Real-time diagnostic complex of automated car active safety system unit

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Abstract. The article is concerned with the created variety of methods of drivegear active safety car system test. The analysis of factors of electronic control stability system test is displayed, as well as main disadvantages and test factors, characteristics and general terms. The system description is indicated, which gives opportunity to test active safety system. In the same way, it is possible to solve the problem of timely risk detection for key components, assemblies, and vehicle systems. And if in the traditional Driver-Car system an experienced driver can “feel” a possible malfunction, then an unmanned car has nothing but its own systems. In this case, it becomes obvious that on-board equipment is needed that monitors the state of the braking system and ABS in real time. As described above, the existing on-board diagnostic equipment does not provide the necessary information. The introduction of an additional diagnostic complex will allow tracking and detecting system failures. This system can be used with a "digital twin".

1. Introduction
Modern automated brake systems (ABS, ESP) belong to the group of complex electric drive systems (Fig. 1) [16]. This system of electric drive is an integral part of the brake system of a modern car. However, the efficient use of any electric drive system in operation is possible only if the methods for monitoring their technical condition are successfully implemented [1,2]. Otherwise (especially with regard to the use of automatic systems), it may result in a much more dangerous situation (caused by the incorrect operation of the actuators). In this case, by deflecting the working processes of a vehicle's brake system it is possible to detect the malfunction of the drive system at the early stages.

2. Main part
To control the state of automated brake system (ABS, ESP) manufacturers use a self-monitoring system, which is aimed at checking the integrity of electrical circuits and signal strength [10,11]. Once the modulator or sensor supply circuit breaks, it immediately turns off the automated brake system (ABS, ESP) and alerts the driver. Obviously, this system does not discover all the possible failures of its elements. The following can be added to that taken into account: changing the section of the channels of the modulator due to their clogging, jamming of the modulator valves, delay in the actuation of the valves, angular compliance of the ABS stator sensor, increased contact resistance, faults in the control unit automated brake system (ABS, ESP) blocks.
The system does not account for the state of the vehicle's service braking system either. Irreversible changes occurring with the brake system drive, such as wear of the brake pad linings, wear of the brake disc / drum, aging of the brake fluid (caused by the accumulation of rubber micro particles from wear of the piston cuffs of workers and the main brake cylinders, rust particles, moisture absorption from the air) etc., have inevitable negative effect on the efficiency of the vehicle braking system. In this case, the correct operation of the ABS is maintained, but the braking efficiency drops all the way to the system failure. It is important that with such malfunctions, the automated brake system (ABS, ESP) self-diagnosis system does not provide a failure signal.

When analyzing the self-diagnostics of the automated brake system (ABS, ESP) unit, it can be concluded that only a small list of system defects is currently available. The fault codes of the vehicle automated brake system (ABS, ESP) block can be divided into several groups:

1. Electrical networks control;
2. Monitoring communication with the units via the CAN bus;
3. Verification of incoming signal data and control of the control unit;
4. Brake system monitoring.

The most important groups shall be further considered in detail.

The failure codes of the first group are the control of electrical circuits occurring as the control unit of the automated brake system (ABS, ESP) detects voltage changes of the signals from each wheel speed sensor. If a circuit breaks or a short circuit is detected, the automated brake system (ABS, ESP) control unit saves the diagnostic code. It may be caused by damaged wiring harness or connectors, noise interference, wheel speed sensor malfunction, ABS-ECU malfunction.

Codes of failures C104B-C105B are of the same type and are responsible for the hydraulic block ABS valves. The cause of the failure codes is the ABS-ECU fault. These diagnostic codes are issued if the solenoid valve does not supply power, even if the ABS electronic unit has turned on the transistor or after the ABS computer turns off the transistor, the solenoid valve still receives power, and if a solenoid valve is detected [3].

The remaining codes of the electric circuits control group are also directed at the detection of defects in electrical circuits of the anti-lock system elements and connecting wires, as well as control of too high or low voltage in the vehicle's on-board network.

