braking System active and inactive indicate that the stopping distance on the poor surface was shortened by 2 and 4 m, respectively. The difference of the stopping distance on the road with good and poor surfaces resulted from the structure of the top layer of both surfaces. As the top layer of the N1 surface was smooth, in the case of the worn shock absorbers even the least noticeable roughness caused the wheels to lose contact with the surface and increase the stopping distance. The top layer of the N2 surface, despite roughness, allowed the car to maintain better contact between of the wheels and the road, and thus to shorten the stopping distance.

Figure 6 presents the braking deceleration changes during tests with the Anti-Lock Braking System active and inactive on the road with the N2 surface.

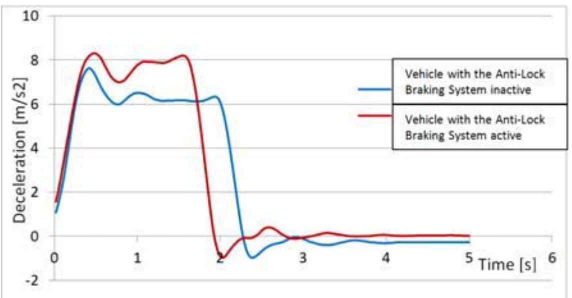

Fig. 6. Diagrams presenting the braking deceleration differences in the case of the vehicle with worn shock absorbers on the N2 surface.

When comparing the diagrams with figure 6, lower deceleration values can be observed in comparison with the tests with the Anti-Lock Braking System deactivated.

After carrying out a series of tests on the vehicle with worn shock absorbers they were replaced with new parts of high quality. After the replacement and 1,000 kilometres the damping efficiency of the new shock absorbers was measured. Table 2 shows the measurement results.

When analysing the damping efficiency of the new shock absorbers their condition can be qualified as good (new). They did not show any signs of wear and their damping efficiency was 74 to 75%. Taking the above into account, the vehicle's front wheels during the road tests were in constant contact with the surface and no case of losing contact was observed. The rear axle shock absorbers were in good condition before the measurement and they were not replaced, so their damping efficiency did not change.

After the assessment of the shock absorbers' technical condition another series of road tests was carried out.

Table 4 The measurement results of the vehicle equipped with the new shock absorbers on two surface types with the Anti-Lock Braking System activated and deactivated.

		Braking on the N1 surface		Braking on the N2 surface	
		Stopping distance [m]	Maximum braking deceleration recorded [m/s^2]	Stopping distance [m]	Maximum braking deceleration recorded [m/s^2]
Anti-Lock Braking System activated	I attempt	10.21	9.0	10.93	5.7
	II attempt	9.67	8.9	10.88	7.2
	III attempt	10.48	8.4	9.86	7.7
	Mean value	10.12	8.77	10.56	6.87
Anti-Lock Braking System deactivated	I attempt	16.38	6.0	9.51	10.0
	II attempt	11.66	6.9	8.59	7.9
	III attempt	11.07	6.9	8.55	8.2
	Mean value	13.04	6.6	8.88	8.7

Comparing the braking results with the Anti-Lock Braking System activated and deactivated indicated that the Anti-Lock Braking System significantly reduces the stopping distance on the N1 surfaces and thus allows higher braking deceleration values.

The results obtained by means of the vehicle with shock absorbers in good working condition were compared with those obtained with worn shock absorbers. It can be noticed that the stopping distance obtained with new shock absorbers on the N1 surface was shorter by approximately 2 metres in comparison to the results obtained with the worn ones and the Anti-Lock Braking System both activated and deactivated. This arises from the fact that the shock absorbers should maintain constant contact of the vehicle's wheels with the surface by damping the bodywork's vibrations resulting from the operation of the suspension elements.

Figure 7 presents the braking deceleration changes during tests with the Anti-Lock Braking System activated and deactivated on the N1 surface in the case of a vehicle with shock absorbers in good working condition.

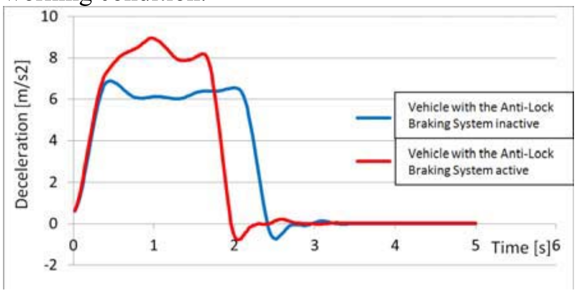

Fig. 7. Diagrams presenting the braking deceleration differences in the case of the vehicle with shock absorbers in good working condition on the N1 surface

The above figure indicates significantly lower deceleration values during braking with the Anti-Lock Braking System inactive.

Judging from the results obtained during the braking tests carried out on the N2 surface with the Anti-Lock Braking System activated and deactivated the stopping distance was shorter with the Anti-Lock Braking System inactive. This arises from the roughness of the surface and thus its higher adhesion factor. This factor was better utilised when the wheels locked up in comparison with the situation when the braking force was modulated by the Anti-Lock Braking System.

