Methods of monitoring the technical condition of the braking system of an autonomous vehicle during operation

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Abstract. Possibilities of diagnosing of a technical condition of braking system of the autonomous vehicles with automated modules while in service are considered. The concept of sharing of onboard means and stands for diagnosing is presented.

1. Introduction

The braking system is an integral part of autonomous vehicles. It is the units of the braking system (in addition powertrain) which are the most important in the implementation of the algorithms for the operation of autonomous vehicles. It is obvious that a lot depends on quality control of its technical condition. Saturation of autonomous vehicles with automation means certainly contributes to increased autonomy and traffic safety. In the process of operation, the operating parameters of these systems deviate from the nominal ones, as a result of wearing out and other factors [5, 6, 7]. It is known to be effective to use any systems in operation only if the methods of monitoring of their technical condition are successfully implemented. Especially this applies to the use of automated systems, because otherwise you can get an even more dangerous situation than without it. However control of the technical condition of the braking system' in an automated autonomous vehicles (even automatic systems) is not always suitable. What are the "pitfalls" in the implementation of the existing problem? They are as follows:

2. Problem

First of all, this is the absence on autonomous vehicles with automated and automatic systems of traditional signs of serviceability. When the vehicle is stopping traces left on the surface of asphalt by braked wheels is one of the signs. These traces make it possible to judge in the first approximation the efficiency of the brake drive and, first of all, whether the braking torque developed at the wheels of the car reaches the maximum possible moment of adhesion in these road conditions. At the same time, the wheel wear on dry asphalt concrete indirectly indicates sufficient braking power, which follows from the dependence shown below

$$M_{br} \geq R_z r_d \varphi (S_x) \tag{1}$$

M_{br} – braking torque on the wheel, R_z - normal load, r_d - dynamic radius of the wheel, $\varphi (S_x)$ – coefficient of adhesion to the road.

By these tracks one can indirectly deduce another important indicator - the unevenness of the work of the braking mechanisms, which arises for various operational reasons. The non-simultaneous occurrence of traces of noise is the motive for getting the vehicle bench tested.

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In the presence of automated elements in the braking system of the autonomous vehicles, the situation changes radically. The absence of tracks on the surface of the road can be regarded in two ways. On the one hand, this may indicate the effective operation of the system and, on the other hand, the inadequate efficiency of the functioning of the elements of the brake drive and its inability to provide in principle the magnitude of the maximum coupling torque (see the formula). The latter facilitates the braking of the wheel in the subcritical region of the φ (S_x) diagram. But in the first case, not everything is so unambiguous. The situation is also complicated by the fact that during the operation of the vehicle, the stand inspection of the technical condition is carried out periodically at the next maintenance through a certain mileage or once a year with the TRP. However, it is known that the sudden failure of the elements of the braking system of the autonomous vehicles, especially automated, entails the aggravation of the severity of the consequences. So, according to the evidence of the traffic police of European countries, the sudden failure of the automated system led to more serious consequences from the road accident.

3. Solutions

It is known that manufacturers equip their products with a self-monitoring system aimed at checking the integrity of electrical circuits and the signal level. Thus, opening of the supply circuit of the modulator or sensor will immediately turn off the units and modules of the system. Obviously, this approach does not exclude all possible failures of its elements. So, you can add a change in the cross-section of the modulator channels due to their clogging and delay when the valves operate, an increase in the angular compliance of the stator of the wheel sensor due to weakening of its fastening, etc. Such faults do not control the self-diagnosis system and do not give a signal of failure.

Therefore, there is an urgent need to improve on-board diagnostics of the technical state of the elements of the braking system, capable of obtaining objective information for the driver about the quality of the work process and the condition of the braking system as a whole during the intercontrolled operation period. In our opinion, during the first stage the diagnosis should be carried out by on-board diagnostics and based primarily on the parameters of efficiency, i.e. give a general "integral" assessment, thereby, making up for the driver lack of objective visual criteria. Consequently, the basis of such on-board diagnostics should be realized braking dynamism and its correspondence to the set value. At the same time, it is advisable to further improve on-board diagnostics of the braking system of autonomous vehicles in the direction of improving the quality of control based on the developed structural and investigative schemes. However, in doing so, it is necessary to remember the inherent operation of the autonomous vehicles, a significant variation in the characteristics of external conditions and, first of all, the fluctuation of the coefficient of adhesion in both the longitudinal and transverse directions.

