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Optimization of Indicators of Internal Combustion Engines of Vehicles with a Mechatronic Control System Using an Oxygen Sensor Adapter

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ABSTRACT: The paper reports the consideration of design, a principle of operation, engineering and adjusting characteristics of the mexatronic control system of the internal combustion engine, index optimization of different systems and devices of internal combustion engines**.**The aim of the modern approach to the control of internal combustion engines (ICE) is to optimize the control (achieving the set goals in the best possible way from the point of view of the accepted criterion in the presence of restrictions). Optimization is to obtain the required quality of the engine by eliminating the redundancy of indicators, that is, the implementation of the full and effective use of the available capabilities inherent in the design of the engine, the materials used in it and the manufacturing technology of each of its samples.

KEYWORDS: internal combustion engine, mechatronic control system, electronic control system, index optimization, ***mechatronic adapter***.

I. INTRODUCTION

Optimization makes sense only in the presence of a generalized quality indicator - an optimality criterion (or objective function), which quite tangibly reflects the effectiveness of management. Also important is the availability of the optimality criterion, the possibility of its definition and use in the control system [3]. In general, the quality of an engine is determined by a combination of technical, economic and environmental indicators. Among these indicators there are both directly controlled and predetermined by the capabilities of the mechatronic control system [2].

II. MAIN PART

The key element of the mechatronic control system is the Engine Control Unit (ECU). An electronic engine control unit (ECU) is a programmable electronic device (fig. 1), which is a combination of hardware and software [1]. The ECU is an electronic board that is housed in a plastic or metal housing toreliably protect the controller.

Fig. 1. Appearance of the electronic engine control unit

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Mechatronic control systems, which include the ECU, together affect the power characteristic of the internal combustion engine, the amount of torque, the economy of the engine, as well as the toxicity of the exhaust gases.

Each individual vehicle mechatronic system has its own control unit. All blocks are combined into a single interconnected circuit thanks to a special CAN bus (Controller Area Network). Blocks connected by a bus are sometimes called a car computer, and the number of controllers can be up to 80 (fig. 2) [5].

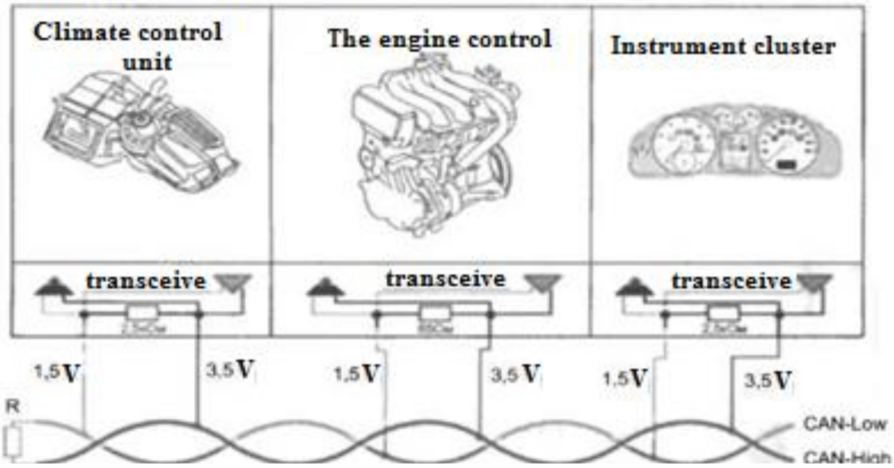

Fig. 2. On-board network and ECU CAN-bus

Directly controlled mechatronic control systems for internal combustion engine technical parameters include: speed, torque, pressure and temperature in fuel supply systems, pressure and temperature of charge air, lubricating oil pressure, coolant temperature, oxygen content in exhaust gases, etc.

Important directly controlled from economic and operational indicators are the current fuel consumption and air consumption.

The environmental indicators are directly controlled by the mechatronic control system: the composition and amount of harmful emissions, the level and spectrum of noise and vibration.

An increase in the quality indicators of an engine is achieved by optimizing its design and manufacturing technology, methods and means of fine-tuning its systems and assemblies, including the control system and the quality of engine control it provides.

