MATEC Web of Conferences **334**, 01037 (2021) https://doi.org/10.1051/matecconf/202133401037
ITMTS 2020

Development of on-board Diagnostic Systems for Vehicles to Improve their Reliability

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Abstract. The article is dedicated to various questions of control and diagnostics of automobile technical conditions by applying on-board diagnostic system. The structure of automated diagnostic system was analyzed. Various types of sensors, signals and required types of their transfigurations were enlisted . The relationship between the structural and diagnostic parameters of the car is given, where all systems and car units are divided into groups. The first group consists of systems, units and machine parts that provide traffic safety, the second group contains the remaining functional systems. A structural and investigation scheme for diagnosing automobile's brake gear with an air pressure brake system was developed.

1 Introduction

The maintenance systems and car services are being updated by implementing modern methods and diagnostic tools of the technical conditions and computer methods of information processing and analyzes. At the operational stage data on failures of the machine parts, units and car systems is recorded. This information is transferred to the developers in order to eliminate the causes of failures and clarify the initial data for assessing the reliability [1,2,3]. In addition, the most significant problem is the control and diagnosis of car`s technical conditions.

Various computer devices are successfully used in almost all technically complex products to simplify interaction with the user, the implementation of complex operating procedures, etc. Meaning that technical products in the transport industry sectors like automobile, railway, maritime and others are no exception. Modern vehicles are equipped with different electronic devices, including those combined in a single complex, so called on-board diagnostic systems. (*On-Board Diagnostic (OBD) systems*) [4].

2 Materials and methods. On-board diagnostic systems (OBDS) as means of preventing sudden failures

OBDS is a kind of automated control system (a man-machine system) set up to automate the working processes of control, diagnostics, acquisition, processing and display of data on

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vehicles. OBDS facilitates the management and simplifies the operation of complex systems. Most often, OBDS is a distributed computer network designed for severe operating conditions (wide temperature range, vibration, bumps and other external actions) which combines the central electronic control unit and peripheral controllers of various car systems [5,6,7]: ICE, ABS / TCS, gearbox control, the climate control in the car and the pre-heater, the inflating of the wheels [7,8], etc. As communication environment to transfer data to the OBDS, CAN [9] is widely used as a differential twisted pair. This is due to the actual dominance of the current standard of the industrial network in automotive engineering [10]. The CAN advantages are the maturity of the standard, wide possibilities for data transfer, advanced hardware support, including the error handling, high reliability, support in real-time mode, focus on distributed control systems [11].

The development of on-board equipment of motor vehicles is progressing in two ways: further improvement of current processes, as well as the development and creation of completely new electric, electronic and autotronic devices [12,13].

The level of development of modern microelectronics, the possibilities of the hardware components base allow to exercise control of complex systems in real time. To various extends the on-board data management systems (ODMS) can acquire the direct control of all the systems in the car. This provides the possibility to automate control over complex motor vehicles, to shift the operational and diagnostic control of systems` status to the ODMS and to provide an opportunity to concentrate directly on the driving process for the driver. Such reconfiguration of functions between the ODMS and the driver, that shifts the information load of control over the car condition and its functionality from driver, thereby increases safety. At the same time, the accuracy of automatic control of car units and motor vehicles increases, which has a favorable effect on its energy efficiency and increases the resource by reducing accidental maximum loads. On the other hand, this expansion of the ODMS functionality requires higher demand on its reliability, since it is necessary to ensure the operation of the all systems by duplicating them in the case of failures of the ODMS to maintain movement and handling of motor vehicles.

Amid the improvement and increasing intellectualization of motor vehicles, on-board diagnostic systems become increasingly important, which would allow not only to determine the reason for the failure, when it had already happened, but to predict it. Such systems would make it possible to fix the systems of maintaining the motor vehicles more efficiently, which would increase both efficiency and safety of the transport system as a whole. The article authors [12] proposed the scheme presented on figure 1 in the form of a structural diagram: the concept of the development of means and methods of diagnosis, which serves to coordinate all elements of the maintenance and service systems.

