Algorithms for diagnostics of the hydraulic pressure modulators of ABS / ESP systems in stand conditions

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Abstract. The article presents possibilities of extending the scope of ABS / ESP systems control as part of periodic vehicle technical inspection. It was proposed to check the functioning of the ABS / ESP system based on the evaluation of its effects in the form of dynamic changes of braking forces measured on the roller diagnostic stand. The tested system is started by a diagnostic tester through the OBD socket in the car during the implementation of active tests. The effect of the system is checked on the basis of the analysis of the course of braking forces. This allows to detect those mechatronic system failures that are not detected by on-board diagnostic systems. The algorithms for control of ABS and ESP modulators using diagnostic testers are presented.

1 Introduction

In recent decades, the car's braking system has become the mechatronic system. The development of techniques and scope of diagnosis in the field of periodical technical tests should take into account this fact [6].

Mechatronic systems, whose main idea is to control the object through a programmable controller that uses signals from sensors, require a different approach to their diagnosis in relation to strictly mechanical systems. The self-diagnosis program built into the controller should be used in control tests. For this purpose, it is necessary to use testers through which any error codes registered by the self-diagnosis system can be read, as well as signals from the sensors and verify the correctness of their operation. The second purpose of using testers is the ability to force acting the circuits of the actuators through the electrical signals from the tester and obtaining answers. The use of testers allows to speed up the process of diagnosis mechatronic systems, as well as to more widely use existing stands for vehicle control tests.

2 Extending the scope of control tests of ABS / ESP systems

The current regulations regarding periodic technical inspections of vehicles include tests of electronically controlled safety systems in a very narrow range [1, 2]. The diagnostician only uses the signaling information on the car instrument panel. On the other hand, the use of diagnostic testers is required to control the operation of mechatronic systems. This allows to significantly extend the scope of diagnosis. Controlling actuators through the tester, with simultaneous recording of the response of the tested system, allows to detect failures that are not registered by the on-board diagnostic system [3]. For ABS and ESP braking systems, the integration of the ABS / ESP modulator valves control with the braking force measurements on a roller stand allows to check this system as a whole. This method allows to use the stands currently used in periodic technical tests.

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Currently, in the diagnosis of ABS / ESP systems in the scope of periodic technical tests, only signaling lights on the instrument panel of the vehicle are used, indicating the efficiency or damage of electronic and electrical components. The second level of diagnosis is the use of a tester that allows reading error codes, sensor indications, actuation of actuators - valves and ABS pump. This level is currently not used in the study of safety systems. In order to carry out such diagnostics, vehicle inspection stations should be equipped with a tester with a dedicated program for these stations [4,5].

The next level is checking the functioning of the ABS / ESP system by running it with a diagnostic tester. This level of testing allows you to evaluate the operation of the system as a whole. The main purpose of its application is to detect disabilities that are not detected by on-board diagnostic systems. It includes tests of the operation and indications of wheel speed sensors, measurement and registration of variation of braking forces at the roller stand during operation of the pump and ABS / ESP valves started-up with the tester. It is also possible to control the zeroing of the steering angle sensor, check the operation of the ω_z speed sensors and lateral acceleration a_y.

Checking the braking system with ABS / ESP at this level allows detection of the following failures which are not signaled by the OBD on-board diagnostic system: incorrect or unstable vehicle wheel speed sensor readings, possibility of connecting electric or hydraulic wires by mistake, leaks or mechanical immobilization of the modulator valves, obstruction or blockage of the brake fluid flow to the brake calipers, improper ABS pump operation, improper zeroing of the steering angle sensor, improper zeroing of the the angular velocity sensor and acceleration sensor, lack of reaction of these sensors on the dynamic forces.

3 Algorithms for diagnostics of the hydraulic pressure modulators of ABS / ESP systems on the roller stand

The ABS and ESP hydraulic modulator includes a high-pressure hydraulic pump, pressure reservoirs and a set of solenoid valves and mechanical valves, Fig. 1. The efficiency of the system depends both on electrical and mechanical systems. The electrical components are covered by the on-board diagnostic system. However, the mechanical part: tightness, flows, speed of operation, is not controlled by the diagnostic tester.

