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COMPARING TWO METHODS FOR TESTING THE BRAKING PROPERTIES OF CARS

Summary. This paper examines two different methods for vehicle braking performance testing, one involving piezo sensors and the other involving a "fifth" wheel. A comparison of the results with the two testing systems was done. The braking process of two cars (with and without ABS) was tested. The results show that very close values were obtained by the two systems. The advantages of these systems were analyzed. The system with a piezo sensor gave more informative results for the braking process. The system with the "fifth" wheel provided an easy way to estimate the car's braking performance.

1. INTRODUCTION

Various measurement systems are needed to carry out scientific research work in the field of automotive technology [1, 5, 8], with the help of which all the most important indicators and parameters of cars and their main operational properties are determined. Specialized measurement systems are already used in practice [2, 6] to measure and evaluate specific operational properties or groups of indicators and parameters (to evaluate the economic properties of vehicles, to evaluate the acceleration and braking properties of cars, etc.). Of special importance to the car is its behavior on the road when moving at different speeds and when braking on diverse road surfaces in terms of their qualities and condition.

One of the main aspects of car performance is the car's braking properties. Many efforts are applied in simulation, such as a possible way to determine braking properties. The authors of [6] were developed a dynamical tire model under uneven roads, which was used to simulate various braking conditions.

The braking properties influence other performance parameters, such as stability [9]. The study is devoted to the influence of braking devices on the stability of car braking properties.

Significant differences were discovered in [10, 11] when car tests were conducted in a stationary condition (test bench) and on real horizontal roads. Braking properties were better on the road than on the bench.

The braking properties are also important for motorcycles. In [12], the braking performance of two types of motorcycles was studied with different tires and braking conditions. Using only the front or rear brake, the authors investigated braking distance.

In [1], a test complex, including a high-speed camera and a laser velocimeter, was used to track the impact event on the tires. The experimental results were used to assess the tire performance in extreme cases of mass impact.

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Another testing system, based on the VBOX data logger equipment, was presented in [8]. Results were obtained using GPS. The author studied the braking deceleration of different cars during emergency braking.

In [13], the authors used the same principle of testing the vehicle properties. Technical devices for measuring and recording are a GPS receiver, a Magellan Triton 300, Canon digital cameras, and an anemometer.

The main problem when GPS devices are used is accuracy. The satellite's coverage of the position can sometimes be determined with a resolution of 20 cm. This is not acceptable for scientific needs.

Usually, researchers prefer to use specialized measuring systems, which can be easily mounted on the test vehicle and allow the measurement and display of the main parameters of the motion.

In [2, 5], different induction speed sensors are presented. The "fifth" wheel systems are widely used [5]. It is easy to use print devices, which give mean results immediately after the end of the test [4].

A similar tester for the braking performance of the BRAKESAFE model was used in [14]. It does not need an electric supply during the test and is easy to use, but the capabilities are not broad. The paper presents results from tests of two types of cars, including deceleration, braking time, and distance to full stop.

The adapters of the National Instruments are appropriate for many applications [3].

The Department of Engines and Vehicles at the University of Ruse "Angel Kanchev" has two systems for researching the braking properties of cars. One system is equipped with the Peiseler "fifth" wheel [5, 7], together with the "DB Print" device [4] and the associated brake pedal control button.

The other mobile system includes the "NI DAQ USB-6008" adapter housed in a protective case, associated piezo sensors for longitudinal and transverse acceleration/deceleration, and a laptop with National Instruments "LabVIEW" software installed [3].

The purpose of this article is to compare the possibilities and the results obtained from two methods of testing the braking properties of a car (with the heel and with piezo sensors).

2. DESCRIPTION OF THE TEST METHODS AND APPARATUS

The information system with piezo sensors consists of a laptop computer, the NI DAQ USB-6008 adapter, and piezo sensors for measuring acceleration and deceleration. An additional set of sensors is included in the complete system. They are used for other measurements. The general appearance of the fully equipped system is shown in Fig. 1.

LabVIEW Signal Express software with the VI Logger application was installed on the computer. It collected, processed, visualized, stored, and analyzed the data from the tests [3].