The concept is based on the subject matter (car), diagnostic tools, and staff member responsible for diagnosis, all of which form a mutually interdependent system for the development of means and methods of diagnosis. The concept of the development of diagnostic means and methods is aimed at implementing strict safety concept, environmental sustainability, as well as the creation of requirements for the design development of the car and its systems (ICE, ICE operating system, electrical equipment, etc.). Motor vehicles should have high structural reliability, moreover production plant quality must be ensured, and compliance with working modes and conditions and on time car maintenance and repair must be ensured.

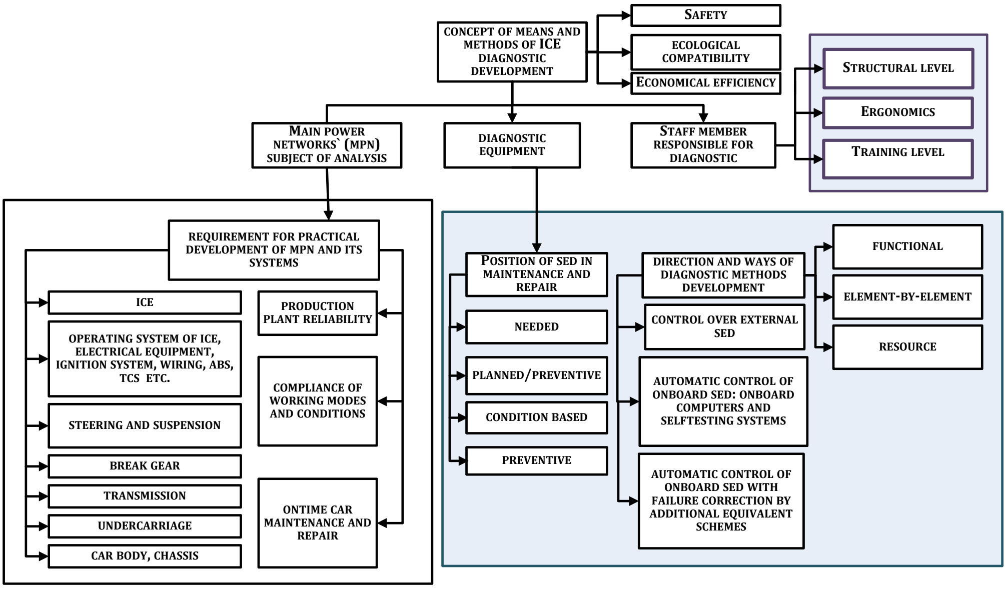

Fig. 1. Structure of means and methods of diagnostic development.

The concept forms directions and ways for development of diagnostic methods: control over fixed (external) systems of engineering diagnostics (SED); automatic control over on-board SED: on-board computers and self-diagnosis system; with the elimination of failures by using backup equivalent network. The concept forms the definition of the location of the SED in the car service system and TR system (the TO and TR strategy): needed; planned/preventive; condition-based; preventive [12]. Also the directions and ways for development of diagnostic methods predetermine the types of diagnosis with the use of a specific SED: functional, element-by-element and resource.

3 Theory: Principles of configuration of motor vehicles diagnostic systems

To monitor and diagnose systems, units and chassis systems while performing functional tasks, they are equipped with sensors and devices necessary to obtain diagnostic data and its processing for getting the analysis conclusion. Diagnostic tools are special instruments and testing devices that can be external or on-board. External devices are connected or work with controlled products only during the inspection and are not part of the product, and on-board devices are structural devices of the car and monitor it continuously or periodically according to a certain program. External means of diagnosis can be stationary (brake testing devices, for checking the wheel alignment angle, etc.) and portable (testers, fuel gas tester, smoke detector, etc.).

