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Mariusz KOSOBUDZKI*

INFLUENCE OF SUSPENSION ELEMENTS' WEAR ON EFFICIENCY OF BRAKING SYSTEM FITTED WITH ABS AS WELL AS DRIVING COMFORT

Cars that are currently manufactured are equipped with modern systems improving a driver's safety and comfort. The ABS (Anti-lock Braking System) is one of the most significant factors that contribute to car users' safety. The author of the article, by designing a model with the Matlab Simulink, attempts to answer the question whether damping effectiveness has some influence on ABS work.

Key words: *ABS system, damping effectiveness, braking efficiency, steerability,*

INTRODUCTION

The issues of ensuring safety and driving comfort to car users as well as environmental protection are still present in designers' awareness. These issues consist of two complementary areas: active and passive safety systems. The main goal of active safety systems is to protect car drivers and passengers from accidents, whereas passive safety systems take action after a road accident has occurred, providing the required life space inside a car (seat belts, airbags, control crash zones [12, 13], etc.).

One active system that contributes to active safety is the anti-lock braking system (ABS). It was employed for the first time by Cadillac in 1971, and since 1978 it has been kept developed on a large scale by BOSCH. The system is to prevent braking wheels against being locked. The braking system in conjunction with wheels rotation ensures that the moving car remains steerable. However, braking force ought to be such as to utilize the maximum tyres' grip to shorten braking distance.

According to ABS designers, the system should lead to a decrease in road accidents. In available papers one can find information that drivers in cars fitted with an

* kpt. mgr inż. Mariusz KOSOBUDZKI – Instytut Dowodzenia Wyższej Szkoły Oficerskiej Wojsk Lądowych

ABS are involved in a comparable number of road accidents as drivers without the system [6]. This fact can be explained in this way that drivers subconsciously believe that modern and sophisticated systems ensure safety, as a result of which their self-control is lowered and they are much more prone to risky behaviour. Another reason is inadequate training of drivers in driving schools [7].

In order to research how an ABS works, various models reflecting real conditions in which it operates with the required degree of accuracy are designed [1,2,3,11]. The author considers the significance of factors like tyres, brakes, suspension, road conditions, etc. which influence the proper operation of the system. There is, however, little information pertaining to the efficiency of ABS systems with relation to one functional parameter, for instance the damping coefficient.

The article discusses the relation between the technical condition of shock absorbers and the efficiency of the ABS system.

1. OPERATION OF BRAKING SYSTEM EQUIPPED WITH ABS

Braking as a phenomenon is an effect of friction force F_h occurring on a braking mechanism as well as between tyres and ground surface F_p. A braking mechanism for a particular car is selected in such a way as to provide enough friction force to overcome grip: $F_h > F_p$. The value of the friction force of a disc brake is described as follows:

$$F_h = 2\mu_h N_h \quad (1)$$

where: μ_h – coefficient of friction force, N_h – press force of brake block.

Grip depends on road grip coefficient μ_t and tyres press force to the ground N in accordance with the quotation:

$$F_p = \mu_t N \quad (2)$$

where: μ_t – coefficient of grip, N – tyres press force to the ground.

The value of coefficient μ_t depends on the type and conditions of road surface, car speed, the type of tyres as well as the value of slip s which is defined as:

$$s = (V_{ref} - \omega R_{dyn}) / V_{ref} \quad (3)$$

where: s – slip of wheel, V_{ref} – reference car speed, ω – angle speed, R_{dyn} – dynamic radius of wheel.

On most road surfaces μ_t attains the maximum value for s = (10÷30%) [8,9] and is called the coefficient of road adhesion μ_p. For the complete slip (s = 100%) μ_t is called the coefficient of motion grip μ_o. The graph of coefficient μ_t with the function of s is shown in Figure 1.