When monitoring communication with the units on the CAN bus, the codes are responsible for the communication between the units. Checks are in the procedure for searching for electrical faults on CAN bus wires, measuring the resistance of end-of-line resistors and estimating the traffic load of computer networks over medium voltage.

When the vehicle is moving, the ABS control unit monitors the signals from each wheel speed sensor. If the signal from these sensors shows a random change in the signal or the value of the signal,
the corresponding diagnostic code is recorded very high all the time and the control lamp on the instrument panel lights up.

During the operation of the system, the ABS-ECU continuously monitors its performance parameters. If any deviations are found, the code is output. The diagnosis is reduced to the CAN bus check. If there are no faults, the ABS unit must be replaced. From the practice of diagnostics, it is known that this code occurs when the ABS control unit is not correctly reprogrammed or interrupted. This brings up a conclusion that in this case the unit monitors the checksums of its software.

The fault may be caused by damage to the wiring harness or connectors, external noise interference, wheel speed sensor malfunction, ABS-ECU malfunction, too large a distance between the wheel speed sensor and the master dial, sticking of foreign materials to the wheel speed sensor and/or drive dial, malfunction wheel bearing, improper installation of the wheel speed sensor, deformation of the drive disk, violation of the magnetization pattern of the master disk, dyeing of the teeth of the master disk. A probable cause of the DTC is the brake fluid pressure remaining high or low for a long time. Since the automated braking system does not have the necessary set of pressure sensors, it is calculated based on the readings of wheel speed sensors. Accordingly, wheel speed sensors will require a diagnostic procedure as well. Checking for this group of codes is not much different from checking for other faults in the speed sensors.

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Code C1395 is responsible for the supply of brake fluid to the hydraulic system of the ABS. The cause of the fault code is an improper hydraulic system unit and a fault in the ABS control unit. The verification procedure for this code includes only two items - the CAN bus check (as mandatory for all codes) and the reset of the DTC. If the error re-appears, replace the ABS assembly.

The analysis of the list of failure codes of the on-board diagnostics system shows that the possible causes of the malfunction, such as noise interference, are not checked in any way. That means the electronic control unit can detect an interference, but there is no verification procedure. This leads to the fact that the search for the faulty element will fail, or indicate a working node, clearly following the diagnostic procedure. The braking system or hydraulic system health are not checked at any stage. This causes erroneous replacements and repairs.

The system overlooks a number of malfunctions, such as the adherence of ferromagnetic dust to the sensor or the master rotor, the clogging of the brake pipes, the change in the cross-section of the channels, the hanging of the ABS hydraulic valves, permanent interference (for example, due to installed optional equipment), erroneous data and commands in the CAN network, internal failures of the ABS control unit, damage to the printed circuit board of the ABS control unit, etc. Complex faults, meaning the joint impact of two or more faults, are not covered either. Such cases are the most complex, because their joint impact can mislead the self-diagnosis system.

The analysis of the existing diagnostic methods shows that their overwhelming majority are aimed at monitoring wheel speed sensors and a computer CAN bus. Even though the system can track deviations in pressure, lack of brake fluid, monitor the reliability of incoming parameters and the integrity of electrical circuits, the diagnosis is quite primitive and reduces to checking electrical circuits.

It is also worth considering that the electric brake system is an integral part of the brake system of the car. In this case, by deflecting the working processes of the vehicle's brake system, it is possible to determine the malfunction of the drive system at the early stages.

The presence of any deviations in the operation of the system, requires testing the executive mechanisms of the automotive brake system of the car. If left unattended, the slightest changes in the operation of the system can cause a system failure in the future.

In this case, there is an obvious need for the on-board equipment that monitors the state of the braking system and ABS in real time. As described above, the existing on-board diagnostic equipment does not provide the necessary information. The introduction of an additional diagnostic complex will allow tracking and detecting system failures [5,12,13].
To perform all the necessary functions, the following blocks should be implemented:

- The array of diagnostic sensors;
- Data analysis unit.