On-board diagnostic tools include car sensors and devices (power supply modules, computers, indicators) for analyzing diagnostic signals and continuous or sufficiently frequent detection of maintenance factors. The simplest tools of onboard diagnostics are implemented in a form of traditional instruments on the driver's panel. More complex tools of onboard diagnostics allow the driver to continuously monitor the condition of systems, machine parts` systems and units such as the braking system, steering control, decelerator, suspension, tires and wheels, lighting and alarm systems.

Automated diagnostic system (ADS) is a set of tools for automatic analysis of the car`s technical condition while performing functional tasks. The ADS should contain: a set of sensors that transfer diagnostic data from the diagnostic item; transducers that receive signals from sensors and convert them into a form convenient for further processing; data processing devices that are relevant for analysis of the received diagnostic data according to the program and for output of the final results as electronic signals; devices for data output that record the results of diagnosis on the data storage units.

The basic idea of on-board systems is observation and verification of the correspondence between the signal level and its standard stored in the memory. If the signal level exceeds allowed limits, the system treats this as a failure and feeds a special message into the memory. These messages can be recalled from memory as a "failure code", which after decoding provide important information for diagnosis. The main disadvantage of on-board diagnostic systems is its imperfection, which does not allow you to completely rely on this data. It is due to the fact that the code will not appear if the sensors or conditions are not coded for the relevant data processing: signal conditioning, filtering, linearization, analog-to-digital conversion and other types of processing.

The analysis of statistical data of the most frequently occurring malfunctions and failures should precede the development of the diagnostic procedures. Charts of the casual links are developed Based on the analysis data: the diagnosed car - the unit - the system - the mechanism - the machine parts` system - the element - the structural parameter - the failure - the external indicator (symptom) - the test results. The number of links in the chain in each specific case (with the respect to different systems and units) can vary. Each link determines the search level or the technological step aimed at finding the failure. The correlation between the structural and diagnostic parameters of the car can be diagrammed where all systems and units of motor vehicles are divided into groups (figure 2). The first group consists of systems, units and machine parts that provides traffic safety (TS), the second group contains the remaining functional systems (FS). Each group contains a certain number of n units and systems out of the total number r. The technical condition of each unit (system) is characterized by a number of $i \leq N$ diagnostic parameters, where N is the total number of diagnostic parameters describing the condition of SED and its separate units and systems. Each of the i-x diagnostic parameters depend on the values of the corresponding k-x structural parameters characterizing the condition of the object and its separate units and systems.

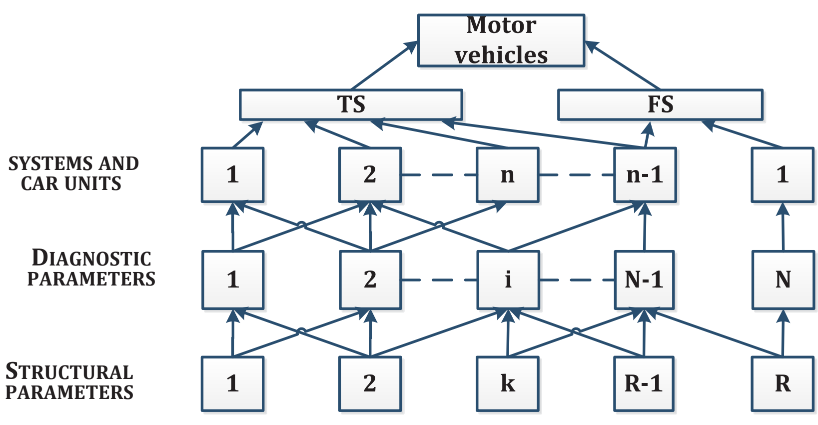

Fig. 2. The correlation of structural and diagnostic parameters.

As an example, figure 3 shows diagram for diagnosing the main failures of the brake mechanism of a car with compressed air brake system [14].