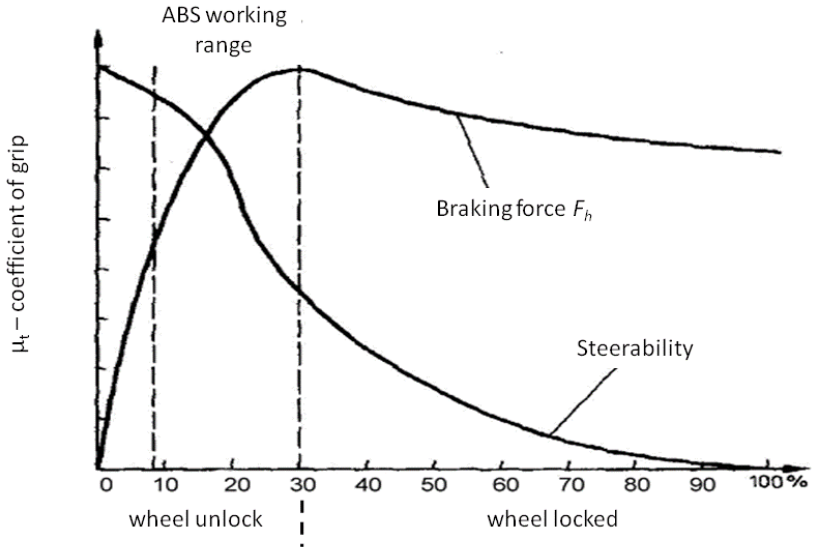


Fig.1. The graph of variability of coefficient μ_t and steerability with the function of s

From Figure 1, it appears that the main goal of ABS is to prevent braking wheels against being locked and to keep the slip value within the intended range. This should ensure steerability and shorten braking distance. The general idea of ABS is presented in Figure 2.

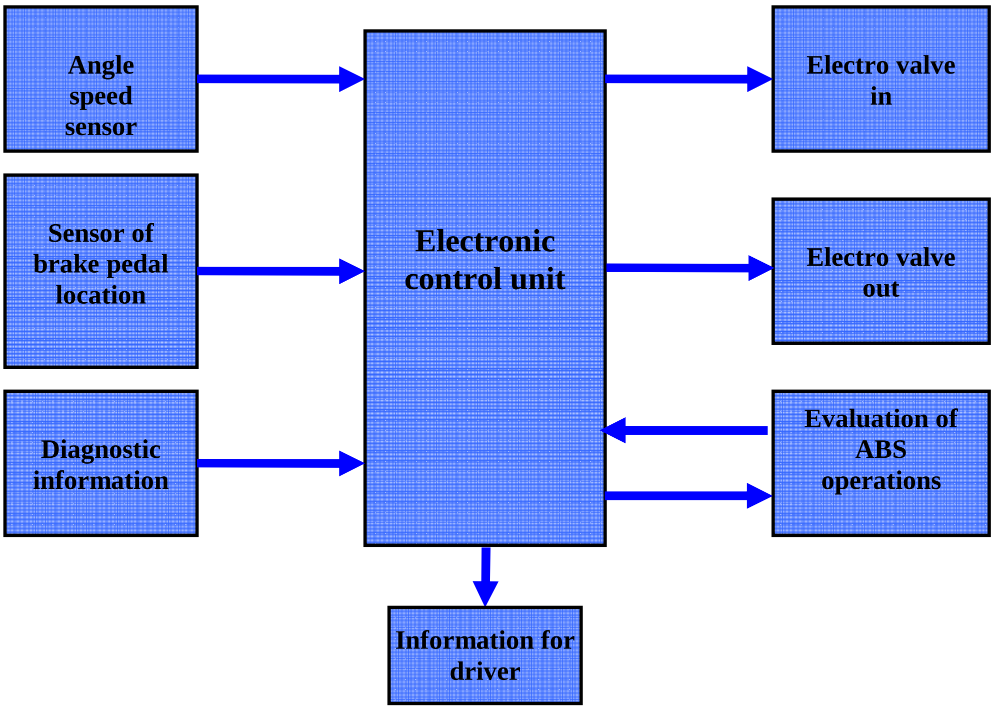


Fig. 2. Diagram of ABS [1]
Source: own development

When a driver presses the brake pedal, it increases the pressure of brake fluid, which triggers off the braking process (phase 1 in Figure 3). An ABS permanently tracks all the changes in wheel rotation and prevents a subsequent rise of F_h if the value of the assumed slip exceeds the acceptable range. If ABS records a rapid decrease in wheel rotation speed (which could indicate that the wheel has just stopped), it triggers the process of decreasing the pressure of brake fluid, which should allow to regain the lost grip (phase 3).

