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MATHEMATICAL MODEL FOR THE DETERMINATION OF TECHNICAL STATE OF ELECTRONIC CONTROL SYSTEM OF «KIA CEE'D» MOTOR VEHICLE ENGINE

Rapid progress in the sphere of electronics and electrical engineering during last years and decades resulted in drastic increase of the number of electronic components in the motor vehicle. Along with hydraulics and pneumatics electronics penetrated in all the components of modern motor vehicle. Separate electronic components and complex electronic systems become more compact, cheaper and at the same time, more efficient. New possibilities for the application of electronics in the motor vehicle emerge, enabling to enlarge the volume of the available functions.

The given study contains the analysis of the methods and means of diagnostics of electronic systems of the automobile transport. It is established that available methods and means of diagnostics of the engine electronic control system do not allow to determine completely the current technical state, it requires the development of mathematical models for their diagnostics.

As the object of diagnostics the electronic control system of the motor vehicle «Kia Cee'd» engine was chosen. The research contains the analysis of the components of the control system of motor vehicle «Kia Cee'd», as the object of diagnostics. Replacement of real technical devices by their idealized models enables to apply various mathematical methods. Mathematical model, which represents the system of functional dependences between each diagnostic signal and structural parameter is suggested in general form. Diagnostic matrix, comprising the list of faults and features of faults is composed for the control system of the motor vehicles «Kia Cee'd». By means of the developed mathematical model it is possible to improve information-measuring part of the diagnostic devices software, this enables to perform efficiently diagnostics of the control system of motor vehicles «Kia Cee'd» engines. In the process of mathematical model development it is taken into account that the reverse transformation of the faults features quantity in the quantity of structural parameters (faults) of the object was single-valued.

Studies of the suggested mathematical model for the diagnostics of the electronic control system of motor vehicle «Kia Cee'd» engine enable to reveal the faults of the engine systems depending on their features, this will enhance the term of faultless operation both of the engine and transport vehicle.

Key words: *mathematical model, diagnostics, motor vehicle, engine, engine control system, diagnostic matrix, block-diagram, fault, feature of the fault, Boolean function.*

Introduction

As a result of powerful development of electronics and microprocessor equipment changes and improvement of the constructions of numerous systems of the motor vehicle take place , first of all, this process concerns systems of the engine control. Conventional mechanical systems of supply and ignition (carburetor, interrupter-distributor, etc.) were replaced by the systems of direct fuel injection and contactless ignition. Their operation is provided by the electronic control units and various sensors, controlling complex processes, occurring in the process of engine and its systems operation. Besides, electronic control units perform self- diagnostics that makes the searching of faults and their elimination easier.

Usage of electronics in the systems of engine control provides the obtaining of optimal formation of mixture (air-fuel) at all operation models, increasing the dynamics, efficiency and decreasing the amount of harmful emissions in the atmosphere that is the priority of nowadays.

It should be noted that practically all the companies-manufactures of motor vehicles use electronic systems of the engine control, although there exists a great number of transport vehicles, using old systems of the supply and ignition.

Problem statement

Nowadays automobile branch of national economy is one of the most developed and promising sphere of economic activity . Modern transport vehicles become more reliable, comfortable and safe, their driving, maintenance and repair is much easier. This became possible as a result of wide usage of electronic equipment, in its turn, all the system of automobile control became more complicated [1]. Electronic systems of motor vehicle have one common feature – they control non-electric processes but they are controlled by the systems of automation. In this case, primary sources of the control signals are a man (driver), program, installed in the electronic memory and input non-electric impacts [2]. System of engine control on the whole, ignition system, fuel injection system, mechanisms of automobile engine have direct impact on many indices of its operation. Such indices include power of the engine, economic efficiency, uniformity and stability of operation, exhaust gas toxicity, etc. It is known that even the invisible faults of the ignition system or injection system (decrease of the breakdown voltage, violation of the time of energy accumulation, ignition timing violation, etc.) greatly increase fuel consumption and increase the content of harmful substances in the exhaust gases [3].

Engines with electronic control system have the function of diagnostics using the method of self-diagnostics [4, 5]. The essence of the method is the built-in the electronic control system the function of selfdiagnostics which enables by means of memory poll of electronic block of faults, quickly determine the faulty constructive element and keep the code of fault in the memory of the block. The advantages of this method are the following: possibility to determine faults of the engine by means of faults codes reading from the memory with minimal time losses and minimal amount of diagnostic operations. Application of this method is complicated by rather high cost of diagnostic equipment and requirements to the qualification of the staff, which in their turn, must have a good command of the traditional methods of diagnostics.