In the case of the braking of a vehicle with new shock absorbers the differences in the stopping distance on the N1 and N2 surfaces can also be seen. In the case of braking with the Anti-Lock Braking System activated the differences are not great and the stopping distance is slightly shorter on the N1 surface; as the top layer was smooth, the Anti-Lock Braking System could utilize the wheel adhesion factor in a more efficient way. On the other hand, the stopping distance on the N2 surface with the Anti-Lock Braking System deactivated was significantly shorter. This shows that locking up the vehicle's wheels on a rough surface is more efficient. After analysing the results it can be concluded that the tested vehicle had its Anti-Lock Braking System calibrated to shorten the stopping distance on the good quality, smooth surfaces of motorways or expressways, and could not fully utilise the adhesion on rough roads with a higher adhesion factor.

The comparison of the tests carried out with the new shock absorbers and the worn ones indicates that the stopping distance was shortened in every case. This was caused by better adhesion between the wheels and the road surface – the wheels maintained contact with the surface throughout braking.

The braking deceleration during the tests carried out on the N2 surface with the vehicle with new shock absorbers and the Anti-Lock Braking System activated and deactivated is presented in figure 8.

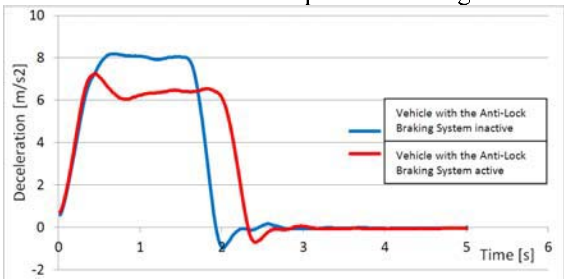

Fig. 8. Diagram presenting the braking deceleration differences in the case of the vehicle with shock absorbers in good working condition on the N2 surface

The above figure indicates significantly higher deceleration values during braking with the Anti-Lock Braking System inactive. During braking with the Anti-Lock Braking System the vehicle's wheels maintained contact with the road and thus the surface roughness did not cause them to lose contact temporarily, and thus it could fully utilise the maximum adhesion factor of the rough surface.

Figure 9 presents the influence of the road surface, condition of the shock absorbers, and operation of the Anti-Lock Braking System on the stopping distance changes. Significant differences in the stopping distances between particular cases can seriously affect road safety, as sometimes an accident is a matter of a mere centimetres. A difference of 6 metres could be crucial to the health and lives of vulnerable road users.

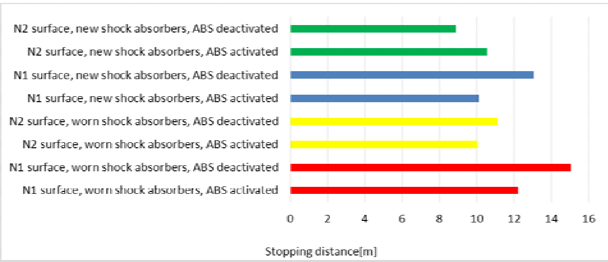

Fig. 9. Diagram showing the changes of stopping distance with three parameters taken into consideration

During braking with the Anti-Lock Braking System activated no change of the vehicle's direction of travel was noticed; during the tests with the Anti-Lock Braking System deactivated such a change did not exceed 0.5 m, and was thus within the tolerance foreseen by the regulations regarding the technical condition of vehicles.

In order to check the braking system, the efficiency of the brakes was measured by means of the roller method on the Beissbarth STL7000 diagnostic line. Initially, the measurements were carried out on the vehicle with worn shock absorbers and then on the vehicle with the new ones. The results were consistent and are presented in the table below.

Table 5 Braking force test results obtained by means of the roller method

Braking force test results	Front axle		Rear axle	
	Left side	Right side	Left side	Right side
Braking force [N]	3220	2980	2770	2360
Braking force difference [%]	7		14	

5. CONCLUSION

The Anti-Lock Braking System as the mandatory active safety system in modern vehicles significantly reduces the risk of accidents or collisions. The correct operation of this system depends, however, on the correct technical condition of the vehicle's suspension, and in particular the shock absorbers. Only one shock absorber of the tested vehicle was worn, and its efficiency was 0%; the second one installed on the front axle had low damping efficiency, but was still acceptable according to the regulations. It is also noteworthy that the diagnostics of the shock absorbers' technical condition is underestimated by vehicle users. The test results indicate that damage to a single shock absorber on the front axle made the stopping distance at a speed of 50 km/h longer by approximately 2 m.

In nearly all cases of emergency braking, both on smooth and rough surfaces, the stopping distance of the vehicle with the Anti-Lock Braking System active was significantly shortened in comparison to the tests carried out with the Anti-Lock Braking System deactivated. It was also noted that the Anti-Lock Braking System was configured to shorten the stopping distance on the smooth surfaces which are used to pave expressways, and was unable to fully utilise the adhesion factor on a rough surface. The Anti-Lock Braking System's algorithm relies on the constant monitoring of the rotational speed of the braked wheels and on reducing the braking force when the wheels start to lock up, or significantly reducing the rotational speed of a wheel; in the case of bumpy roads this can make the stopping distance longer, as the vehicle's wheels may temporarily lose contact with the surface, which was particularly noticeable during braking with worn shock absorbers. The system treated that case as a wheel slippage and automatically reduced the braking force, thus reducing braking efficiency.

Though modern vehicles are equipped with various systems which increase active safety, the correct and efficient operation of these systems is ensured only if the vehicle is fully operational. One of the most important issues is to diagnose the systems directly responsible for the vehicle's safety. The user must maintain the vehicle in a correct technical condition to increase road safety.

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