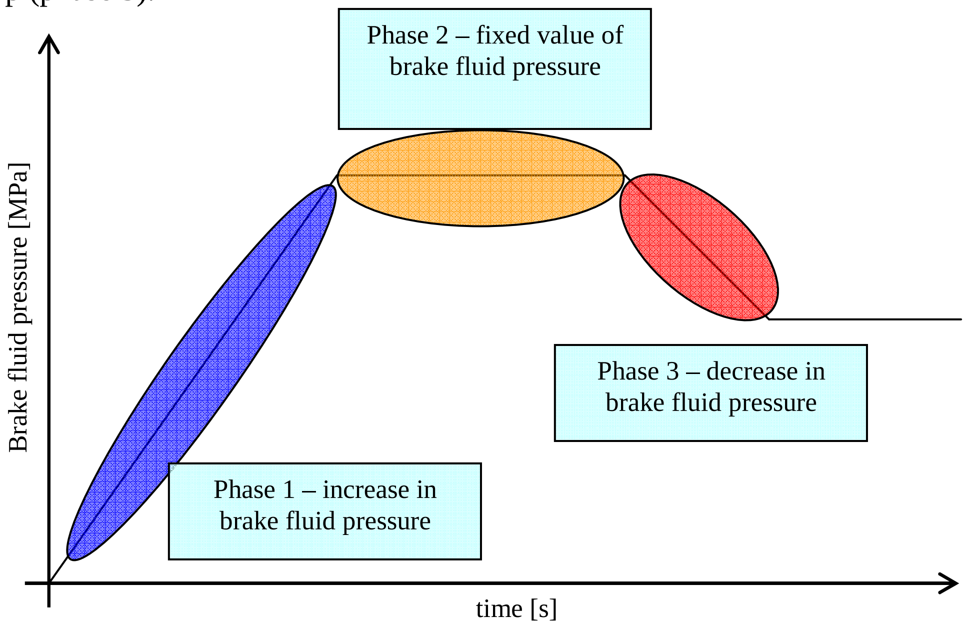


Fig. 3. Phases of ABS operation

Source: own development

After that the process of increasing the pressure of brake fluid starts again. When a car reaches some pre-determined speed, an ABS switches off.

2. CONNECTION BETWEEN DAMPING RATIO AND ABS EFFICENCY

By analysing ABS operation, it appears that the system needs a few data, such as well-defined wheel rotation speed and a permanent comparison to the reference car speed, in order to work properly and efficiently [1]. In the event that one wheel is about to stop, braking force F_h is decreased. This should restore grip. The lock of wheels could result from the change of road conditions (road surface) or the loss of contact between a tyre and the road. The latter instance occurs as an effect of a decrease of the damping ratio of suspension (wear of shock absorbers). In both cases ABS decreases the value of F_h and extends braking distance, which is an undesirable effect.

3. ABS MODEL

To simulate the way in which ABS works, a computer model [10] in the Matlab Simulink, shown in Figure 4, was created. The model made it possible to observe the changes of braking distance as an effect of shock absorbers' wear. The model did not take account of any other changes in suspension. The simulation was conducted for the front and rear axles.

The major simplifications within the model are as follows:

1. the car is fully operable and its condition is stable during simulations; only the damping ratio changes;
2. the modelled car is ideally symmetrical; the mass of wheels and their stiffness on the left and right sides are the same;

3. there is no asymmetric distribution of mass;
4. the suspension of the model is built from springs and shock absorbers only; no other things are present in the suspension;
5. the side shift of a tyre on the ground does not occur;
6. simplified curve $\mu_t = f(s)$ was adopted for the purpose of calculations;
7. the model was equipped with disc brakes;
8. the coefficient of friction between the disc brake and the brake block is constant; there are no changes relating to temperature;
9. the dynamic radius of wheels is constant;
10. the damping ratio while deflecting and stretching shock absorbers is the same;
11. the mass of the car's model is m = 1300 [kg].