High requirements to the qualification of the staff is connected with the fact that very often self diagnosis on the faulty transport vehicles does not reveal any failure or determines the reasons or failure incorrectly, as in the memory of self diagnosis only the data regarding the deviation of the parameter values of those constructive elements, with which electronic control block has electrical connection are entered . Emergence of hydrodynamic or mechanical failures self diagnosis does not determine and this may lead to the establishing incorrect diagnostic conclusion [6].

Statistic of failures of separate components of the motor vehicle shows that approximately 30…35 % of all the failures are failures of electronic system of engine control [2].

Thus, studies, aimed at improvement of the methods and means of diagnostics of the electronic system of engine control of «Kia Cee'd» vehicle is relevant scientific-technical task.

Analysis of recent studies and publications

Nowadays diagnostics of the engines and their systems is performed using several methods and various equipment. Great contribution into the development of methods and means of diagnostics of the internal combustion engines and their systems was made by: Kurnikov I. P. [3], Merotto L. [5], Kanarchuk V. E. [7], Kukurudziak Yu. Yu. [8], Ludchenko O. A. [9] and others. Methods of technical diagnostics of engines, which are widely used are performed at their partial disassembly. Application of modern contactless and non-demountable methods of diagnostics, based on the analysis of the output parameters of the engine, functionally connected with its structural parameters enables to solve the problem of labor intensity reduction, quality of diagnostics, however these methods are insufficiently studied.

Problems of diagnostic systems design are considered in the studies of Zhang J. [4], Chabanyi V. Ja. [10], Jatskovskyi V. I. [11], Anisimov V. F. [12], Kovalenko V. M. [13] and others.

Analysis of literature and scientific sources showed that available methods and means of the internal combustion engines diagnostics, in particular, electronic control system of the engine, do not fully correspond to modern requirements regarding their current technical state that requires the development of mathematical models for automation of their main parts diagnostics .

Objective of the research

Reliability of transport means depends on the reliability of their units and blocks, one of such block is the internal combustion engine.

Enhancement of the reliability and decrease of labor intensity of diagnostics in the process of technical maintenance of the motor vehicle engine can be obtained as a result of improvement of the tools for diagnostic of the electronic systems of engine, these tools must have the possibility to digitize the obtained by means of direct measurement data and further process them using mathematical tools.

Objective of the study is the development of mathematical model of the diagnostics of the control system of the engine of motor vehicle «Kia Cee'd», the model takes into account both faults and features of faults.

To reach the given objective the following tasks are to be solved:

– consider the construction and characteristic features of electronic control system of «Kia Cee'd» motor vehicle engine operation;

– develop mathematical model of the control system of motor vehicles «Kia Cee'd» engines, this model will enable to improve information measuring part of the diagnostic equipment software.

Analysis of electronic control system of motor vehicle «Kia Cee'd» engine

Electronic control system of the motor vehicle is intended for the operation of the cyclic fuel supply to the engine, depending on the engine operation modes, its temperature state, regulating characteristics and parameters of the environment [14, 15].

Gasoline (G4FA, G4FB, G4FC) and diesel (D4FB, D4EA) engines, installed at the motor vehicles «Kia Cee'd», are equipped with electronic control system of the engine with the distribution system of fuel injection. This system provides performing of modern norms, regarding the toxicity of emitions and evaporation at maintaining high driving performance and low fuel consumption [16].

Control device in the system is electronic control unit [17]. On the base of the information, obtained from the sensors, electronic control unit calculates the parameters of fuel injection regulation and ignition timing control. Besides, according to the installed algorithm electronic unit controls the operation of the electric motor of the fan of the cooling system and electromagnetic clutch of air conditioning compressor, performs the function of self- diagnostics of the elements and informs the driver about failures.

In case of failures of certain sensors and mechanisms, electronic unit switches on the emergency modes, providing the engine operation. Amount of fuel, supplied by the injectors is determined by the duration of electronic signal from electronic control unit. Electronic unit monitors the data, regarding the state of the engine, calculates the required fuel and determines the necessary duration of fuel supply by the injectors (signal duration). To increase the duration of fuel supply process, the duration of the signal increases, and decrease the duration of the process of fuel supply – decreases.

Control system of the engine comprises electronic unit, sensors, actuating devices sockets, fuses.

Fig. 1. Electronic control unit

Fig. 2. Crank shaft position sensor

Fig. 3. Camshaft position sensor

Electronic control unit (controller) (Fig. 1) is connected by means of electric wires with all the sensors of the system. Obtaining the data from the sensors the unit performs calculations according to the parameters and control algorithm, contained in the memory and controls the actuating devices of the system.