The diagnostic algorithm is constructed in a way to determine the working efficiency and isolate the failures by the selected list of parameters and the sequence of their measurements. For each particular case the depth of failure isolation is determined and it includes: replacement of the part, replacement or repair of the unit or machine parts, service work. This level is determined by operational (and economic) factors, specified reliability measures, the requirements for safety insurance of the SED crew, preserving the environmental attributes and performing the assigned tasks. The final stage is the development of basic and integrated route technologies. The task of statistical modeling is in the basis of the algorithm development. The technical condition of the SED is determined by the structural parameters, but since in most cases it is impossible to keep track on them without disassembly, diagnostic parameters are used that are the indirect values connected with structural parameters and providing sufficient data of the technical condition of the car.

The following diagnostic parameters are used in assessing the technical condition of motor vehicles: work process-related parameter; parameters of companion processes (vibration, noise, etc.); dimensions (clearances, idle clearance, backlash, axis misalignment, etc.). The choice of diagnostic parameters is determined by their correlation with structural parameters, as well as their compliance with the requirements of unambiguousness, stability, sensitivity, data capacity and functionality.

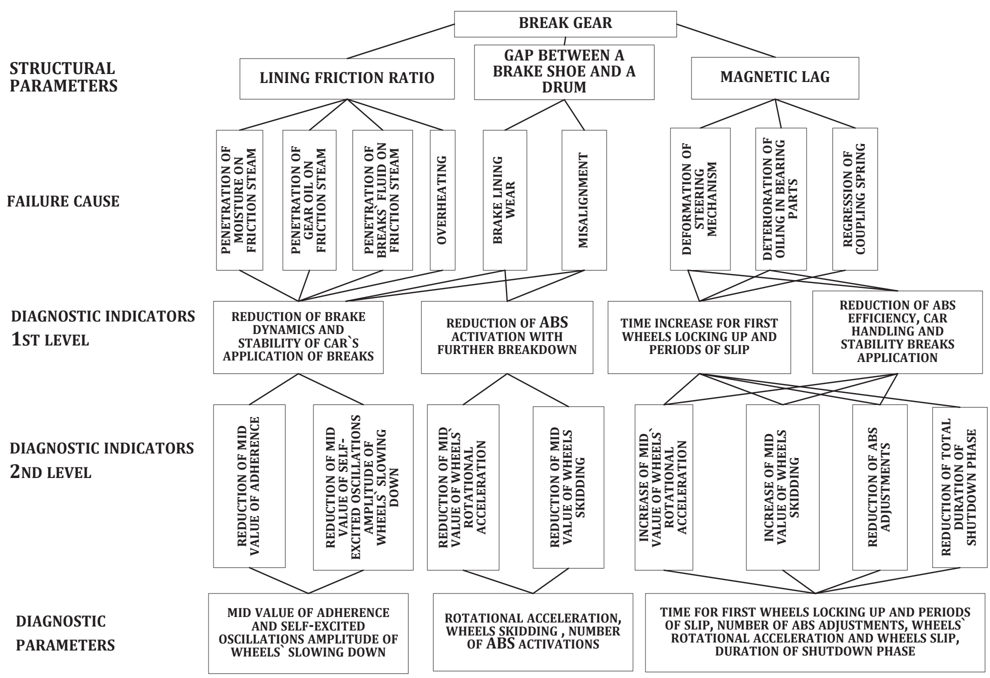

Fig. 3. Diagram for diagnosing the car`s brake mechanism with a compressed air brake system equipped with ABS.

4 Results and discussion: Improving the reliability of motor vehicles by improving the diagnostic systems

As the analysis of long-term failure statistics of KAMAZ vehicles shows, the greatest number of which is accounted for by engine, transmission, electronic devices and systems. Improvement of on-board diagnostics systems for these motor vehicles units will allow to monitor their condition and prevent premature failures, as well as adjust maintenance service conditions. Since the most common causes of engine failures are premature cranking mechanism wear, so diagnostic parameters, types and sensors` locations were determined to monitor the condition and parameters of the engine working process.