Another major component of the system is the National Instruments DAQ USB-6008 adapter housed in a protective case. The adapter has inputs to which the sensors for measuring accelerations and decelerations are connected via wires (Fig. 2). When testing, the adapter was connected to a 12V supply from the cigarette lighter or the test vehicle's battery. The NI DAQ USB-6008 converted the raw information from the sensors from analog to digital and fed it to the laptop for visualization and processing.

Piezo sensors were designed to measure the accelerations and decelerations of the test vehicle during its movement. They were positioned so that their direction of action coincided with the longitudinal and transverse accelerations and decelerations, respectively Fig. 3 [2].

The system for testing braking properties with a "fifth" wheel mounted on the test vehicle is shown in Fig. 4 and 5. It consisted of a DB Print device and a "fifth" wheel. The "fifth" wheel was equipped with suction cups and mounting brackets for easy attachment to the vehicle. A magnetic pulse sensor built into the "fifth" wheel was used to measure the required values [2, 5]. The output of this sensor was connected to a DB Print device (Fig. 6) with different reporting modes depending on the needs. The system can also work with a PC connection and special software via an RS 232 serial interface.

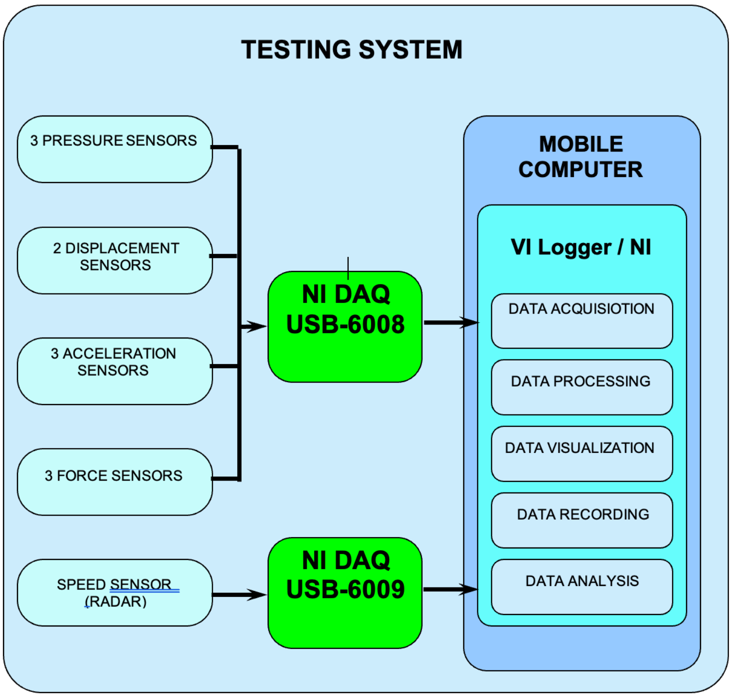


Fig. 1. Block diagram of the entire mobile car testing system

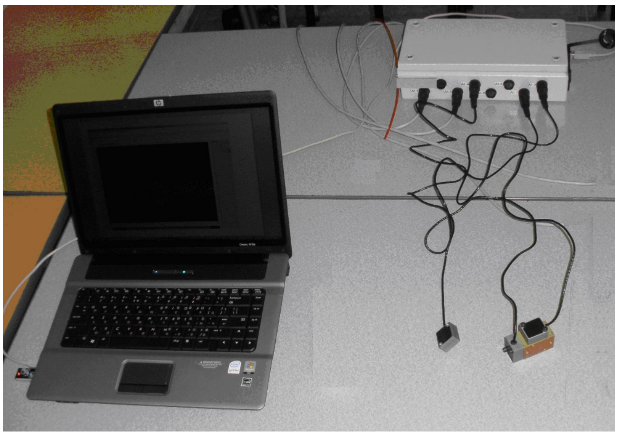


Fig. 2. General view of the mobile testing system equipped only with piezo sensors for car acceleration and deceleration properties