Electronic control unit supplies with DC of 5 and 12 V different sensors and switches of the control system.

Electronic control unit is unfit for repair and in case of failure it must be replaced.

Crankshaft position sensor (Fig. 2) is intended for the synchronization of the electronic control unit operation with top dead points of the pistons of the first and fourth cylinders and angular position of the crankshaft. The action of the sensor is based on Hall effect. Crankshaft position sensor is installed in the rear part of the engine against the fly wheel crown. During the rotation of the crankshaft the fly wheel teeth change the magnetic field of the sensor, inducing the pulses of A.C. voltage. Control unit by the signals of the sensor determines the rotation frequency of the crankshaft and generates pulses to the injectors. In case of sensor failure the start of the engine is impossible.

Camshaft position sensor of the inductive type (Fig. 3) in installed in the front part of the cylinder head. In the process of rotation of the intake camshaft protrusions on its front journal change the magnetic field of the sensor, inducing the pulses A. C. voltage. Sensor signals are used by the electronic control unit for the organization of the phase-wise fuel injection according to the order of cylinders operation and for the control of the gas-distribution phases change depending on the engine operation mode. In case of failure of the camshaft position sensor line, the electronic unit enters its code in the memory and switches on the signal lamp.

Temperature sensor of the cooling fluid (Fig. 4) is installed in the cooling system of the engine. Sensitive element of the sensor is thermistor, electric resistance of which varies inversely proportional to temperature. At a low temperature of cooling fluid (–20 °C) the resistance of the thermistor is approximately 15 kOhm, if the temperature grows to +80 °C the resistance decreases to 320 Ohm.

Electronic control unit supplies the circuit of the temperature sensor with constant «reference» voltage. Voltage of the sensor signal reaches maximum value on the «cold» engine and decreases as it heats up. By the voltages value electronic unit determines the temperature of the engine and takes it into account in the process of calculation of the regulating parameters of the injection and ignition.

In case of sensor failure or problems in the circuit of its connection, electronic control unit determines the code of failure and remembers it. Additional thermistor is installed in the sensor hosing for the control of the indicator of cooling fluid temperature in the combination of the devices.

Fig. 4. Coolant temperature sensor

Fig. 5. Throttle position sensor

Fig. 6. Oxygen concentration sensor

Throttle position sensor (Fig. 5) is installed on the housing of the throttle assembly and connected with the throttle shaft. Sensor represents potentiometer, on one of its end «plus» of supply voltage (5 V) is sent and the other end is connected with "mass". From the third potentiometer output (from slider) the output signal passes to the electron control unit.

When the throttle valve rotates (under the action on the control pedal), voltage on the sensor output changes. If the throttle valve is closed the voltage is below 0.5 V. When the throttle valve opens, the voltage at the output of the sensor grows, if the throttle valve is completely open the voltage must be more than 4 V. Monitoring the output voltage of the sensor, electronic unit adjusts the fuel supply, depending on the throttle opening angle.

Throttle position sensor does not need adjusting, as the control unit considers idle mode (i. e., complete closing of the throttle valve) as zero mark.

Oxygen concentration sensors (Fig. 6) screwed into the threaded holes of the cat -collector and exhaust pipe of the exhaust gas release system. Sensor at the input of the cat- collector serves for the control of the composition fuel air mixture, and the sensor at the output – for the assessment of the efficiency of neutralizer operation. In the metal flask of the sensor galvanic element is installed, «washed by» the flow of the exhaust gases. Depending on the content of oxygen in the exhaust gases as a result of burning of fuelair mixture the voltage of the sensor signals changes.

Information from each sensor arrives into the control unit in the form of low (from 0.1 V) and high (to 0.9 V) level. At the low level signal control unit obtains the information about high oxygen content. High level signal proves the low content of oxygen in the exhaust gases.

Constantly monitoring the voltage of the sensor signal the control unit corrects the volume of fuel, injected by the injectors. At a low level of the sensor signal at the input into cat -collector (lean air fuel mixture), the amount of the supplied fuel increases, in case of high level of signal (enriched mixture) – decreases. If the difference between the signal levels of the sensors at the input and output of the neutralizer is less than the values, admissible at this operation mode control unit identifies the failure of the cat -collector.

Detonations sensor (Fig. 7) is attached to the upper part of the cylinder block in the area between the second and third cylinders and detects abnormal vibrations (detonation strikes) in the engine. Sensitive element of the detonation sensor is piezo crystal plate. In case of detonation, at the output of the sensor, voltage pulses are generated, they increase with the increase of the intensity of the detonation strikes. Electronic unit by the signal of the sensor regulates the ignition advance to eliminate fuel fire.