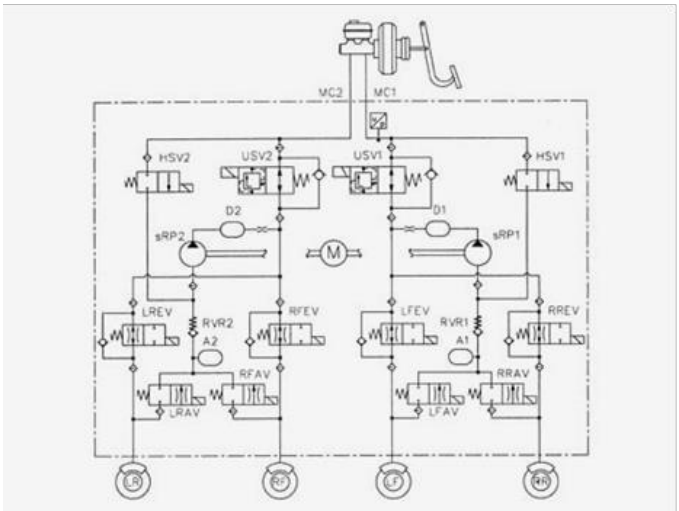


Fig. 1. Diagram of the ESP electrohydraulic modulator (ABS Bosch 5.7). RREV, RRAV, LFEV, LFAV, RFEV, RFAV, LREV, LRAV - valves of ABS, HSV1, USV1, HSV2, USV2 - ESP valves, sRP1, sRP2 - ABS pump.

The purpose of the research presented in the article was to assess the possibility of controlling the operation of valves and ABS / ESP pumps by measuring the variation of braking forces at the roller stand.
The test objects were hydraulic brakes of various passenger car brands equipped with ABS or ESP systems.

The valves and ABS / ESP pump were started by signals from the diagnostic tester. Testers from different manufacturers were used (KTS, TEXA, CDIF). Measurements of braking forces were carried out on a roller stand enabling registration of dynamic changes of braking forces.

The possible algorithms for controlling these systems using a roller brake stand and the results of these tests are presented.

3.1 Subsequent actuation of the ABS/ESP valves

3.1.1 ABS system

The diagnostic procedure allows to evaluate the operation of valves and ABS pump for subsequent car wheels based on the course of braking forces. In the graph (Figure 2), the braking forces are shown during the next steps of actuating the pressure control valves in the right front wheel. During the test the rate of rise and decrease of the braking force during operation of the ABS valves can be assessed. The next steps of the test concern testing of individual valves for subsequent vehicle wheels in accordance with the instructions given by the tester program and performed by the diagnostician. This way of communication between the program and the diagnostician causes a significant extension of the time of diagnosing the entire system.

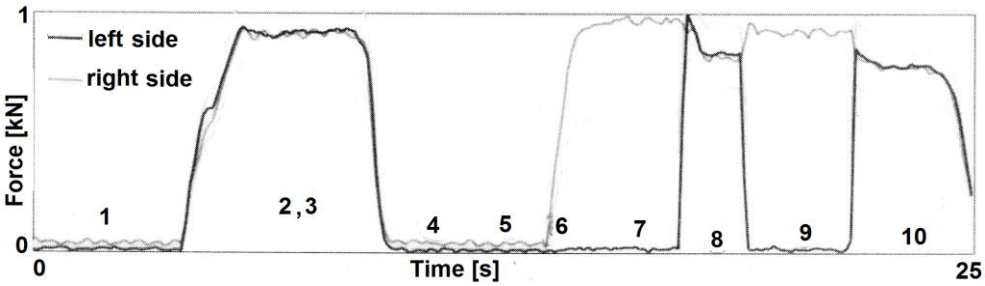


Fig. 2. The course of the braking forces of the front wheels when checking the operation of ABS valves. Next steps have been marked - commands of the diagnostic program: 1 – start the station, 2, 3 - checking braking forces, 4, 5, 6, 7 - checking the intake valve tightness, 8, 9 - intake and exhaust valve control, 10 - end of the test. Opel Astra II.

Another example of the control procedure shown in Figure 3 is to check the operation the ABS valves without first checking the intake valve for leaks.