As is known, it is possible to obtain information about the current state of the braking system of autonomous vehicles in two ways: airborne control and by means of bench diagnostics. When solving the task, each of them has its own pros and cons. Improving airborne diagnostic tools is certainly appealing, since it is possible to obtain information in the on-line mode, i.e. in the intercontrol period. However, in this case, the autonomous vehicles design requires the introduction of a number of additional sensors (working medium pressure sensors in service brake cylinders, brake pad wear sensors, deceleration sensors, etc.), and an additional diagnostic unit for recording and processing current information. The situation is further complicated by the fact that the fluctuation of the coefficient of adhesion does not allow unambiguously to set the standard normal values of the signals of all additional sensors. This will require an analysis based on the statistical data obtained in the series of inhibitions.

4. "Advantages and disadvantages" of stand diagnostics

In bench diagnostics, the phenomenon of fluctuations in the coefficient of adhesion along the way is reduced to a minimum, and control over the technical state of the elements of the braking system is carried out in fixed and therefore completely reproducible conditions, which is an undoubted "plus".

All the existing stands, which can diagnose the braking system of the autonomous vehicles, can be divided into two large groups: roller power and drum-type inertial. Stands of the area type are omitted from consideration due to the need to provide relatively high speeds if there are automated modules on the autonomous vehicles.

When assessing the quality of functioning of an automated braking system in laboratory conditions on inertial stands, an important condition is the maximum possible reconstruction of the actual conditions of interaction of the tire with the road surface. The latter is achieved, on the one hand, due to the adequate normal distribution of the normal loads in the contact spot of the tire, and on the other hand, the reconstruction of the law of variation of the coefficient of adhesion from slippage. The first condition determines at least a one and a half to twofold ratio of the diameters of the running drum and the wheel of the autonomous vehicles, and the second is the need to introduce a cleaning system for the drum in the contact spot from the tire wear products, for example, by applying and then removing the kaolin powder from the spot. All that has been said above significantly complicates the construction and increases the dimensions of the inertial-type stand, transforming it into a research category. This excludes their mass application in the dialer stations and in the Transport Company's.

In the wide-spread roller power braking stand on rollers, longitudinal riffling is applied to eliminate slippage of the tire, which practically excludes the possibility of reproducing the tires close to real road conditions. However, this function is not required in the power stand, since the main task is to assess the maximum possible realization of the braking torques on the wheels and the difference in braking forces for compliance with permissible standards. Therefore, this design does not allow diagnosing an automated system. Rollers virtually eliminate the possibility of wheel slippage.

Let's try to turn the noted disadvantage into an advantage, eliminating the unstable link "wheel-rollers", which can be achieved by introducing special simulators or electronic control circuits to the moment of resistance of the brake rollers. The way out of this situation can by means of diagnosis using the simulation of movement and brakes of the autonomous vehicles. In the first way, the system can be triggered on the stand by two methods: by using a special mode dialer that simulates the signals of the wheel speed sensor or software loaded into the control unit, which imitates signals at the program level in the diagnostic mode.

5. Diagnostic method

At the first approach, several well-known autonomous vehicles of the same brand, model and model year are stripped of the main characteristics of the wheel speed sensor of each wheel, as well as from the vehicle speed sensor to determine the average values. The signals with the received characteristics are supplied to the input of the system control unit with the aid of a master. In this case, a pulse generator capable of providing emulation of the signals from the wheel rotation sensors and the vehicle speed sensor can be used as the setpoint generator. The generator is controlled dynamically from a personal computer, so it can work according to a predetermined law.

The procedure for checking the effectiveness of the system is as follows. The four wheel speed sensors and the vehicle speed sensor are disconnected, and the outputs from the driver are connected in their place, after which the autonomous vehicles is mounted on the roller power stand. When the wheels rotate, the driver presses down on the brake pedal with the required force. At the same time, the operator activates the wheel rotation condition sensor, which generates signals in accordance with the previously obtained characteristic, thereby imitating the periodic occurrence of each of the wheels. The conclusion about the technical condition of the braking system of the autonomous vehicles is carried out on the basis of the analysis of the oscillogram by the method of "comparing the states" of the tested vehicle and taken for a standard of a known serviceable autonomous vehicles.

The second approach is aimed at simulating the movement of the autonomous vehicles "inside the control unit". The program code of the control unit incorporates an additional special program responsible for diagnosing the system on a power roller stand. The test procedure is similar to the first case, except for the connection of the diagnostic equipment to the OBD-II connector.