An internal combustion engine is a multidimensional control object, since the number of input parameters is greater than one and each input parameter affects several output control actions. In this case, the ICE control system is multidimensional. [4]

In fig. 3 shows one of the variants of the mathematical model of a gasoline internal combustion engine with a mechatronic ignition and fuel supply control system with exhaust gas neutralization by a three-component neutralizer.

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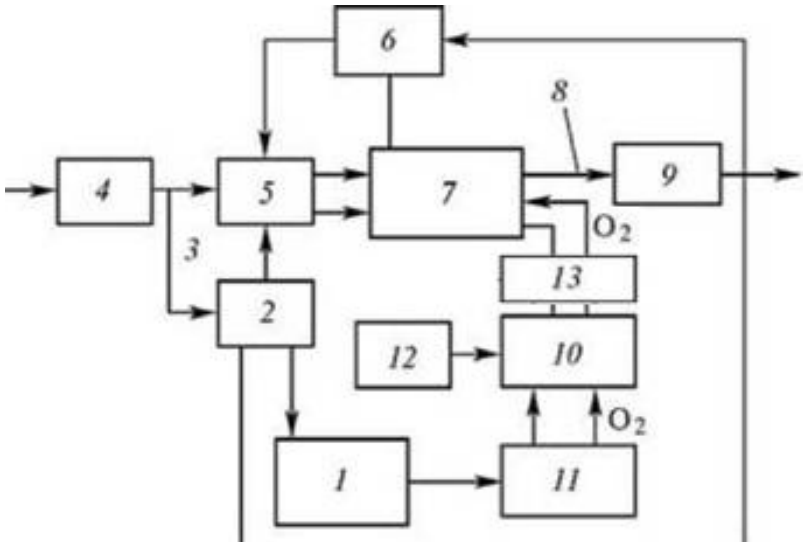

Fig. 3. A mathematical model of an internal combustion engine as an object of regulation to minimize fuel consumption and to limit the toxicity of exhaust gases, taking into account the oxygen sensor adapter: 1 – ICE control controller; 2 – fuel injection unit; 3 – suction pressure sensor signal Pк (internal combustion engine load); 4 – throttle valve in the intake manifold of the internal combustion engine; 5 - cyclic fuel supply (fuel consumption) and air (air consumption); 6 - ignition system; 7 - parameters of the indicator and working process of the internal combustion engine (parameters of the mathematical model of the internal combustion engine); O2 - oxygen concentration; 9 - ICE load parameters; 10 - engine exhaust tract; 11 - oxygen sensor in the exhaust gases; 12 - exhaust gas neutralizer; 13 - oxygen sensor adapter.

The algorithm for calibrating the control of such a mechatronic system according to the mathematical model of the engine has the following steps[5].

1. The choice of the initial configuration of the engine (in this case, it is the ignition system, fuel injection system, sensors and actuators).

2. Determination of the engine model with verification of its adequacy by experimentally determining its parameters. These procedures are performed on automated driving cycle (EC) test benches.

3. Calculation of the operating modes of the internal combustion engine during the execution of the driving cycle with the determination of the control matrix reference points, which must be stored in the permanent storage device of the control unit controller. The main parameters are ignition timing, cyclic fuel supply depending on the cyclic intake air flow rate or throttle valve position, the temperature of the coolant, oil, intake air.

4. Formation of the control surface for the driving cycle zone.

5. Estimation of the achieved level of indicators. In the case of management efficiency, management optimization is carried out, and in the absence of efficiency, the calculation is resumed from the previous stages.

6. Calculated determination of optimal control without restrictions on the toxicity of exhaust gases outside the driving cycle zone in order to obtain an adjustment surface with a minimum fuel consumption and optimal engine dynamics.

7. Formation of the basic matrix of ignition and fuel injection control.

The obtained values of the control reference points are put into the permanent programmable memory of the microcontroller, the mechatronic control system, taking into account the technological tolerances for the knock resistance of the fuel and the intensity of city driving.

Of particular importance in the development of software for the controller of a mechatronic control system are the static and dynamic errors of sensors and actuators.

The exchange of information via CAN communication lines has acquired particular importance with the advent of combined power plants on vehicles, which have reduced fuel consumption and reduced exhaust gas toxicity in conditions of heavy urban traffic.