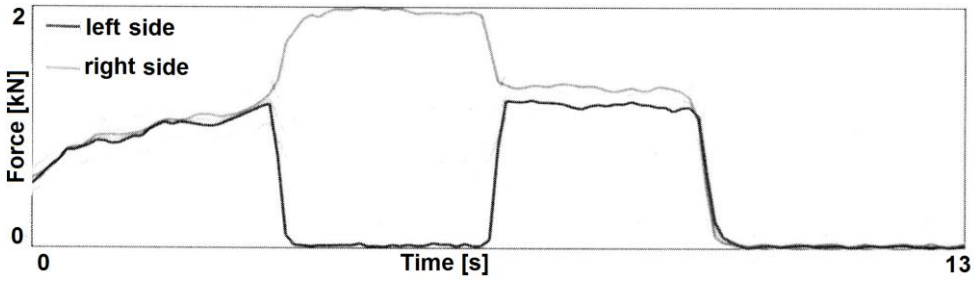


Fig. 3. Result of the ABS front left and right valve control. Bosch KTS tester, Ford Focus car.

Next procedure used in tests is simultaneous actuation of ABS valves in the brakes of the wheels of the tested axle. Its advantage is the acceleration of control by simultaneous actuation of valves on both wheels of the tested axle, Fig. 4. The test allows to evaluate the rate of decrease and the increase of the braking forces and tightness of ABS inlet and outlet valves. The difference in the braking forces of the left and right wheels in the tested car presented in the figure results from the mechanical failures of the brake.

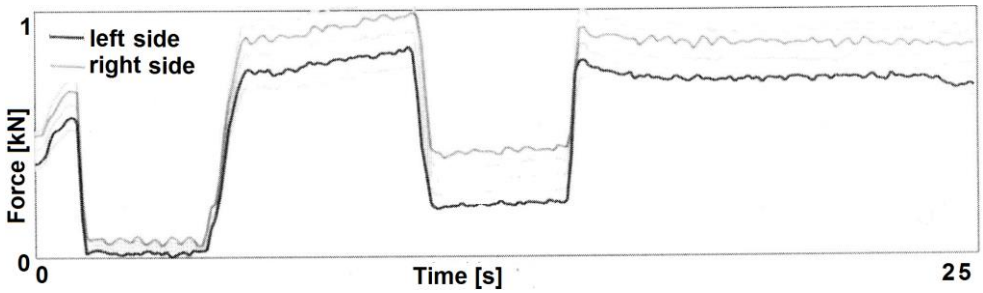


Fig. 4. Results of operation and leak testing of ABS inlet and outlet valves. Front wheels. Renault Scenic car.

3.1.1 ESP system

The procedure includes examining the operation of the ESP valves and pump without pressure on the brake pedal.

• The procedure of gradual pressure decrease

The next steps of the test and their effect are presented in the braking force diagram, Fig. 5:

1 - ABS pump activation, pressure increase in the brake caliper, brake force (without pressure on the brake pedal)

2 - Operation of ESP and ABS valves - pulsed pressure reduction, step changes in braking force

3 - Switching off the ABS pump - reducing the pressure and braking force to the minimum value

The next points, from 4 - 6, characterize the operation of the ABS system.

The course of the braking force in the figure 5 shows the control of the ESP and ABS pressure control valves in the brake caliper of the right front wheel. The same algorithm is used to control the valves of other wheels.

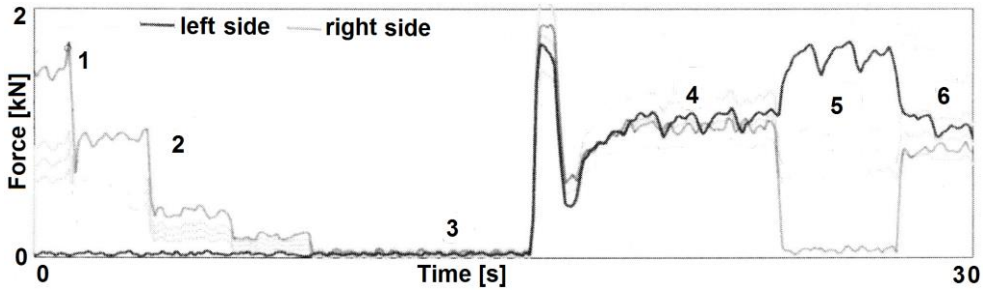


Fig. 5. The course of the test of the ABS/ESP valves and ABS / ESP pump test of the front right wheel. Audi A4. KTS tester. Description in the text.