The second approach is more promising, since the main drawback of the method using an external signal setter [2, 3, 4] is the connection of additional cables, which takes some time, since the control unit on some autonomous vehicles can be located in hard-to-reach places. So, for example, on a Volvo

V40 CC model in 2014, the battery must be removed before access to the ABS unit and it is advisable to take into account the need for access to the control unit during the development stage [1]. The figure shows, as an example, the appearance of the assembled signal emulator board [8, 9, 10].

The software method is more preferable, because it is more technological. In this case, there is no need to interfere with the electric circuit of the autonomous vehicles and, therefore, the testing time is shortened, which allows increasing the efficiency of the brake stand, reducing training costs for the operator and reducing the probability of error. It must be remembered that only the manufacturer is entitled to interfere with the software of the automated module unit.

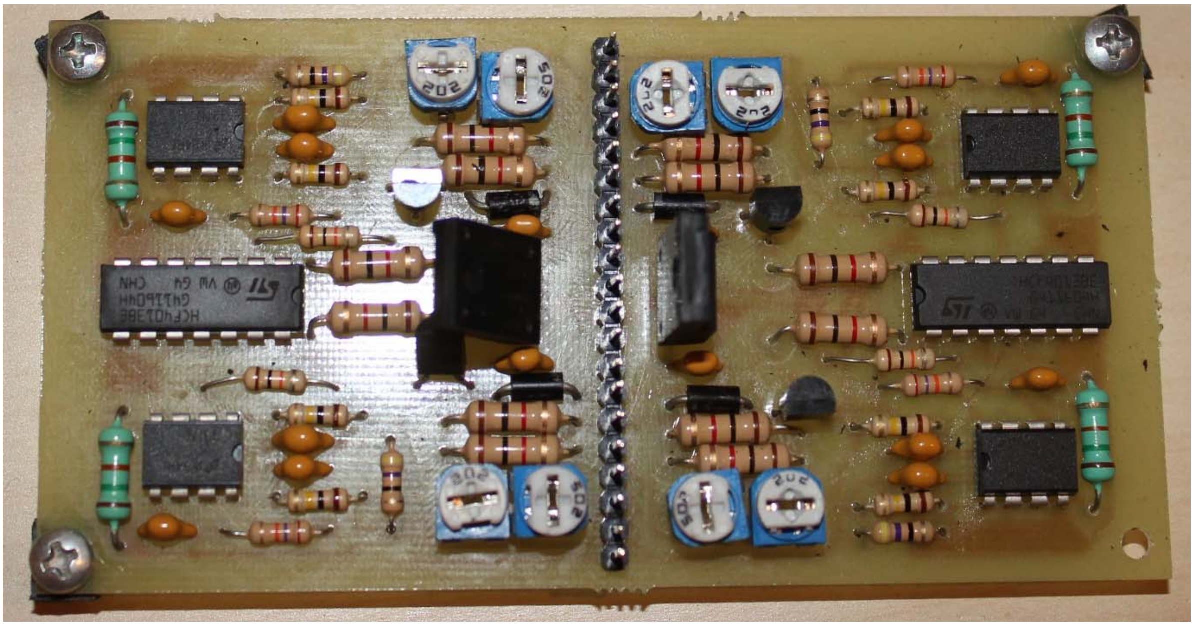

Figure 1. Appearance of the assembled emulator board.

Therefore, for the application of the software method, it is necessary to develop a basic universal algorithm for the operation of the diagnostic program, which can be embedded in the code of the ABS control unit with minimum costs, i.e. it is necessary to work together with the specialists of the system manufacturer. If we consider the workshop or the official dealer center as an organization specializing in certain brands of autonomous vehicles, then the manufacturer of ABS should be interested in improving the quality of service.

6. Conclusions

Taking into account the features of the functioning of the braking system of autonomous vehicles with automated diagnostic elements, it should be carried out on a complex basis, including both on-board diagnostics during the intercontrol period and on the most common power roller stand provided with the mode dial.

Further development of on-board diagnostic tools for autonomous vehicles with automated modules should be carried out on the basis of developing new diagnostic methods, using for this multi-level structural and investigation schemes, primarily focused on performance parameters.

Advanced element-wise diagnostics should be carried out in bench conditions, with the maximum possible exception of random factors affecting the process, which is possible with the use of widely used bench equipment with a relatively small cost and overall dimensions, for example, power roller stands, with appropriate modification.

It is advisable to refine the power roller stands in the direction of creating special mode controllers that allow using the standard equipment of the stand to estimate the delay time of the modulator

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operation, the rate of change of the brake moments, the thresholds for setting up the logical unit of the systems, and so on. A perspective direction can be considered the inclusion of a self-diagnostic module in the control unit, with recorded test modes for testing on power roller stands.

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