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An internal combustion engine as an object of automatic control by input parameters produces controlled characteristics (power, environmental and dynamic). The rest of the vehicle units perform the functions of ensuring traffic safety and comfortable conditions for the driver and passengers.

Input parameters measured by sensors of electronic control systems (engine crankshaft speed, throttle opening angle, ignition timing, cyclic fuel consumption, air consumption, etc.) affect the course of the engine's working process. The values of the input parameters are determined by external influences on the engine from the driver or the automatic control system, therefore they are called controllers.

In addition to the input control parameters, the engine during its operation is affected by random disturbances that interfere with the control. Random disturbances include changes in the parameters of the state of the external environment (ambient temperature, atmospheric pressure, ambient humidity), the properties of fuel and oil, and the state of the road surface.

The engine speed can be determined by measuring the interval between adjacent pulses at the output of the crankshaft position sensor.

The interval between pulses is measured in seconds, one engine revolution corresponds to two pulses from the crankshaft position sensor (for a 4-cylinder engine), therefore:

$$n = \frac{60}{2T} = \frac{30}{T} \min^{-1}, \qquad (1)$$

where T is the interval between adjacent pulses at the output of the crankshaft position sensor.

Methods of direct or indirect determination of air mass can be used to determine the amount of air. Air mass measurement directly measures the amount of air entering the engine. Two different methods are used depending on the design of the sensors used:

- the air mass is measured;
- the volume, density and temperature of the air are measured, and then its mass is calculated.

When using the indirect method, the amount of air entering the engine is not measured, it is calculated by measuring the value of the parameter on which it depends. The mass of air entering the engine cylinders is determined by the expression:

$$A = \frac{nV\mu P}{RT}, \qquad (2)$$

where A- is the mass of air; n- is the engine speed; V- is the volume of the engine cylinder; μ - utilization factor of engine volume; P - pressure (vacuum) in the intake manifold; R - is the gas constant; T- is the temperature in the intake manifold.

From the above expression, it follows that the amount of air entering the cylinder per cycle depends on two variables: vacuum in the intake manifold and air temperature. This is the basis for the method of indirect measurement of the amount of air.

There are many types of air flow sensors, but mainly sensors that measure air volume (based on Karman vortices) or air mass (based on thermistors) are used. The sensors based on Karman vortices at the output have a pulse signal, the frequency of which is proportional to the volume of passing air per unit of time.

In this case, the amount of air is determined by the dependence:

$$g \sim \mathrm{A}/n_e, \qquad (3)$$

where **g** -is the amount of injected fuel; **A** -is the amount of air; $\mathbf{n_e}$- is the engine speed.

The air mass in this case is calculated by the electronic engine control unit using the data from the flow meter, air temperature and barometric pressure. Sensors based on thermistors at the output have an analog signal that changes in proportion to the mass of the passing air.

Indirect measurement systems use the absolute pressure in the intake manifold behind the throttle valve as a parameter for determining the air flow rate. In this case, the amount of injected fuel is determined by the expression:

$$g \sim \mathrm{P}/n_e, \qquad (4)$$

where **g**is the amount of injected fuel; **P -** pressure (vacuum) behind the throttle valve; $\mathbf{n_e}$is the engine speed.

When using this method, it is necessary to take into account the delay in the change in vacuum in relation to the change in mass. This method of measurement is cheaper, but less accurate.

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The requirements for the engine change depending on the operating mode of the engine, and the control programs must change accordingly.

The operation of the mechatronic control system cannot be ensured without determining the mode in which the engine is currently operating. Based on this, an algorithm is selected according to which control should be carried out at the moment.

The mode of operation of the engine is determined using a program - a mode manager based on information supplied to the microcontroller, primarily from sensors.

The algorithm of operation of this program, which recognizes the operating mode of the engine, is shown in a simplified form in fig. 4 (in relation to a gasoline engine) [1].