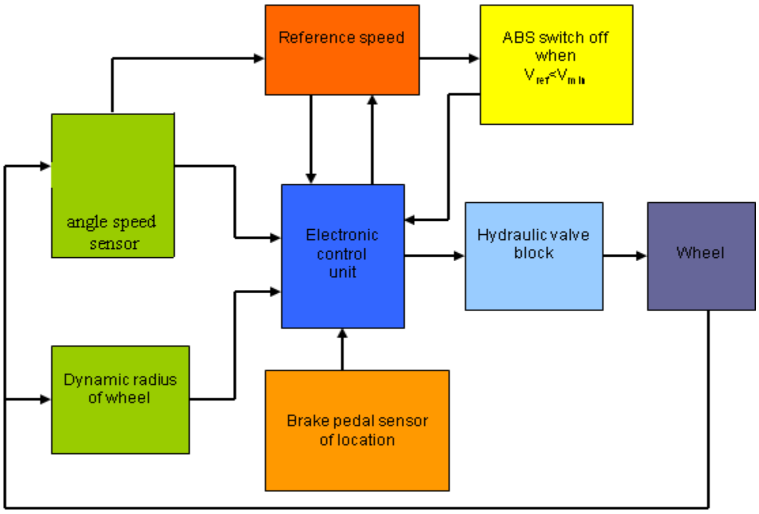


Fig. 4. Diagram of designed ABS model

Source: own development

4. RESULTS

Three levels of the damping ratio were considered;

a) k_1 = 10000 [Ns/m] - 100% for fully working (shock absorber new);
b) k_2 = 7500 [Ns/m] - 25% wear;
c) k_3 = 5000 [Ns/m] - 50% wear.

The parameters selected for the simulation were as follows:

1. the road was described by function:

$$h(x) = b\sin(\omega x) \tag{4}$$

$$\omega = 2\pi/L \tag{5}$$

where: h – height of unevenness, b – amplitude of unevenness, ω – frequency of unevenness, L – length of unevenness wave.

Table 1. Selected values for simulation

Symbol	Value
b	0.05 m
L	5 m
ω	1.256 1/s

2. coefficients: $\mu_p = 1.24$; $\mu_o = 0.78$;

3. car speed: V = 8, 18, 28 [m/s];

The course of the variability of wheels load caused by braking force at speed V=28 [m/s] is presented in Figures 5 and 6.

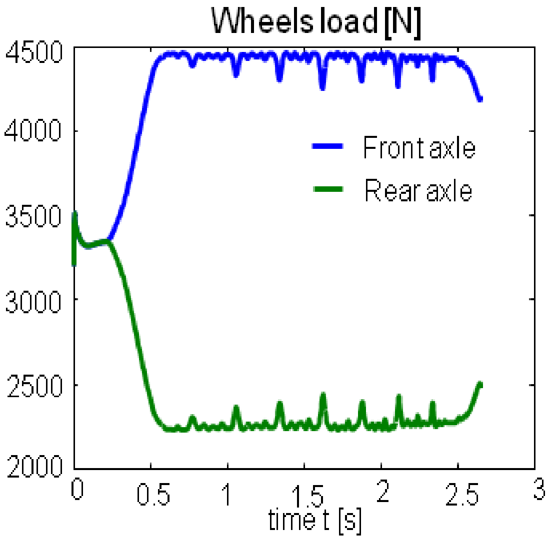


Fig. 5. Variability of wheels load during braking process
Source: own development

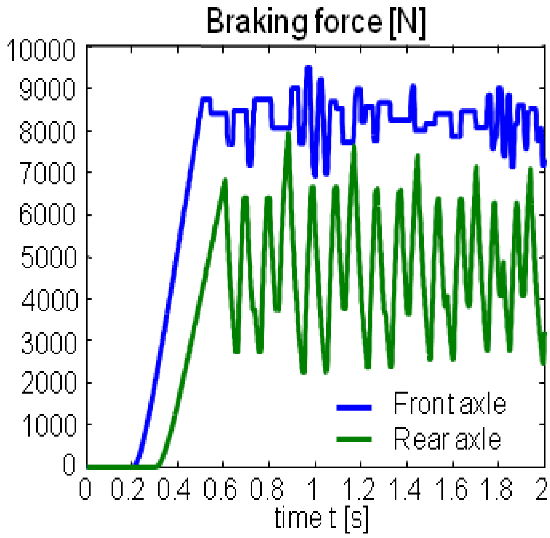
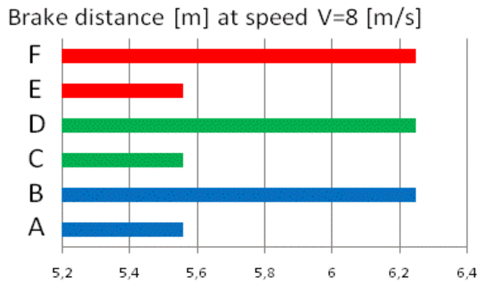


Fig. 6. Variability of braking force (ABS is on)
Source: own development

In the figures below the results for three different car speeds are shown. The model of the car with damping ratio k_3 (50% wear) was subject to the biggest movement of the centre of gravity, which decreases the sense of comfort. The differences, however, were not substantial. Much more significant differences were observed in an increase in braking distance.