The array of sensors allows capturing the parameters of the vehicle motion in braking mode, including the initial speed, deceleration, rotation of the car relative to the vertical axis, rotation of the vehicle relative to the transverse and longitudinal axis, braking distance, wheel lock. Obviously, the vehicle braking mode depends on the physical parameters of the driver and the mode of braking and the control of the trajectory that is being implemented, including the brake pedal force, the braking intensity, the steering wheel position during braking (angle of rotation), the braking time, the gearshift lever position (for the manual gearshift) position of the clutch pedal. The braking mode also depends on the environmental parameters, such as temperature, road surface type, weather conditions, time of day.

An adaptable plug-in diagnostic unit receives data on the work processes of the brake system components of the car and ABS in real time.

The data obtained by diagnostic sensors are analyzed by a microcomputer (diagnostic unit). In order for the diagnostic system to be scalable, the role of the diagnostic unit is performed by the Rospberry Pi 3 microcomputer. The sensors are connected via the integrated PLD-40 interface (GPIO, UART, I2C, SPI). This interface allows connecting various status sensors. The Raspberry Pi 3 operating system has the necessary software to process and analyze the signals coming to the PLD-40, as well as to arrange the signal analysis algorithm in the original software product created by the authors of the article with a custom graphical shell.

To test and debug the diagnostic complex, as well as study the regularities of work processes in the drive of the automotive brake system of the car, a full-size model of the automotive brake system of the car is used.
The model works to simulate the working processes of the drive of the car's automated brake system [6,7,8].

![Assembled diagnostic unit](image1)

**Figure 4.** Assembled diagnostic unit.

![Graphical interface](image2)

**Figure 5.** Graphical interface.

The unit is connected to the computer via a cable for relay control signals transmission, and with the ABS device using electric wires soldered to the solenoid terminals and the electric motor. To operate the solenoid, the computer sends a control signal to the relay, which activates the internal diode and allows supplying power to the controlled solenoid [9,11].

Direct control of solenoids and emulation of signals of wheel speed sensors allow simulating any modes of operation of the brake system.

Using a full-size model rather than a car makes it possible to simulate various malfunctions of the automated braking system and to study the corresponding deviations in the work processes without any risk to the driver / operator safety [4,14,15].

![Connection to the ABS solenoids](image3)

**Figure 6.** Connection to the ABS solenoids.

![Solenoid ABS](image4)

**Figure 7.** Solenoid ABS.

Thus, for example, consider the effect of an increase in the delay time of the operation of the modulator valves on the process of braking the wheel. The studies were carried out in the range of the time lag of 0.03 - 0.09 s. They showed that the manifestation of this malfunction is more pronounced when braking on a surface with average values of the coefficient of adhesion, for example, wet asphalt, from high initial speeds in the loaded condition of the vehicle. This circumstance is caused by the fact that under the given conditions, during the braking time, the greatest number of cycles of regulation of the ABS operation takes place, which makes it possible to more clearly trace the nature of the manifestation of the above-mentioned malfunction.
Figure 8. The change in the duration of the phases of the ABS operation when braking on wet asphalt concrete as a result of an increase in the delay time of the operation of the modulator valve.

As follows from the comparison of the physical parameters of the dynamic processes of braking the vehicle wheel on wet asphalt concrete with an increase in the delay time for the operation of the modulator valve to 0.05 s and 0.09 s, respectively, with the initial braking rate $V_0 = 19.4 \text{ m/s (70 km/h)}$, with an increase in the delay time of the operation of the modulator valve, the time spent by the wheel in the state of the jib increases, and is unstable, especially in the middle part of the braking process, during a period of 1.5 to 3 s.

This phenomenon has a proven negative effect on the stability of the vehicle. In addition, with an insignificant increase in the delay time of the valve operation, the ABS transition is observed in some cycles for two-phase regulation, since a further increase in the delay time of the valve operation leads to instability of the "cut-off" phase. At the same time, when assessing the duration of the main phases of ABS operation, it was noted that a decrease in the efficiency of regulation is also a consequence of a significant increase (from 0.47 s to 1.42 s) in the inhibition phase and a less significant but clearly pronounced increase in time before ABS enters into operation.