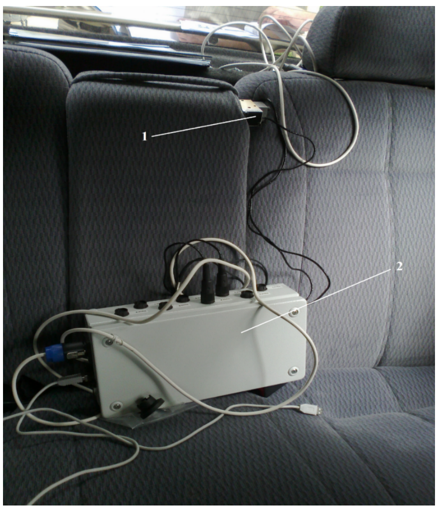


Fig. 3. Placement of (1) the piezo sensors and (2) the adapter in the car

Fig. 4. Testing system with a “fifth” wheel mounted on the car without ABS

Fig. 5. Testing system with a “fifth” wheel mounted on the car with ABS

The tests with the test car were done at the University of Ruse. The mode of movement of the car was as follows: accelerating movement until reaching a certain speed and then engaging the brakes with maximum force (decelerated motion) until the car came to a complete stop. The surface was dry asphalt.

The tests were carried out simultaneously with the “fifth” wheel and piezo sensor systems. The values of the longitudinal accelerations and decelerations with the piezo sensor system were taken every 0.1 s.

Two cars were investigated. The first one—VAZ 21102 (Fig. 4), without ABS—had BELSHINA 175/70 R13 tires. The second one—Nissan (Fig. 5), with ABS—had AMTEL 215/65R16 98 H tires. The tire tread pattern was summer type, and the wear was less than 5%. Concerning braking properties, the lateral acceleration (Figs. 7–14) was not considered.

a)

b)

Fig. 6. (a) General view and (b) placement of DB Print device in the car during tests

3. ANALYSIS OF THE RESULTS OBTAINED

3.1. Effect of processing

The function of adding a Trend line with a moving average value was used to process the graphs. Since piezoelectric sensors are very sensitive and the results contain accumulated "signal noise" (Fig. 7), it was necessary to apply this function as a low-pass filter for signal processing.

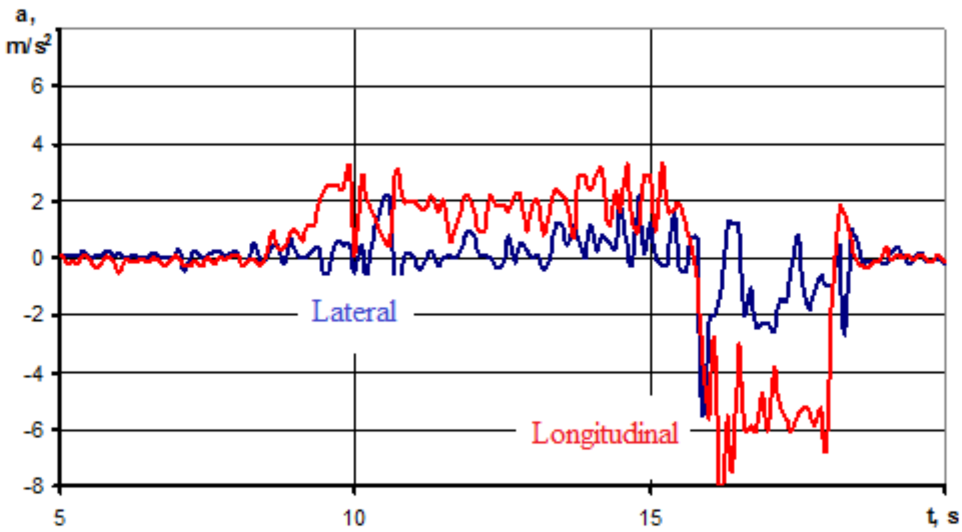


Fig. 7. Variation of longitudinal and lateral acceleration/deceleration depending on the time without processing