k=100%		k=75%		k=50%	
ABS on	ABS off	ABS on	ABS off	ABS on	ABS off
A=5,56	B=6,25	C=5,56	D=6,25	E=5,56	F=6,25

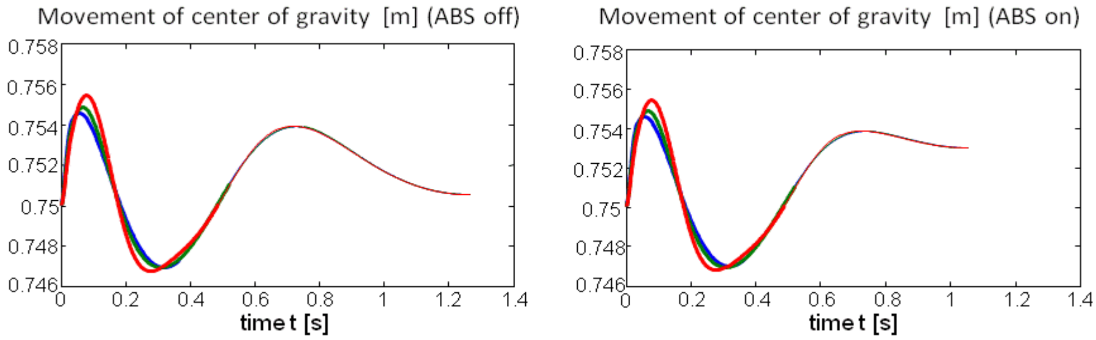
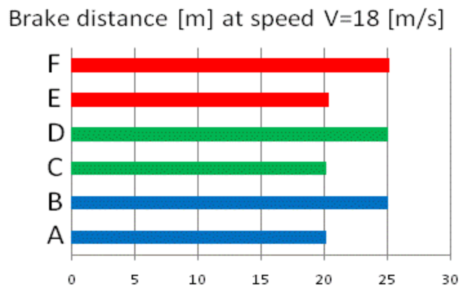


Fig. 7. Braking distance and movement of centre of gravity at speed V=8 [m/s]
Source: own development



k=100%		k=75%		k=50%	
ABS on	ABS off	ABS on	ABS off	ABS on	ABS off
A=20,18	B=25,11	C=20,2	D=25,12	E=20,37	F=25,15

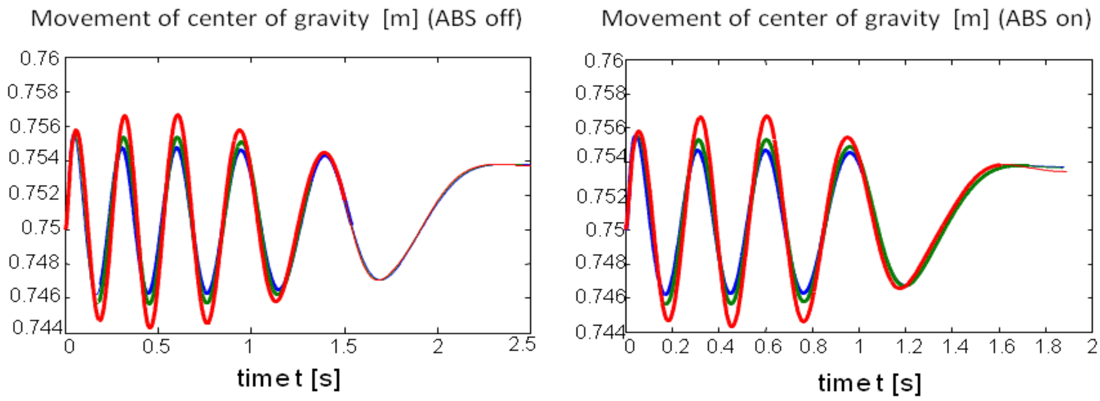


Fig. 8. Braking distance and movement of centre of gravity at speed V=18 [m/s]
Source: own development