Fig. 7. Detonation sensor

Fig. 8. Absolute pressure sensor

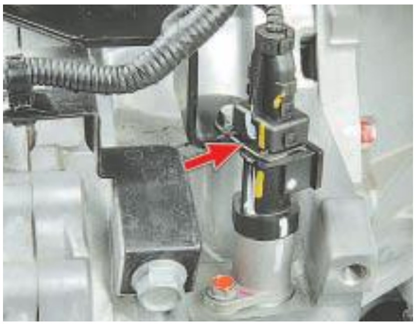

Fig. 9. Speed sensor

Absolute pressure sensor (Fig. 8) in the inlet pipe transforms the depression into electric voltage, depending on its value electronic control unit determines the loading of the engine. Sensor is installed at the inlet pipe and is connected with its cavity by a rubber tube. Output voltage of the sensor varies in accordance with the pressure in the inlet pipe – from 4.0 V (at completely open throttle valve) to 0.79 V (if the throttle valve is closed). If the engine does not function the control unit of the sensor voltage determines the atmospheric pressure and adapts injection regulation parameters to the height above sea level. Values of the atmospheric pressure, stored in the memory are periodically updated during the uniform motion of the motor vehicle and when the throttle valve is completely open.

Speed sensor (Fig. 9) is installed on the gear box. Sensor principle of action is based on Hall effect. Sensor sends rectangular voltage pulses to the electronic control unit, their frequency is proportional to the rotation frequency of the driving wheels.

Fig. 10. Diagnostic socket

Fig. 11. Continuous variable valve timing system

To remove from the memory of electronic control unit failures codes, detected during operation of the engine control system, diagnostic sockets are used (Fig. 10). One diagnostic socket is located on the right, in the engine compartment, another – in the vehicle interior under the instrument panel, on the left. The device, reading the information from the serial data line can be connected the scanning device.

Electromagnetic valve of the continuous variable valve timing system (Fig. 11) is installed in the cylinder head of the engine. Valve regulates the pressure, of the oil, supplied to the actuating mechanism of the phase change, installed at the front end of the camshaft of the inlet valve.

System performs optimal adjustment of the gas distribution phases, changing them in all the range of the gas distribution phases, changing them in all the range of values, frequency and loading of the engine, this increases power and torque at any speed mode.

Presentation of the basic material

As a result of automation of the logic process of making diagnosis the faults of the object of diagnostics can be prevented.

Solution of the problem of logical process of diagnostics automation requires the development of the models of control system elements of motor vehicle «Kia Cee'd» engine as the objects of diagnostics, describing at the same mathematical level the interactions between numerous possibly faults and numerous values of diagnostic parameters.

Replacement of the object of diagnostics by the model is connected with the allocation of main, essential for putting the diagnosis elements and properties, connected with the problem of determining real technical state of the objects. However, certain number of elements and bonds of the object, very important from the point of view of its operation as a device, intended for the execution of certain work, become secondary and can be excluded in the process of the development of the model of technical device, as the object of diagnostics.

Replacement of the real technical devices by their idealized models enables to use various mathematical models. Mathematical model of the object of diagnostics means numerous analytical, logical, statistical, graphic and other qualitative relations, connecting the output parameters of the object with its input and internal parameters.

The most universal model of the object of diagnostics is its presentation in the form of the «black box», its input and output parameters have finite set of values. It is expected, that all possible states of the object form finite set of states. In this case, the object is «black box» not because its internal structure and parameters are unknown, but because the prohibition is imposed on the access to them and state of the object can be determined, only studying its output parameters (without disassembling) [1, 18].

To present the object of diagnostics in the form of the «black box» it is necessary to set (Fig. 12):

– number of all input actions Y from stimulating devices and external environment;

– number of all output features of faults C;

– number of all faults of the object of diagnostics B;

– operator A, which transforms quantities B and Y in quantity C:

$$C = A\{Y, B\}. \qquad (1)$$

Taking into account the fact, that during diagnostics elements of quantity Y *are* stabilized (or changed according to the set law), expression (1) is transformed into:

$$C = A\{B\}. \tag{2}$$

In other words, any output parameter of the object of diagnostics is a function of its technical state at this state of inputs.

If the fault of the object of diagnostics $\{B_i\}$ is referred to the output parameters of the automated system, then diagnostics task is formulated in the following way: by the known features of the faults $\{C_j\}$, determine the unknown faults of the object of diagnostics $\{B_i\}$.