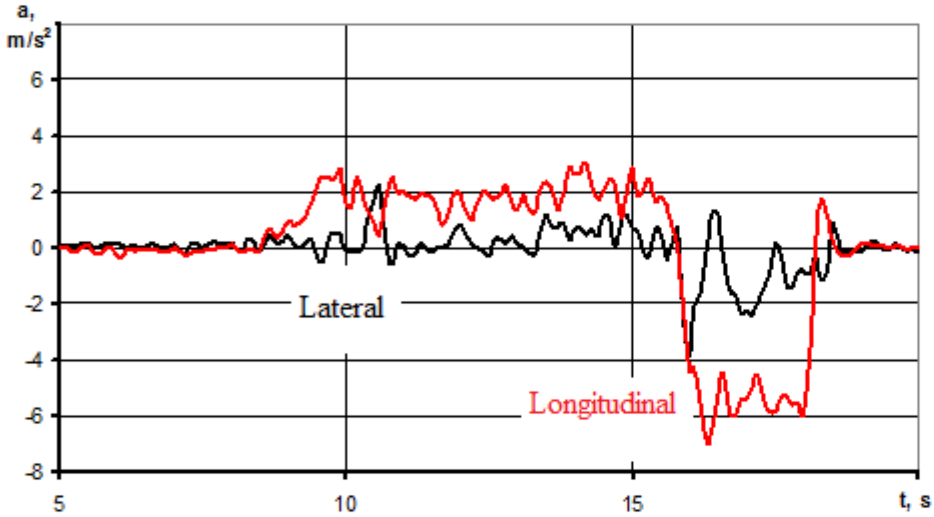


Fig. 8. Variation of longitudinal and lateral acceleration/deceleration depending on the time with a moving average processing of 2 points

It was necessary to determine how many points were required to calculate the moving average. Treatments covering two points, six points, and 16 points were performed. After processing, the graph for one of the trials is presented in Figs. 8–10. From Fig. 8, it can be seen that with a two-point moving average, the noise is not sufficiently filtered and the oscillations remain significant.

With a 16-point moving average (Fig. 10), the plot curves distort the results too much, with the lag time from the longitudinal lag curve being reduced. In Fig. 9, with a floating average of six points, the oscillations are sufficiently reduced and the nature and shape of the dependences do not differ significantly from the initial ones from Fig. 7.

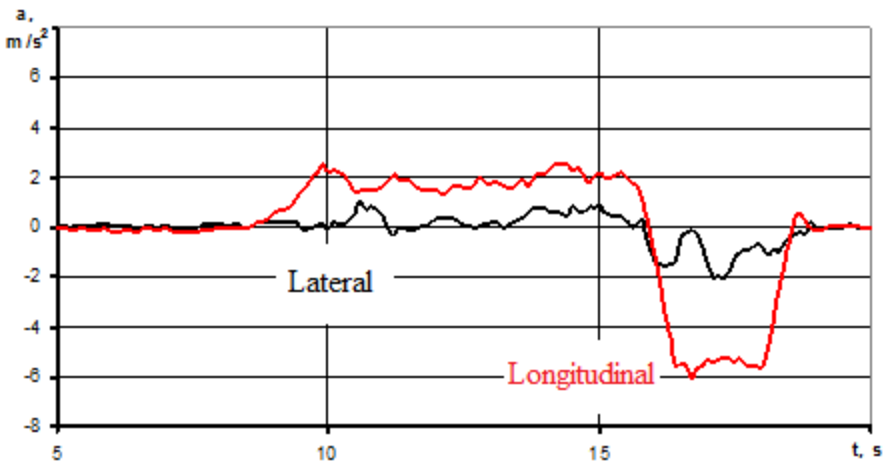


Fig. 9. Variation of longitudinal and lateral acceleration/deceleration depending on the time, with a moving average processing of six points

3.2. Results for the car without ABS

Acceleration and braking tests of the test car were carried out at tire air pressures of 0.15 MPa and 0.25 MPa and different car loads (two and five passengers). The tests were carried out on the internal campus of the University of Ruse on the horizontal asphalt road in good condition (Fig. 4). During the test, car motion was firmly ahead. The results of the system with the piezo sensors are shown in Figs. 11–14.