• The procedure of gradual pressure decrease

This algorithm allows precise control of ESP valves without pressing the brake pedal. During the test, the tester program starts the ABS pump and controls the valves, gradually increasing the pressure in the tested brake caliper (fig. 6). The stability of the braking force and the speed of force changes are evaluated. This allows to check both the operation of the

ESP valves of the tested wheel and the tightness of valves servicing the adjacent wheel. The ABS valves are tested in the next steps, as in figure 5.

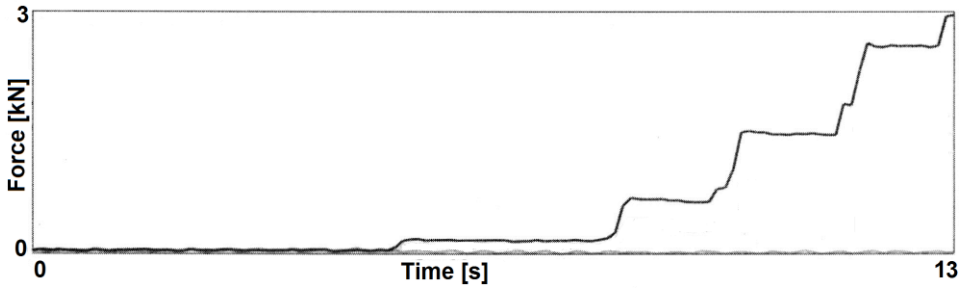


Fig. 6. The result of testing the operation of ESP valves and pump. Front left wheel. Ford Focus.

• Control of ESP valve operation - blocking the wheel

Fig. 7 shows the result of registration of braking forces during the test the valves of the left and right wheel of ABS system. The final part of the graph concerns the control of the dynamic activation of ESP valves, which led to the blocking of the right wheel on the stand.

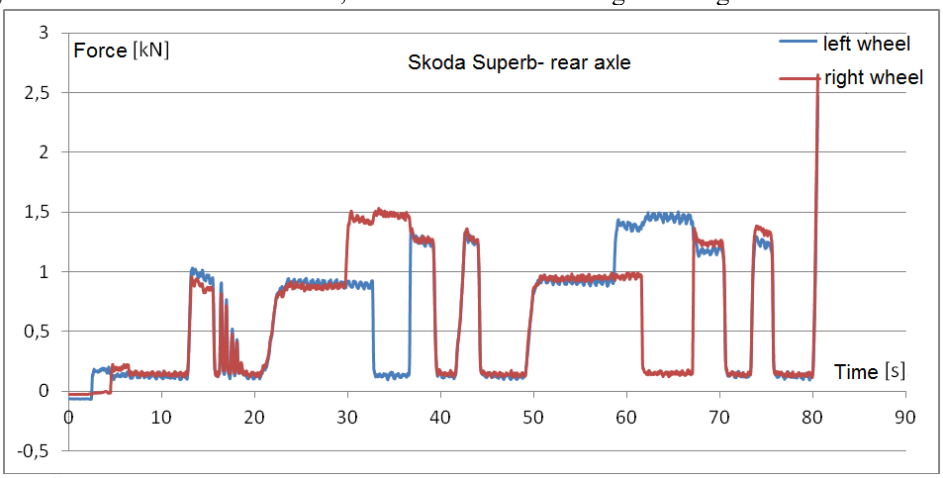


Fig. 7. Test of the inlet and outlet valves of the ABS system of the left and right rear wheel and control of the ESP valves. Skoda Superb. The results developed in Excel.

The above algorithms allow to check the operation of all ABS / ESP modulator solenoid valves. The disadvantage is the long test time, over 2 minutes for one axis.

During testing of ABS / ESP valves mechanical failures of the brakes, unrelated to the operation of ABS / ESP valves, are visible. Fig. 8 shows a clear pulsation of the braking force caused by the side beating of the brake disc.