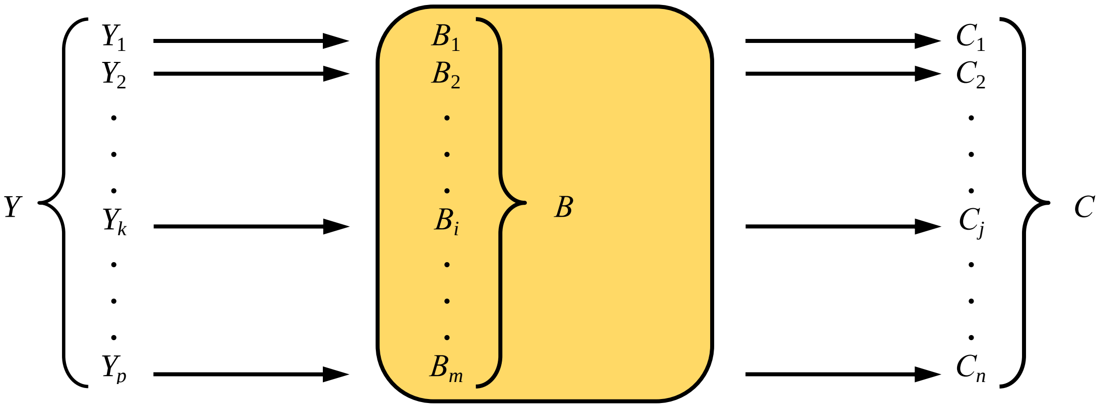

Fig. 12. Presentation of the object of diagnostics in the form of the «black box»

For the successful solution of this problem it is necessary to known the type of A operator, in other words, the exhaustive description of the connections between all the output parameters and all possible states (faults) of the object is needed.

A number of models of objects of diagnostics, where different forms of the description of the above-mentioned interconnections differ from each other, are described below.

If analytical model of the object of diagnostic is available, the task for the diagnosis setting in general form is formulated in the following way. According to these faults features C_1, C_2, ..., C_n, obtained as a result of the technical state (faults) of the object of diagnostic B_1, B_2, ..., B_m, if functional dependences between each diagnostic signal and structural parameters are known:

$$\begin{cases} C_1 = \phi_1(B_1, B_2, ..., B_m); \\ C_2 = \phi_2(B_1, B_2, ..., B_m); \\ .... \\ C_j = \phi_j(B_1, B_2, ..., B_m); \\ .... \\ C_n = \phi_n(B_1, B_2, ..., B_m). \end{cases} \tag{3}$$

System of equations (3) is mathematical model of the object of diagnostics, that has m structural parameters and n diagnostic signals.

Obvious advantage of making the diagnosis, using analytical model is the possibility to obtain specific failure of the object of diagnostics, that enables to determine technical state of the object not only at the moment of diagnostics but, accumulating the information, obtained during several diagnostic examinations of the object, analyze the change of the structural parameters in order to forecast its technical state.

However, practical application of such analytical model now is limited, due to the following reasons:

– type of functions φ_j for greater part of units and mechanisms is not determined;

– if function φ_j does not meet the requirements of continuity and differentiation by each of its arguments, that takes place in real models, then the solution of the system of equations (3) is connected with mathematical difficulties;

– greater part of diagnostic parameters can not be expressed in the form of analytical functions of structural parameters.

In same papers on technical diagnostics of machines and mechanisms possible technical states (faults) of units and systems and features of these faults are described in the form of the so-called diagnostic matrices [18 – 27].

Based on the experience of motor vehicles «Kia Cee'd» operation, Table 1 contains the diagnostic matrix of electronic control system of engine, they are equipped with [1, 2, 15].

Table 1

Diagnostic matrix of electronic control system of the motor vehicle «Kia Cee'd» engine

Fault of electronic control system of the motor vehicle «Kia Cee'd» engine	Fault feature of the electronic control system of the motor vehicle engine «Kia Cee'd» engine					
	C_1	C_2	C_3	C_4	C_5	C_6
B_1	+	+	-	-	-	-
B_2	+	-	-	-	-	-
B_3	-	+	-	-	-	-
B_4	-	+	-	+	-	-
B_5	-	-	+	-	-	-
B_6	-	-	+	-	-	-
B_7	-	-	+	-	-	-
B_8	-	-	-	+	-	-
B_9	-	-	-	+	-	-
B_{10}	-	-	-	+	-	-
B_{11}	-	-	-	+	-	-
B_{12}	-	-	-	+	-	-
B_{13}	-	-	-	-	+	-
B_{14}	-	-	-	-	-	+
B_{15}	-	-	-	-	-	+
B_{16}	-	-	-	-	-	+