As shown by the longitudinal acceleration/deceleration curve of Fig. 11, an average deceleration of 5.75 m/s^2 was obtained in the section of intensive braking. The mean deceleration under intensive braking (Fig. 12) was 6.13 m/s^2. It can be seen that the average deceleration is higher with a lower load (two passengers). This is probably due to the decrease of the grip coefficient with an increase in the vertical load on the tires.

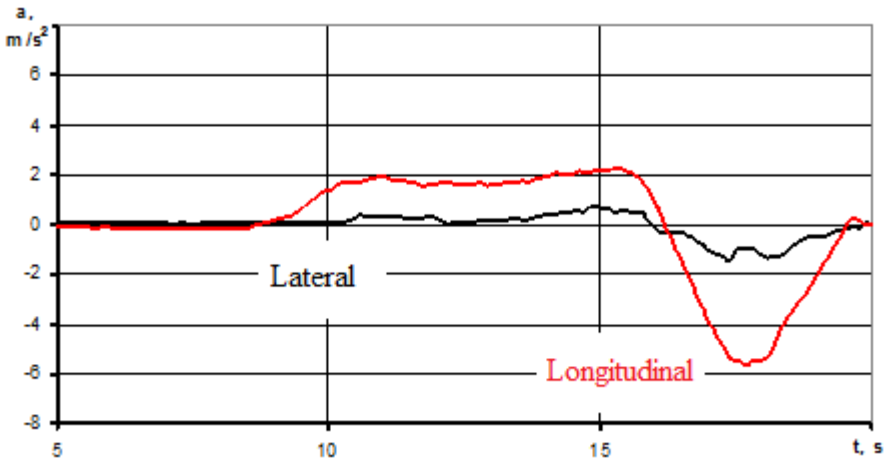


Fig. 10. Variation of longitudinal and lateral acceleration/deceleration depending on the time, with a moving average processing of 16 points

An interesting result can be seen in the lateral acceleration/deceleration curve for the car without ABS. In the period of intensive braking, lateral acceleration appeared. It is probably caused by the unequal brake forces of the wheels (the wheels are blocked; see Fig. 4) and the different weights of the passengers. The effect was stronger when there were five passengers (Figs. 11 and 13). During the experiments with the car with ABS, this effect was not significant.

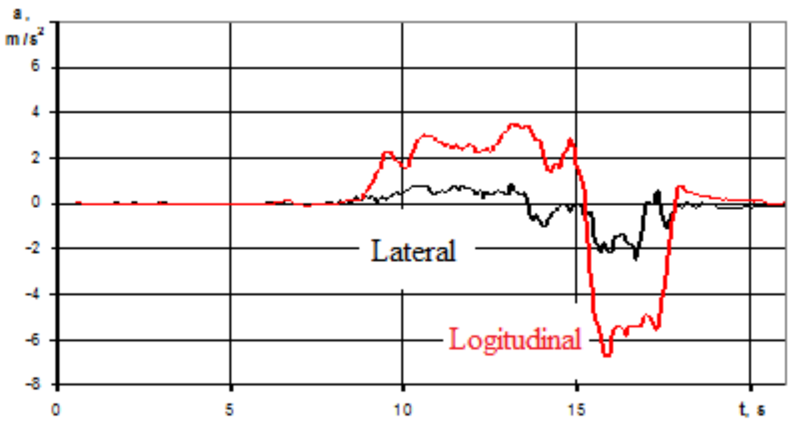


Fig. 11. Variation of longitudinal and lateral acceleration/deceleration depending on the time at a tire pressure of 0.25 MPa and five passengers in the car

The average deceleration at a tire pressure of 0.15 MPa is 5.55 m/s^2 for five passengers and 5.81 m/s^2 for two passengers (Figs. 13 and 14). These values are less than the deceleration at 0.25 MPa tire air pressure (5.75 m/s^2 and 6.13 m/s^2 for five and two passengers, respectively), which is probably due to the larger deformation of the tires and the uneven distribution of the specific pressure in the contact patch of the tires with the road [1, 6].