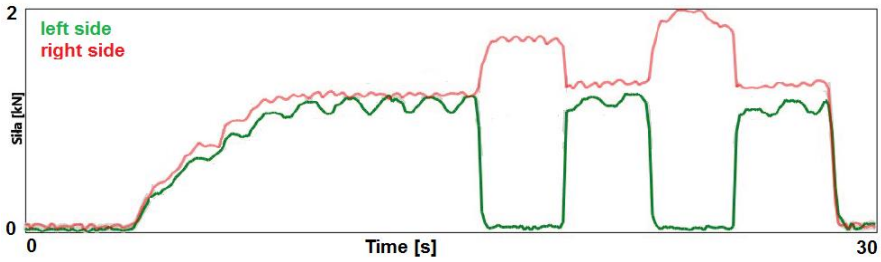
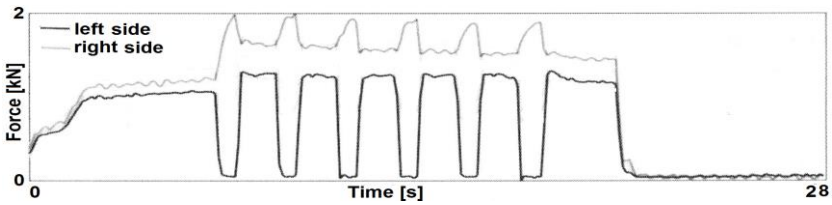


Fig. 8. The course of the braking force of the front left wheel after closing the intake valve and opening the outlet valve. Mitsubishi ASX.

3.2 Automatic actuation of the ABS/ESP valves

After starting the roller stand and opening the test program in the "Activation" mode, the diagnostician presses the brake pedal and starts the program. The program automatically performs the test by automatically executing the valve control sequence: closes the intake valve, opens the outlet and activates the ABS pump, fig. 9a). This cycle is repeated four times. Then the valves of the subsequent wheels are inspected, Fig. 9 b), c), d). The test allows to assess the rate of decline and the increase of braking force on the tested wheel and the repeatability of these actions.

a)



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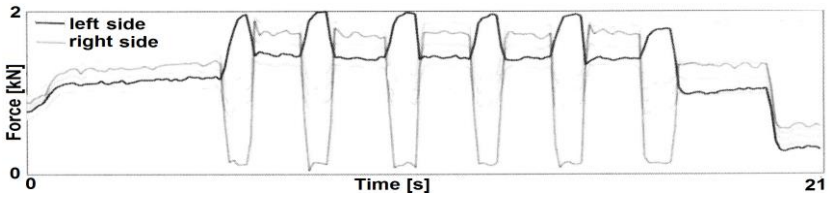

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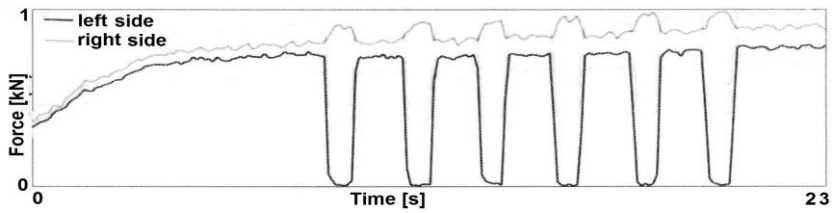

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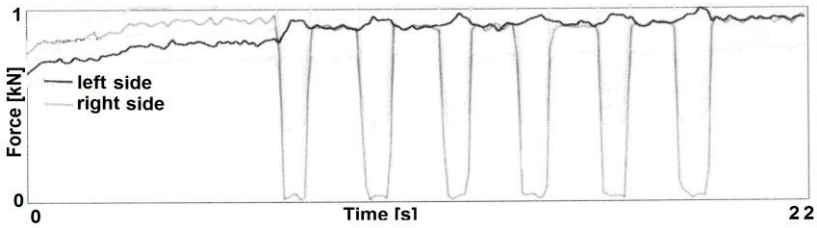


Fig. 9. Results of the ABS/ ESP pump and valves control. Automatic valve operation, a) front left wheel, b) front right wheel, c) rear left wheel, d) rear right wheel. Renault Scenic car.

The above algorithms allow to check the In the ABS / ESP diagnostic software of the Renault Talisman car there is an automatic control mode of ABS inlet and outlet valves for use on a roller stand, fig. 10. The ESP valves test works by activating the ABS pump and observing a dynamic increase in braking force to block the wheels, fig. 10.

The automatic valve actuation program allows to shorten the time of diagnosing the valves of ABS/ESP modulator on the roller stand to a few minutes. It is simple to implement for the

diagnostician and can be used in periodic technical tests. The adoption of one diagnostic algorithm (automated) for different vehicle makes the diagnostic work easier during periodic technical tests.