In the diagnostic matrix the following faults of the electronic control system of the motor vehicle «Kia Cee'd» engine will be denoted: B_1 – fault of ignition system ; B_2 – fault of fuel injection system ; B_3 – lack of reliable contact of the electronic control unit with «mass»; B_4 – low voltage in the on-board grid (faulty generator); B_5 – discrepancy of the heating ratio of the installed spark plugs; B_6 – damaged high voltage wires; B_7 – fault of the temperature sensor of cooling fluid or its electric circuit; B_8 – faulty sensor of mass air flow; B_9 – faulty high voltage wires; B_{10} – pollution of the spark plugs; B_{11} – pollution of the ignition devices; B_{12} – non-reliable contact of the ignition devices with «mass»; B_{13} – faulty spark plugs; B_{14} – lean air/fuel mixture is the reason of increasing the voltage of the oxygen concentration sensor signal as a result of the formation of the depositions on the flask of the sensor; B_{15} – throttle valve sticking in the open position; B_{16} – faulty sensor of cooling fluid temperature or its electric circuit.

The features of the above-mentioned faults of electronic control system of motor vehicle «Kia Cee'd» are introduced in the matrix: C_1 – starter rotates the crankshaft, but the engine does not start for a long time (after the start the engine immediately stops); C_2 – engine does not develop rated power (motor vehicle slowly accelerates at partial pressing the accelerator pedal); C_3 – detonation knocks in the engine during acceleration; C_4 – lack of rapid reaction of the engine to the change of the throttle valve position, especially when the car is moving from a standstill; C_5 – engine operates with interruptions (car jerks when the load on engine increases, uneven noise during the exhaust gases release); C_6 – unstable operation of the engine in idle mode, accompanied by the increased vibration and stops.

As it is seen from Table 1, each fault is characterized by a certain combination of the values of its features, which can take two conventional values: «-» or «+».

On the cross-section of the i^{th} row and j^{th} column «+» is put, if i^{th} fault is available, j^{th} feature leaves the area of its admissible values, in opposite case «-» is put.

For the synthesis of such matrix infinite number of technical states of the object must be replaced by the finite set of technical states, each of them is connected with certain fault (or their combination) or with the operational state (Fig. 13).

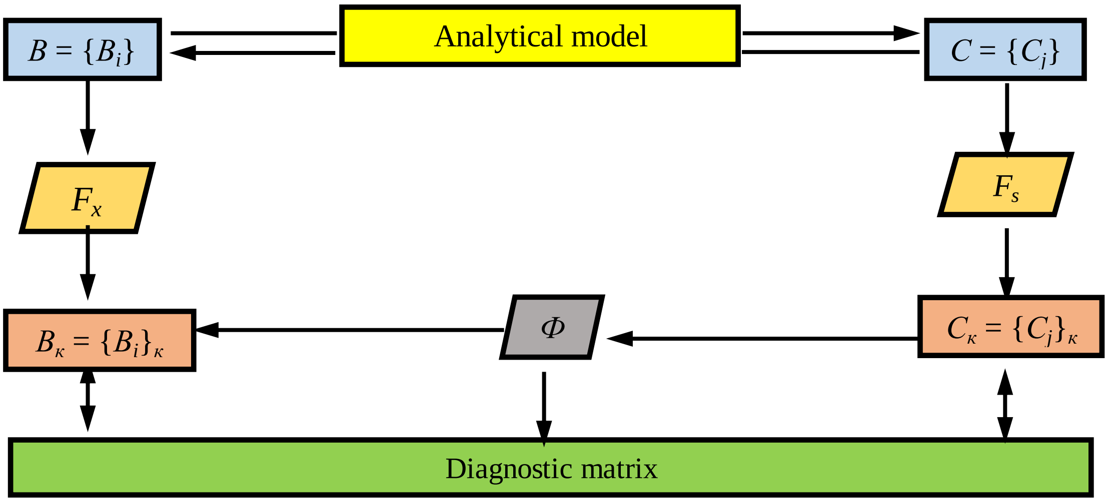

Fig. 13. Block-diagram of the synthesis of diagnostic matrix of electronic control system of motor vehicle «Kia Cee'd» engine:
$B = \{B_i\}$ – infinite number of object technical states;
$B_\text{к} = \{B_i\}_\text{к}$ – finite number of technical states;
$C = \{C_j\}$ – infinite set of features of object technical states;
$C_\text{к} = \{C_j\}_\text{к}$ – finite set of features of object technical states;
F_x – operator, converting quantity $\{B_i\}$ into quantity $\{B_i\}_\text{к}$;
F_s – operator, converting quantity $\{C_j\}$ into quantity $\{C_j\}_\text{к}$;
Φ – operator, which converts the quantity of technical states of the object into the quantity of diagnostic parameters