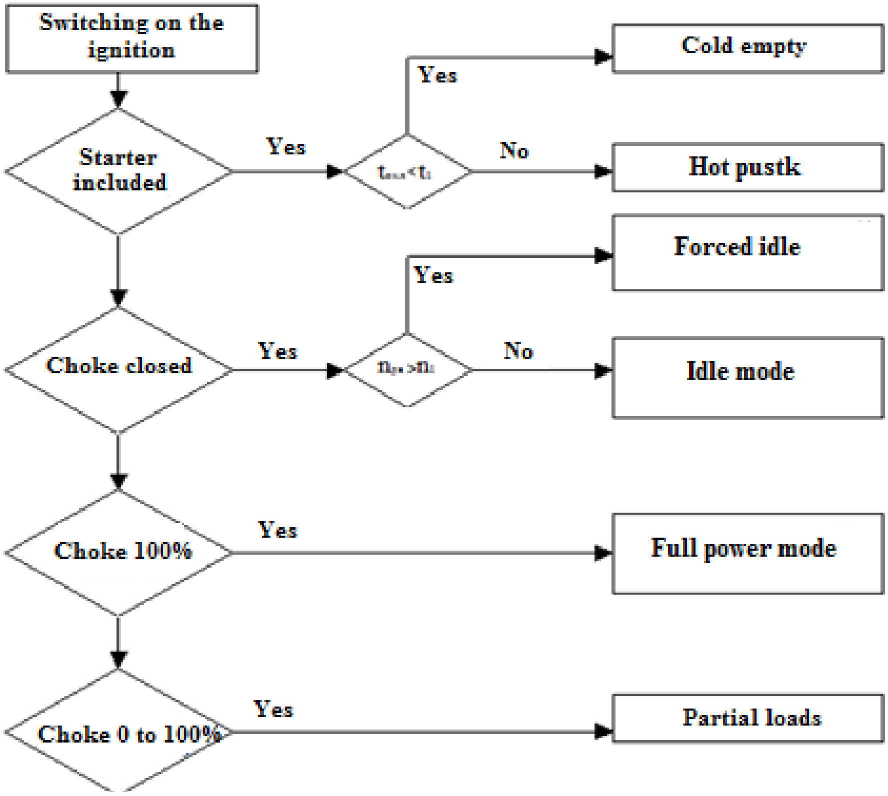

Fig. 4. Algorithm for identifying the operating mode of a gasoline engine: t_{cool} - liquid temperature in the cooling system; n_{de} - is the engine speed; t_1 - is the value of the liquid temperature in the cooling system, delimiting the conditions of cold and hot start; n_1- is the limiting idle speed.

After turning on the ignition, the transition to the start control program is carried out either in the case of turning on the starter, or in the case of starting the vehicle while driving downhill, if the engine crankshaft begins to rotate. After turning on the starter, the further choice of the hot or cold start program depends on the readings of the liquid temperature sensor in the cooling system. At$t_{охл} < t_1$(fig. 4) the cold start algorithm is switched on, at $t_{охл} < t_1$– the hot start algorithm.

The transition from starting the engine to operating modes occurs when the engine speed exceeds the set one ($n_{de}>n_e$). Immediately after exiting the start mode, a check is made to see if the engine is running at idle or forced idle. In both cases, the throttle valve is fully closed; if $n_{de}>n_1$(fig. 4), then the forced idle algorithm is activated, and if $n_{de}<n_1$- the idle mode algorithm.

The intermediate position of the throttle valve between full open and full close characterizes the operation of the engine at partial loads, and full opening of the throttle valve at maximum load.

The mode manager program can be common for all control actions or be embedded directly into the control loops of individual control actions. It can also be supplemented with specific criteria to identify certain modes.The dispatcher program can include the functions of determining the mode area where the exhaust gas recirculation system

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should operate, the mode area in which closed-loop control of the fuel supply is carried out according to the signals from the oxygen content sensor in the exhaust gases, etc. However, these tasks can be solved by introducing the necessary requirements directly into the program for managing certain impacts.

With the exception of the engine start mode, the fuel injection time (duration) (T) is determined taking into account the following factors:

- basic duration of injection (T_1), which changes with the change in the amount of air;
- values of the correction factor (K_c) of the basic injection duration;
- injector response delay (T_2).

$$T = T_1 \cdot K_c + T_2, \tag{5}$$

In start mode, the duration of fuel injection (T) is determined taking into account the following factors:

- basic injection duration (T_1), which is calculated taking into account the coolant temperature;
- the value of the correction factor (K_t), depending on the temperature of the intake air;
- duration of injector actuation (T_2)

$$T = T_1 \cdot K_t + T_2, \tag{6}$$

The amount of air entering the engine cylinder per cycle is calculated by the ECM based on signals from the air flow sensor and the engine crankshaft position sensor.