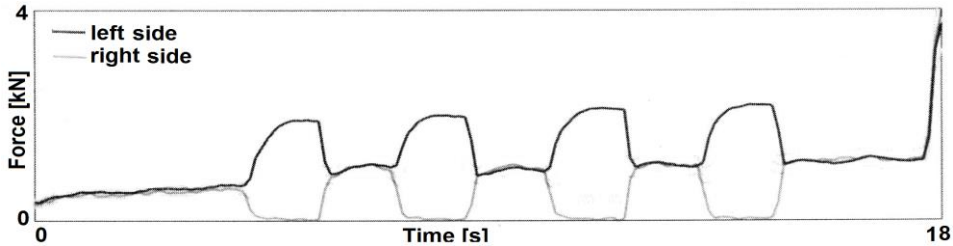


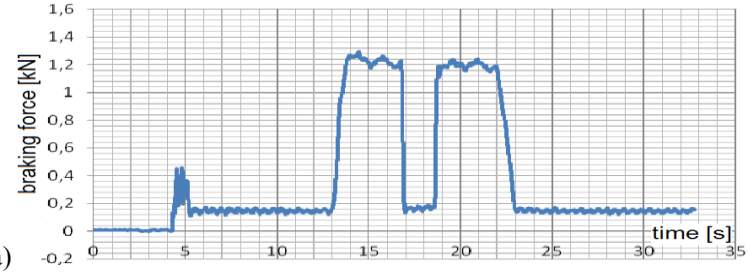
Fig. 10. The result of testing the inlet and outlet valves ABS of the right front wheel and the operation of the ESP valves. Renault Talisman.

4 Study of ABS / ESP valves actuation times and analysis of results

The method of testing the operation of the modulator of the ABS and ESP system on the roller stand allows to evaluate the response of the system in the form of changes of braking forces to forced activation of valves and ABS pump. Because on a low-speed roller stand with a circumferential speed of rollers up to about 5 km / h, the ABS system does not start itself, it is necessary to force its operation with an electric signal sent from the diagnostic tester to the valve controller.

Diagnosing the ABS / ESP system at the roller stand by measuring and recording the braking forces allows the evaluation of this system in the following scope:
- control of the operation of individual valves and ABS pump,
- checking the correct connection of hydraulic pipes to the ABS / ESP modulator
- assessment of the tightness of the valves based on the evaluation of the stability of the braking forces at a fixed pressure on the brake pedal.
- assessment of the rate of rise and decrease of braking forces when using ABS / ESP valves.

Investigations of the rate of change of braking forces, measured at the roller stand, under the action of ABS valves showed differentiation between braking systems of different manufacturers. The change of braking forces by about 1 kN took place in the time 0.1 - 0.2 s, Fig. 11. For the ESP system, the time of force increase by 1 kN was about 0.1 s, Fig. 12. Based on the performed tests of the ABS/ESP modulators and controllers, it can be concluded that for efficient ABS systems the rise time and deceleration of the braking force under the electromagnetic valve operation should be 5 - 10 kN / s, and for the ESP valves approximately 10 kN / s.

a)


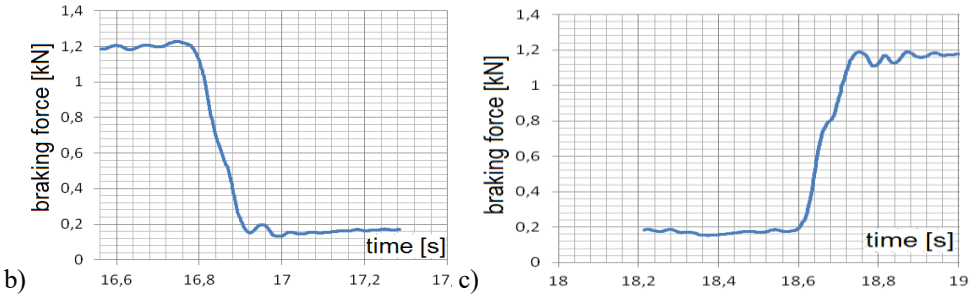


Fig. 11. a) The course of braking force of the right front wheel when the ABS valves are activated, decreasing b) decreasing c) increase of the braking force of the front right wheel when the ABS valves are activated. Honda