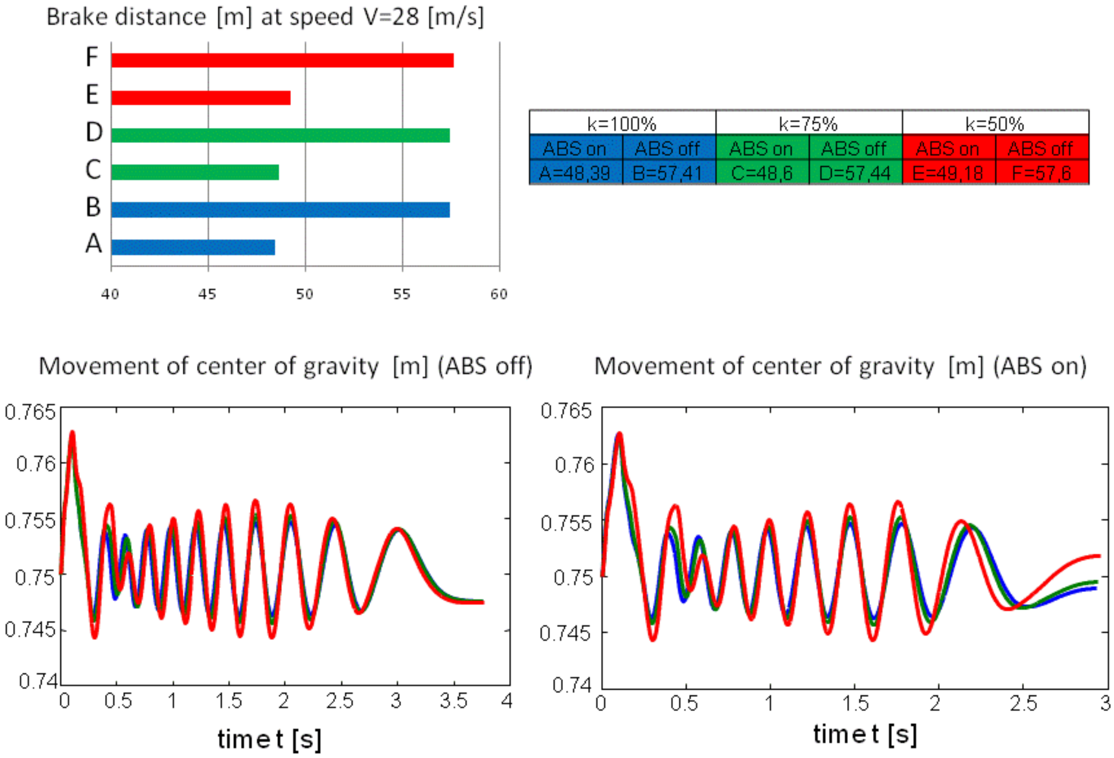


Fig. 9. Braking distance and movement of centre of gravity speed V=28 [m/s]

Source: own development

CONCLUSIONS

The conducted experiments show changes in braking distance and comfort caused by the normal operation of cars. The main conclusion after the performed simulations seems to be that there is an increased sensitivity of the braking process of the car with ABS resulting from a decrease of the damping ratio (wear of shock absorbers) in comparison to the car without ABS. The influence of the damping ratio on braking distance after the performed tests is non-linear and increases along with a rise of car speed.

The designed model of the car and an ABS system allows one to perform a number of different simulations relating to four-wheel cars moving on different roads. The results reflect real phenomena with good approximation.

CONTENTS

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WPŁYW ZUŻYCIA ELEMENTÓW ZAWIESZENIA NA SKUTECZNOŚĆ DZIAŁANIA UKŁADU HAMULCOWEGO Z SYSTEMEM ABS ORAZ NA KOMFORT JAZDY

Streszczenie

Współcześnie produkowane pojazdy mechaniczne są wyposażane w coraz to nowsze układy wspomagające pracę kierowcy. Jednym z seryjnie montowanych dzisiaj w pojazdach układów jest ABS. Bezdyskusyjną korzyścią z jego stosowania jest zachowanie sterowności pojazdu podczas hamowania, co przekłada się wprost na komfort jazdy. Uważa się również, że skraca się dzięki niemu droga hamowania. Nieczęsto można jednak znaleźć informacje, mówiące o zależności długości drogi hamowania od stanu technicznego zawieszenia pojazdu.

Mariusz KOSOBUDZKI

Autor niniejszego artykułu stara się przy pomocy modelu wykonanego w programie Matlab Symulink przedstawić skuteczność jego działania w funkcji stanu technicznego amortyzatorów.

Artykuł recenzował: dr hab. inż. Tadeusz SMOLNICKI, prof. PWr.