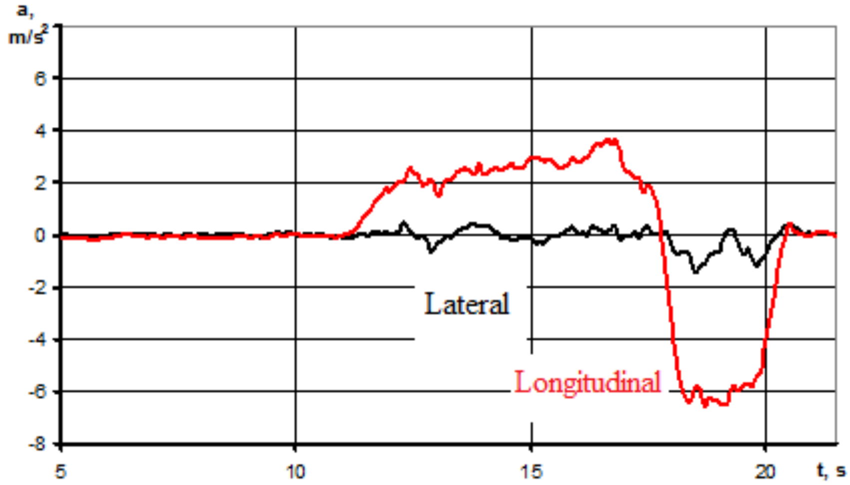


Fig. 12. Variation of longitudinal and lateral acceleration/deceleration depending on the time at a tire pressure of 0.25 MPa and two passengers in the car

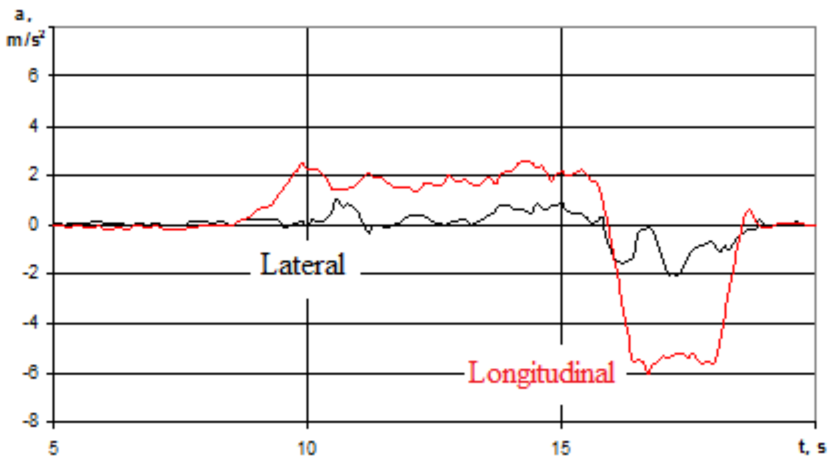


Fig. 13. Variation of longitudinal and lateral acceleration/deceleration depending on the time at a tire pressure of 0.15 MPa and five passengers in the car

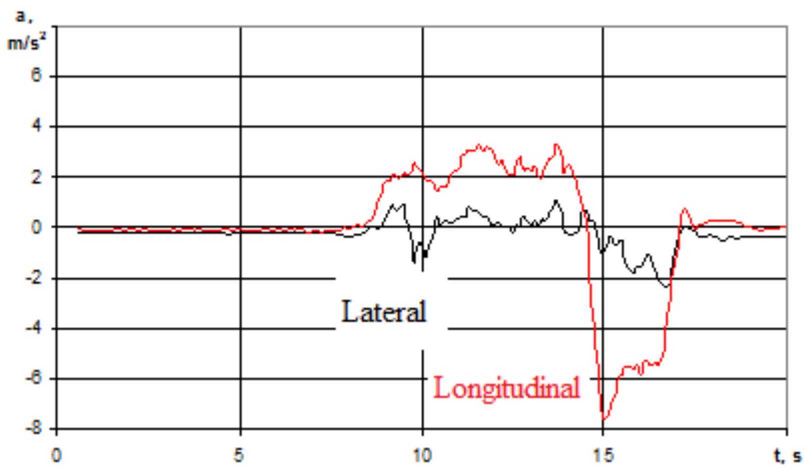


Fig. 14. Variation of longitudinal and lateral acceleration/deceleration depending on the time at a tire pressure of 0.15 MPa and two passengers in the car

The longitudinal acceleration/deceleration graphs show that after the car stops, a positive pick in acceleration occurs up to about 0.7 m/s^2. This is due to the increase of the inertial force in the direction opposite to the braking forces after the car stops.