Such transformation may be written in the form:

$$\{B_i\}_\text{к} = F_x\{B_i\}, \qquad (4)$$

where $\{B_i\}$ – is the set of features of technical states of the object of diagnostics, each of them can take in general case infinite number of values; $\{B_i\}_\text{к}$ – finite set of features of technical state of the object of diagnostics, each of them can take only two conventional values «-» and «+», which correspond to the absence and presence of i^{th} fault; $i = 1, 2, \ldots, m$; F_x – operator, which converts quantity $\{B_i\}$ into quantity $\{B_i\}_\text{к}$ in the following way: for any i^{th} parameter of B_i value «-» is assigned, if the value is in the area of the admissible values, in opposite case, value «+» is assigned.

Transformation of the infinite quantity of values of input processes parameters into finite quantity of values of diagnostic parameters can be written in the form:

$$\mathrm{\{C_j\}_\text{к} = F_s\{C_j\}}, \qquad (5)$$

where $\{C_j\}$ – is the quantity of features of the output processes, each of them can take in general case infinite quantity of values in certain interval; $\{C_j\}_\text{к}$ –is finite quantity of diagnostic features, each of them can take only two conventional values: «-» or «+»; $j = 1, 2 \ldots, n$; F_s –is the operator that converts quantity $\{C_j\}$ into quantity $\{C_j\}_\text{к}$ in the following way: any j^{th} feature of C_j is assigned conventional value «-», if the value is in the area of values which correspond to the operational state of the object of diagnostics, in opposite case value «+» is assigned.

As a result of the transformations, performed, two finite values $\{B_i\}_\text{к}$ and $\{C_j\}_\text{к}$, are obtained elements of which in a way are connected with each other.

In general form this connection can be expressed as:

$$\{C_j\}_\text{к} = \Phi\ \{B_i\}_\text{к}, \qquad (6)$$

where Φ – is the operator, that converts the quantity of technical states of the object into the quantity of diagnostic parameters.

Transformation (6) represents the operation of any engineering object as the converter of the quantity of structural parameters into the quantity of diagnostic parameters and is the modification of the model (1).

Transformation (6) can be expanded by means of the system (3).

System of equations (3) connects each feature of fault C_j with all structural parameters of the object of diagnostics, this reflects the connections between structural parameters and diagnostic signals.

Diagnostic matrix, as the model of the object of diagnostics, shows that it is a tabular form of equations system (1) presentation.

Parameter C_1 in diagnostic matrix can be considered as two-valued Boolean function, which depends on the arguments B_1 and B_2. Boolean function depends on the arguments B_1 and B_2, if the relation takes place:

$$\phi\left(B_1,\ B_2,\ ...,\ B_{i-1},\ 0,\ B_{i+1},\ ...,\ B_m\right) \neq \phi\left(B_1,\ B_2,\ ...,\ B_{i-1},\ 1,\ B_{i+1},\ ...,\ B_m\right).$$

As it follows from this definition and Table 1, C_1 greatly depends only on B_1 and B_2.

Dependence $C_1 = \varphi_1$ (B_1, B_2) is expressed in the given case in the form the function of logical addition (disjunction):

$$C_1 = B_1 + B_2.$$

Corresponding analysis of other features of faults enables to write down the system of equations (3) for this matrix for diagnostic electronic control system of the engine of motor vehicle «Kia Cee'd» in the form:

$$\begin{cases} C_1 = B_1 + B_2; & C_4 = B_4 + B_8 + B_9 + B_{10} + B_{11} + B_{12}; \\ C_2 = B_1 + B_3 + B_4; & C_5 = B_{13}; \\ C_3 = B_5 + B_6 + B_7; & C_6 = B_{14} + B_{15} + B_{16}. \end{cases} \tag{7}$$

All the serial transformations, leading to synthesis of the model of object of diagnostics in the form of diagnostic matrix, are presented in block-diagram (see Fig. 13). In the case, when the model of the object of diagnostics is presented in the form of diagnostic matrix, diagnostic problem is formulated in the following way: by the features of faults C_1, C_2, …, C_n obtained in the process of diagnostics, faults B_1, B_2, …, B_m must be determined at the moment of control if functional dependences between diagnostic parameters and all the structural parameters, set in the form of diagnostic matrix or system of equations (7) are known. Each structural parameter and each diagnostic parameter takes only one value: «-» or «+».

It is obvious that for the solution of the diagnostic problem reverse transformation of the quantity of diagnostic parameters into the quantity of structural parameters is needed, because when making the diagnosis the values of the diagnostic parameters are known.