The engine control unit closes the power transistors, ensuring that the mixture in the cylinders is ignited in accordance with the order of operation of the cylinders calculated by it, based on signals from the crankshaft and camshaft position sensors. When calculating the closing moment of the transistor, it must be borne in mind that with a change in the speed of the engine crankshaft, the time during which it rotates by 1°, also changes (if the speed increases, then the time decreases, and vice versa). Therefore, first, the time (t) required to turn the crankshaft by 1° is calculated. It is easily determined from the cycle time (T), which is already known:

$$t = T/180 \tag{7}$$

After determining the time t, all the necessary data are available to calculate the moment when the power transistor closes (the moment the spark is applied). The angle of 75 ° to top dead center is taken as a reference point.

After determining the time t, all the necessary data is available to calculate the moment when the power transistor closes (the moment the spark is applied). The angle of 75 ° to top dead center is taken as a reference point.

$$T_1 = t(75 - \vartheta) \tag{8}$$

where ϑ — is the ignition timing calculated by the electronic engine control unit.

The engine, equipped with a mechatronic control system, provides a significant improvement in economic and environmental performance, an increase in engine power and operational reliability. Mechatronic control ensures the stability of transient processes in the engine and less rigidity of its working process, and, consequently, a decrease in noise and vibration.

The presence of a mechatronic control system has improved the quality of engine operation, creating the possibility of introducing centralized control and management of operation, while simplifying it. This was a consequence of the elimination of manual adjustments and settings of engine units, operational control and the presence of automatic adjustment of settings, systematic improvement of control algorithms based on the analysis of information on the results of operation of both a particular engine and all engines of the same typeIn addition, the mechatronic control system led to a decrease in the cost of repair maintenance and its simplification (for example, by eliminating mechanical and hydro mechanical speed controllers, the need for manual adjustments of fuel equipment at special stands) [3].

Improving the circuit and design of the engine in the presence of a mechatronic control system, and in particular the exclusion of some of its components and assemblies, significantly expands the possibilities of free placement of other units on the engine, thereby simplifying both the design and manufacture of new engines with a mechatronic control system.

The determination of the amount of fuel supply and the selection of the necessary phases are carried out by electromechanical injectors according to the information issued by the microcontroller. It is also typical to reduce the time and improve the quality of the manufacture of motors with a mechatronic control system as a result of simplifying the design of the motor and increasing the degree of automation of the debugging and commissioning of motors after manufacture.

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Systems are equipped with mechatronic control: fuel supply, gas exchange, pressurization, ignition, change in compression ratio, exhaust gas recirculation, cooling, lubrication and others. The greater the number of electronic systems used in the engine, the greater the possibility of optimizing the engine management. For each specific modification of the engine and its operating conditions, a list of electronic systems can be selected that is optimal in terms of the ratio of the achieved environmental and economic effect and cost.

III. RESULTS AND DISCUSSIONS

The classification of control systems on the basis of information processing divides them into four main groups.

Systems with programmed control. This group includes automatic open-loop engine control systems and all other engine control systems with intermediate links and feedback.

Systems with software - adaptive control. The use of these systems was a consequence of the need to reduce the toxicity of exhaust gases using neutralizers, which are effective only with a stoichiometric composition of the combustible mixture. It was possible to ensure the stoichiometric composition of the combustible mixture under operating conditions only with the introduction of feedback using an oxygen sensor installed in the exhaust pipeline. Another incentive for the use of program-adaptive systems was the desire to protect the gasoline engine from the destructive effects of detonation. Software-adaptive systems are becoming more widespread every year. They are used in supercharged engines in combination with other gas exchange control devices.

Systems with adaptive control. Such systems are the highest level of automation in engine cycle control.

Intelligent control systems. This is a group of systems of the near future that are already beginning to appear and are likely to take a leading place in ICE control systems and units with their use.

IV. CONCLUSION

Thus, for effective control of both the working process and the engine as a whole, it is necessary to obtain and process information about various physically dissimilar processes occurring in the systems and engine units. All necessary information comes from measuring devices, which include sensors, adapters and primary signal processing circuits.

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