The "fifth" wheel system is activated when the brake pedal is depressed via the control button mounted on the vehicle brake pedal.

After the experiment, the main values, including initial speed, total stopping time, and stopping distance, were printed on paper by the DB Print device (Fig. 15). The same data are presented in Table 2. We chose to take into account the average deceleration in the range of 80–10% of the initial speed. Thus, it can be compared with the average deceleration in the intensive braking process obtained by the system with the piezo sensors. The results for the "fifth" wheel and the piezo sensor systems are shown in Table 1.

The average deceleration results obtained by the two systems did not differ significantly in the first attempt. They differ by up to only 0.08 m/s^2, or about 1.3%.

Table 1

Results of the study with the "fifth" wheel and piezo sensor systems for cars without ABS

Test №	**Tire pressure, MPa**	**Number of passengers**	**Braking 40–0 km/h, Indicators**		
			Braking time, s	Average deceleration in the intensive braking process, m/s^2 ("fifth" wheel)	Average deceleration in the intensive braking process, m/s^2 (piezo sensor)
1	0.25	5	2.53	5.83	5.75
2	0.25	2	2.34	6.17	6.13
3	0.15	5	2.49	5.53	5.55
4	0.15	2	2.61	5.77	5.81

3.3. Results for the car with ABS

The methodology and proceeding of the data obtained are the same as described in Section 3.2 for the car without ABS. The initial speed was 100 km/h, and an inter-town road in very good condition was used for the experiments. The tire pressure was 0.25 MPa, and the load was only two persons (driver and operator). During this series of tests, the influence of the tire pressure and load of the car on the deceleration was not studied. Under these conditions, only the difference in the results obtained by two systems were compared. For example, Fig. 15 presents the results as printed on DB device sheets.

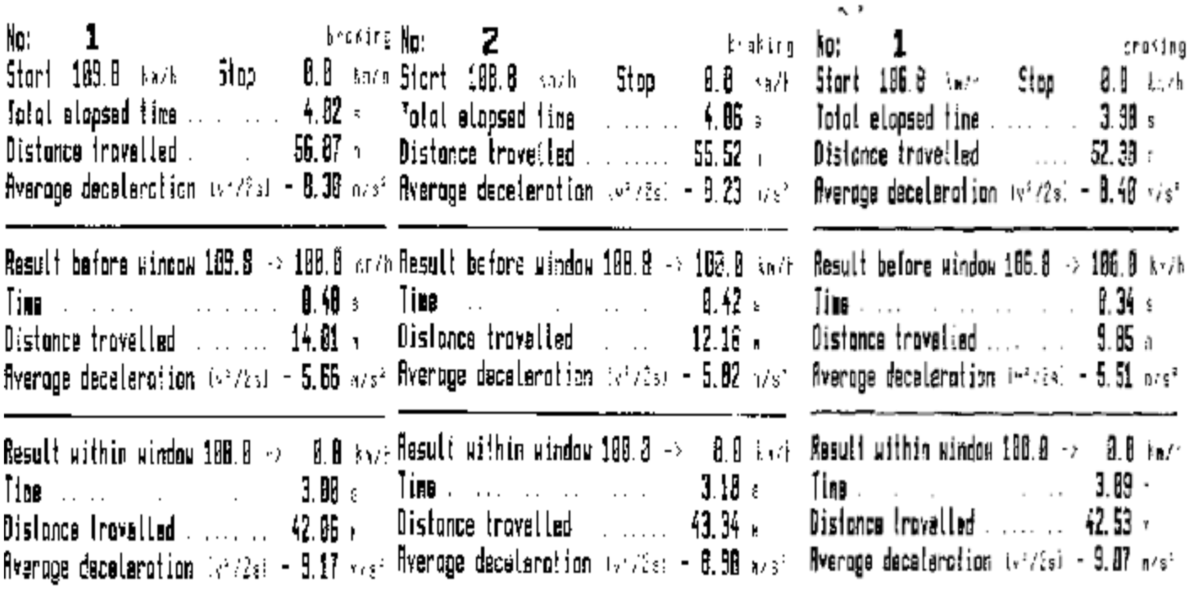
The braking properties are summarized in Table 2.