To develop recommendations on the choice of diagnostic signs for increasing the delay time for the operation of the modulator valve, the authors consider the change in the average realized values of the main parameters when braking on wet asphalt (Fig. 9). As the graphs show, in all the considered range of the increase in the delay time of the operation of the modulator valve, the average realized coefficient of adhesion of the wheel with the road surface decreases (to 4.9%).

Figure 9. Modification of the average realistic values of the main parameters during braking on wet asphalt concrete as a result of an increase in the delay time of the operation of the modulator valve.
This confirms the negative impact of the analyzed fault on the performance of an ABS. It should be noted that the values of the remaining average parameters in the entire considered range exceed their initial value corresponding to the modulator's condition. However, as a diagnostic indication of an increase in the delay time of the operation of the modulator valve, an increase in the amplitude of the angular deceleration of the wheel should be used, since its variation over the entire range occurs practically along a linear relationship, which will positively influence the accuracy of the diagnosis. In addition, this parameter meets the requirements of both informativeness and sensitivity, since its increment reaches 44.5%.

Depending on the given initial conditions of braking, with the help of a microcomputer, it is possible to distinguish between braking modes (emergency braking, service braking, partial braking, total braking, braking by the engine, braking with a spare braking system) and memorizing the operating parameters of the braking system and the car's ABS.

These data are sorted and stored in the ROM of the microcomputer, taking into account the simulated braking mode. An example of data on the pressure in the brake drive, fixed on four wheels, is shown in the figure below.

![Figure 10. Pressure in the brake drive.](image)

The data obtained during the braking process are recorded, and compared with data obtained under similar conditions and recorded in the ROM earlier. If there is a significant deviation, the microcomputer gives the operator information that the electric drive system is faulty. At the same time, based on the received data, the system makes a conclusion about possible malfunctions.

In the event that the microcomputer detects a malfunction, the collected data on the performance of the brake system and ABS can be useful in repairing and will make it possible to initially track the deviation of the operating parameters and prevent the failure of any element.

3. Conclusions

The diagnostic complex, based on the slightest deviations of the working processes of the automotive brake system of the car, allows determining the malfunction at the initial stage.

An important difference from the existing diagnostic systems is the possibility of establishing the exact fault in the element of the automotive brake system of the car, as well as determining the cause of the fault. The efficiency of the diagnostic process is increased, which leads to a reduction in the possibility of a repeated failure.

The use of the diagnostic system in conjunction with the chassis stand model, allows adapting of the system, if changes are made to the design of the automotive brake system of the car by the manufacturer.

Equipping with such a system will allow real-time monitoring of the technical condition, in particular of an automated brake system. The data obtained are compared with the reference "digital double" of the car. That is, the program itself analyzes whether all units and components behave...
normally, based on the year of release, mileage and working conditions of the vehicle. If there are deviations from the "digital" norm, the "smart" system gives a warning signal that prevention is needed. For example, replacing brake pads.

Note that this norm (that is, a digital model of car wear) is taken on the basis of tests, both full-scale and using virtual physical modeling technologies. After that, the mathematical laws of the digital double are specified. Thanks to the new system, the estimated service life of the car can be extended up to 20-25 percent. And the costs of maintenance and repair can be reduced by almost half - by 40-45 percent.

Such a system for monitoring the technical condition is certainly applicable to all types of vehicles. But it will bring the greatest economic effect for enterprises, both in freight traffic and in passenger traffic. Ideally, this should work like this: an analysis of the technical condition of a particular machine in real time is transmitted to a single control system. This allows the company to quickly respond to identified risks, adjust the operating mode of cars, check the availability of necessary components in the warehouse, and pre-order them if necessary. Then it is possible to find a window in the transportation cycle, form an application for targeted and timely service. At the same time, repair specialists will not need a complete assembly-disassembly in order to find a specific failure: the vulnerable node will be known in advance.

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