The results of the analysis of the vehicles` reliability indicate that during the long and intensive operation almost all reliability measures change significantly and, moreover, decline. It turns out that as far as the influence of operational factors for the items arise, develop and accumulate damages, which, in turn, are the causes of the origin and development of failures, i.e. items "grow old". It is possible to reduce the negative consequences of this process, ensuring the just-in-time and quality of service, repair and preventive works, and vehicle operation. It is necessary to provide estimability of the current condition and forecast for the residual life according to the analysis results.

There is a number of methods for the technical state prediction. These are statistical analysis, parameters` measurement diagnosis, the method of confidence limits, allowed level of reliability function, the partial implementation of the test parameter, technical and economic indicators taking into account reliability function of the unit. To choose a sustainable rate and level of repair and service work is possible only on the basis of a regular data collection and in-depth analysis of the current technical condition of motor vehicles units and machine parts based on the results of diagnosis.

Considering the importance of continuous monitoring of the motor vehicles, it is necessary to improve the methods and means for developing on-board information management systems, the accompanying software that implements the test cycles and status monitoring based on the work algorithms incorporated in it, which afterwards transferred to the on-board control system, identifying the links between diagnostic and structural parameters of machine parts and the establishment of functions between them.

Wear of crankshaft bearings, as well as of other oil consuming machine components, affecting the working efficiency of the most critical and highly loaded connecting rod bearings, is estimated by the oil pressure level in front of the connecting rod bearings. For dimensions` measurement, it is necessary to install a high pressure and oil temperature sensor on the tail shaft. Thermal oil sensor is proposed to use to measure the temperature and burning oil consumption in on-board diagnostic system. The oil level sensor is installed in the lower part of the engine oil pan in the range of the working oil level in the crankcase. The oil level is controlled on the move, signal with measurement values are transferred to the appropriate devices, where the calculation of the oil consumption is performed per 100 km.

As the cylinder-piston group (CPG), the crankshaft bearings, as well as other engine friction parts wear out, the resistance to cranking increases. Loss of the oil properties also contributes to an even bigger increase in resistance and wear rate. A starter current sensor can be used to control this value, since the value of the starter current allows to monitor the amount of resistance to cranking, which characterizes engine wear or coil-winding short circuit. Decrease in the starter current level is caused either by a low battery charge or by faults in the power contacts of the starting relay. Thus, the starter current is the diagnostic parameter of both the ICE and the starter system, which includes a starter and a starter battery. Wearing of the GPG, as well as the score of the CPG or the bearings of the crankshaft lead to an increase in crankcase gas pressure due to oil burning and gas bursting.

High pressure sensor is proposed for usage to estimate the consumption of crankcase gases in the onboard diagnostic system.

The general engine wear leads to a decrease in the oil supply pressure to the turbocharger (TCR). Values of pressure and air temperature in the engine induction manifold are used to monitor the condition of TCR. The diagnostic failure indicator in the TCR is a reduction in charging pressure below the standard, which is also typical for cold conditions, while the unacceptable limit for oil pressure is below 0.3 MPa. Pressure sensors [15,16] are used for measurements.

The wear of valve lifting cam by 0.5-1.8 mm leads to an increase in fuel consumption in comparison with the standard values. Since the engine power remains within prescribed limits, and the specific fuel consumption rate increases, this leads to its incomplete combustion and smoke increase, which can be monitored by a fuel consumption sensor.

A low level of cooling fluid allows to determine the presence of leaks in the cooling system. At the same time it is necessary to control temperature of the cooling fluids as well as the level of it.

5 Conclusions

Test runs of KAMAZ vehicles with installed sensors made possible to establish the dependencies of the state parameters of the machine components and units of the motor vehicles. Analysis of the obtained data has shown that this method has good perspective, since good selection of sensors and improvement of on-board diagnostic systems will allow you to determine the wear values and predict the time of the eventual failure.

Improvement of methods for diagnosing the technical condition of motor vehicles and on-board diagnostic systems is a promising trend, the significance of which will increase as the motor vehicles further intellectualization process. Onboard diagnostic systems will increase the safety of the transport system in general, as well as the efficiency of the service system due to more accurate forecasts for the spare parts and rational equipment loading.

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