In general form reverse transformation can be presented by the expression:

$$\left\{B_i\right\}_{\kappa} = \Phi^{-1}\left\{B_j\right\}_{\kappa},$$

or in the expanded form

$$\begin{cases} B_1 = f_1\left(C_1,\ C_2,\ ...,\ C_n\right); \\ B_2 = f_2\left(C_1,\ C_2,\ ...,\ C_n\right); \\ B_m = f_m\left(C_1,\ C_2,\ ...,\ C_n\right). \end{cases} \tag{8}$$

It is not difficult to establish the form of f_m function in each case on the base of the following considerations.

In the diagnostic matrix one of the rows, for instance, tenth row will be considered separately. From the matrix it is seen, that the presence of the fault B_4 causes simultaneously leaving of the features C_2 and C_4 from the area of their admissible values. Values of other diagnostic parameters remain within the limits of norm, if only fault B_4 is available. Thus B_4 is Boolean function, in this case, conjunction (or function of logic multiplication):

$$B_4 = C_2 \cdot C_4.$$

Corresponding analysis of all other columns of the considered matrix enables the reverse transformation (3) to be written in the form of Boolean functions (conjunctions):

$$\begin{cases} B_1 = C_1 \cdot C_2; & B_5 = C_3; & B_9 = C_4; & B_{13} = C_5; \\ B_2 = C_1; & B_6 = C_3; & B_{10} = C_4; & B_{14} = C_6; \\ B_3 = C_2; & B_7 = C_3; & B_{11} = C_4; & B_{15} = C_6; \\ B_4 = C_2 \cdot C_4; & B_8 = C_4; & B_{12} = C_4; & B_{16} = C_6. \end{cases} \tag{9}$$

As it is seen from this example, the process of diagnosis on the base of the model of the object of diagnostics, expressed in the form of diagnostic matrix, consists of the following steps:

– by means of corresponding measurements, and transformations (5), features of all faults C_1, C_2, $\ldots, C_n$ are established;

– values of the diagnostic parameters are substituted in the system of Boolean functions (8);

– values of all Boolean functions of the faults B_i (i = 1, 2, …, m) are calculated, and if $B_i = 1$, then i^{th} fault is in the object.

Proceeding from the fact that object of diagnostics is operational only in the case when all the faults are missing, then its operation function F_P has the form:

$$F_P = \overline{B_1 + B_2 + B_3 + \ldots + B_{17}}. \tag{10}$$

Going back to the block-diagram of diagnostic matrix synthesis (Fig. 3), the condition of diagnostic realization in general form can be formulated in the following way: to perform diagnostics it is sufficient that the reverse transformation of the fault features quantity in the quantity of the structural parameters (faults) of the object be single-valued.

If in the process of diagnostic matrix synthesis this condition is not fulfilled and in the system (8) there are two or more equal functions, then the list of diagnostic parameters must be completed with new parameter, which would be an additional argument only in one of the considered equal functions.

Conclusions

1. It is established that the efficiency of transport vehicles operation is determined by the technical state of their internal combustion engines, impact on the technical states is defined by the objective information, provided by the technical diagnostics on the base of various methods and technical facilities.

2. In the course of analysis of the recent studies and publications on the suggested subject it is established that any specific mathematical dependences for the determination of technical state of the motor vehicle engine control systems are not revealed.

3. Analysis of the specific features of the construction of electronic control system of motor vehicles «Kia Cee'd» engine , as an object of diagnostics. is performed .

4. As the object of diagnostics, electronic control system of motor vehicle «Kia Cee'd» engine is presented in the form of the «black box», input and output parameters of which have finite set of values.

5. Diagnostics matrix is composed for the electronic control system of the motor vehicle «Kia Cee'd» engine, it contains the list of faults and features of faults. Diagnostic matrix, as the model of the object of diagnostics, shows that it is a tabular form of mathematical model presentation of object of diagnostics.

6. In the process of diagnostic matrix synthesis it is revealed that there are such levels of function in the system (9):

$B_5 = B_6 = C_3$; $B_9 = B_{10} = B_{11} = B_{12} = C_4$; $B_{14} = B_{15} = B_{16} = C_6$.

Thus, the list of diagnostic parameters of electronic control system of motor vehicle «Kia Cee'd» engine must be completed with new parameters, which would become additional arguments only in one of the considered functions levels.

7. Developed mathematical model of the automation of the diagnostic process of electronic control system of the motor vehicle «Kia Cee'd» engine needs the introduction of new additional diagnostic parameters, this is the subject of further scientific research in this direction.

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