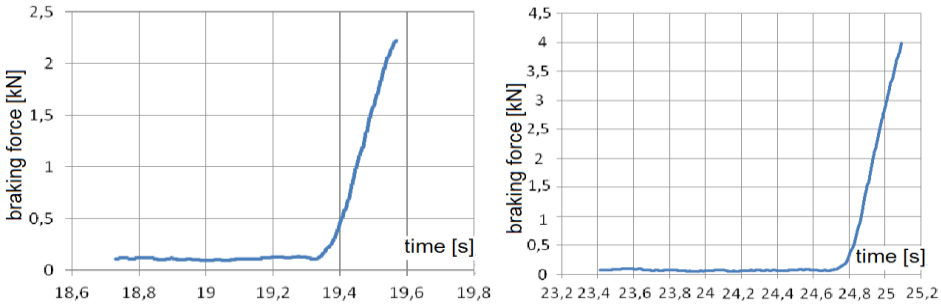


Fig. 12. a) The course of the braking force after the pump and ESP valves are activated

Studies of ABS / ESP systems from different manufacturers showed different diagnostic software. It can be listed the following types of this software:
- individual actuation of valves in turn for individual car wheels,
- simultaneous start of valves for wheels of the tested axis,
- automatic procedure for starting valves with repetitions,
- control of ESP valves operation with increasing pressure pulses
- control of ESP valves operation by a high pressure impulse that causes blocking wheels.

For diagnostic purposes, the diagnostic tester software that automatically starts the control procedure is suitable. This makes it possible to control the system on a roller stand by one person and significantly shortens the time of this control compared to the individual actuation of the valves.

It should be noted that testers from different manufacturers have software that allows to control the ABS / ESP valves of the same vehicle to a different extent.

Diagnostic software for some ABS / ESP systems contains information on the inability to control valves on a roller stand. There is also diagnostic software to check the valves and ABS pump only in terms of electrical efficiency.

Such diversity makes it difficult to introduce this scope of diagnosis into the practice of periodic vehicle technical inspection. For these purposes, it is necessary to harmonize the control procedure.

5 Conclusions

1. The conducted research revealed a variety of diagnostics software for testing the operation of the valves and pump of the ABS / ESP system. The scope of diagnosing the ABS / ESP system on a roller stand depends not only on the ABS / ESP driver software, but also on the diagnostic program implemented to the tester. The same ABS / ESP system in a particular car can be diagnosed in a slightly different range and in a different way with the participation of testers from different manufacturers.

2. There are two approaches to checking ABS valves in the diagnostic software:
- electrical inspection,
- control by evaluating the operation of the entire braking system.

The electrical tests are not related to the mechanical control of the system. Adding the measurement of the braking forces on the roller stand to this procedure extends the scope of the ABS / ESP system evaluation. This allows detection of not only an incorrect electrical connection, but also too low dynamics of changes in braking forces caused by mechanical malfunctions.

3. The condition for using the roler stand for the evaluation of the ABS / ESP system is its software allowing to record the dynamics of the braking forces during the test and to present the test results graphically.

4. Extending the scope of tests of ABS and ESP systems during periodic vehicle inspection requires the development of unified software for vehicle control stations, so that the diagnostician has easier and uniform IT access to the ABS / ESP controllers and actuators of individual systems. A reference database is also required to evaluate the operation of the system being tested.

5. New diagnostic programs for ABS / ESP systems (in new vehicle models) should enable control of ABS / ESP valves on a roller stand in an automatic cycle. This option facilitates and speeds up the diagnosis process.

References

1. Rozporzą dzenie Min. Transportu, Budownictwa i Gospodarki Morskiej w sprawie zakresu i sposobu przeprowadzania badań technicznych pojazdów oraz wzorów dokumentów stosowanych przy tych badaniach. Dz. U. z 7.09.2012 r., Poz. 996 (2012)
2. Directive 2015/45/EU of the European Parliament and of the Counsil of 3 April 2014 on periodic roadworthinees tests for motor vehicles and their trailers and repealing directive 2009/40/EC (2009)
3. Raport CITA: Study on a new performance test for electronic safety components at roadworthiness tests – Final Report, 2014, Summary 2006.
4. Chr. Theis, *Test methods and data for the PTI of ECSS and their international provision Federal ministry of transport and digital infrastructure, Germany.* (CITA Conference – Dubai , 2015)
5. Periodic Technical Inspection with the PTI Adapter 21 Plus. FSD Germany - 2015
6. A. Gajek, *Directions for the development of periodic technical inspection for motor vehicles safety systems.* (The Archives of Automotive Engineering, **2** , 2018)