From the average deceleration results obtained by the two systems, it is clear that they do not differ significantly. They differed by up to only 0.07 m/s^2 in the first attempt, and the differences ranged from 0.3–0.8%.

4. CONCLUSIONS

Two vehicle braking systems were tested, one with piezo sensors and the other with a "fifth" wheel, and their results were compared. The following conclusions can be drawn from the analysis of the results:

1. The system with the "fifth" wheel provides more information regarding the final values of the parameters during the braking mode of the car (initial speed, total time for stopping, braking distance, and deceleration). It is appropriate to use this system if certain basic braking indicators are needed.
2. The system with the piezo sensors allowed the study and visualization of longitudinal and lateral acceleration/deceleration change during the entire experiment. Thus, it is appropriate for use if the actual process of acceleration/deceleration changes over time is investigated.


No: 1 braking
Start 109.8 km/h Stop 0.0 km/h
Total elapsed time ..... 4.02 s
Distance travelled ..... 56.87 m
Average deceleration (v²/2s) - 8.38 m/s²

Result before window 109.8 -> 100.0 km/h
Time ..... 0.48 s
Distance travelled ..... 14.01 m
Average deceleration (v²/2s) - 5.66 m/s²

Result within window 100.0 -> 0.0 km/h
Time ..... 3.00 s
Distance travelled ..... 42.86 m
Average deceleration (v²/2s) - 9.17 m/s²

No: 2 braking
Start 108.8 km/h Stop 0.0 km/h
Total elapsed time ..... 4.06 s
Distance travelled ..... 55.52 m
Average deceleration (v²/2s) - 8.23 m/s²

Result before window 108.8 -> 100.0 km/h
Time ..... 0.42 s
Distance travelled ..... 12.16 m
Average deceleration (v²/2s) - 5.82 m/s²

Result within window 100.0 -> 0.0 km/h
Time ..... 3.10 s
Distance travelled ..... 43.34 m
Average deceleration (v²/2s) - 8.98 m/s²

No: 1 braking
Start 106.8 km/h Stop 0.0 km/h
Total elapsed time ..... 3.98 s
Distance travelled ..... 52.39 m
Average deceleration (v²/2s) - 8.40 m/s²

Result before window 106.8 -> 100.0 km/h
Time ..... 0.34 s
Distance travelled ..... 9.85 m
Average deceleration (v²/2s) - 5.51 m/s²

Result within window 100.0 -> 0.0 km/h
Time ..... 3.09 s
Distance travelled ..... 42.53 m
Average deceleration (v²/2s) - 9.07 m/s²

Fig. 15. Results printed by DB Print device concerning the braking process of the Nissan car (with ABS) from 100–0 km/h

Table 2

Results of the study with the "fifth" wheel and piezo sensor systems for cars with ABS

Test №	Tire pressure, MPa	Number of passengers	Braking 100-0 km/h, Indicators		
			Braking time, s	Average deceleration in the intensive braking process, m/s^2 ("fifth" wheel)	Average deceleration in the intensive braking process, m/s^2 (piezo sensor)
1	0.25	2	3.00	9.17	9.10
2	0.25	2	3.10	8.98	9.00
3	0.25	2	3.09	9.07	9.02

3. Data from the "fifth" wheel system were obtained directly, while for the piezo sensor system, data were obtained after additional processing. It is appropriate to use the function with a moving average value of six points.
4. The two systems showed identical results for the average deceleration in the range of intensive vehicle braking. The differences between values of separate experiments were below 1.3%. As such, either system can be chosen depending on the specific goals and objectives of a given study.
5. The methodology, equipment, and processing used are applicable to the study of the braking properties of cars, as they represent the real process over time, have good repeatability, and provide reliable results.

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