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METHOD FOR MODELING THE PARAMETERS OF THE INTERNAL COMBUSTION ENGINE

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ABSTRACT

This paper describes the modeling of internal combustion engines using mathematical models. Mathematical models were used for automated test of internal combustion engines (ICE) that allowed us to predict the behavior of the engine when control parameters have been changed. A description of the engine control rules implemented from a mathematical point of view. Rules are a set of restrictions on the type and location of the graph based on the values of the technological parameter from the time that is written in a mathematical form. The fixing of the possibility of these errors reduced the time spent on developing technologies and testing engines to improve the usability of automated test systems (ATS). To solve this problem, a method based on the use of nodal points was proposed. Its essence lies in the fact that the technologist does not work with the graphic images of control operations themselves, but with the nodal points of their conjugation. An algorithm for planning test technologies using this method is described. Using the method, the technologist specifies the technological parameters of engine that will be included in the newly developed test technology.

INTRODUCTION

In the modern world the problems of saving fuel and energy resources become acute. Road transport consumes more than 30% of produced petroleum products [1], and fuel costs make up about 20% of the cost of any product.

The pollution of the environment is also an acute problem, and motor transport accounts for more than half of the harmful effects.

The development of modern engine is on the way to improving the economic, environmental and operational performance of engines [2]. This is primarily due to the use of electronic control systems – fuel injection and ignition control. It can significantly reduce the toxicity and energy consumption of vehicles.

In the process of car using, aging of its components and assemblies inevitably results in deterioration of its economic, ecological and effective indicators [3]. In this regard, in order to maintain the engine in good condition and to timely detect the deviation of parameters, leading to deterioration in the economic, environmental and effective performance of its work, the leading role belongs to the system of maintenance and repair, its scientific validity and excellence. At the same time, testing and diagnostics of engines is very important.

METHODS

Due to the fact that the ICE has many technical states, in fact, in diagnosing, it is necessary to split this set into a finite number of recognizable classes of states, combining in each class states having the same physical nature [4]. For example, one class can include the state of the engine, characterized by defects in the components of the valve mechanism, the bearing units of the crankshaft and so on. This class of states is characterized not only by a single sign of the state, but also by a single method of diagnosis [5]. Based on the statistical analysis of the failures of the diagnostic object, standards for each class of technical states are formed (the values of the diagnostic parameters averaged for this class).

To create a system of diagnostic parameters and standards, diagnostic model of the object is used, in some cases facilitating the process of searching for informative parameters in the signal under investigation [6].

The final stage of the engine diagnostic system is the decision making subsystem, which estimates the technical state of the engine and its elements based on the values of the diagnostic parameters using different criteria.

The main tasks when creating a system of technical diagnostics are the choice of the diagnostic method and the developing of an algorithm for determining the technical state of engine.

The development of the method for diagnosing engines includes a group of sequential tasks: the description of the object of diagnosis by a minimum set of state parameters and diagnostic parameters; identification of diagnostic parameters most sensitive to common defects; separation of technical states into classes [7]. At the same time the tasks of measuring diagnostic parameters, ensuring the control ability of the diagnostic object are being solved.

KEY WORDS

internal combustion engine, diagnostic, test, mathematical model.

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When developing engine diagnostic algorithms, the following approaches are applied [8]. The first is that the measured values of the parameters of the engine being diagnosed are immediately compared with the values of the same parameters measured earlier in the same engine [9]. As a result of the comparison, the deviations of the measured parameters are calculated, and all further diagnostic operations involving the appropriate mathematical models are performed with the indicated deviations.

The second approach is that the values of the parameters measured on the diagnosed engine are calculated with the help of a mathematical model of the values of other parameters not directly measurable that are compared with the values obtained previously for the same or similar models for the same engine model in the same mode, and on the basis of their analysis, diagnostic recommendations and decisions are made.

The development of the engine diagnostic system was carried out in accordance with the type of diagnosis to be performed: functional or test [10]. The system of functional diagnostics provides control over the running engine during its normal operation, evaluating it according to the diagnostic parameters [11]. In the case of a test diagnostics, the engine was subjected to artificial action to determine the operability of the assembly or part.

RESULTS AND DISCUSSIONS

As mentioned above, the program for managing technological parameters is a graph of the dependence of its value on time. This graph can be analytically described by a piecewise-defined function $f(t)$.

Because of this, the description of rules for engine control is convenient to implement from a mathematical point of view [12]. Rules represent a number of restrictions imposed on the type and location of the graph of the dependence of the value of the technological parameter on time, which is convenient to write down in mathematical form [13].

A list of the grammatical rules of the graphic language for the description of engine testing technologies is formulated as follows:

1. The time is counted from zero to infinity, technological parameters can take only non-negative values that are not greater than some maximum allowable value and not less than some minimum allowable value:

$$D(f_i) = [0; +\infty) \quad (1)$$

where f_i – function that describes the dependence of the value of the i -th technological parameter on time.

$$E(f_i) = [Y_{i\min}, Y_{i\max}], \quad (2)$$

where $Y_{i\min}$ – minimum allowed value of the i -th technological parameter,

$Y_{i\max}$ – maximum allowed value of the i -th technological parameter.

Thus, the graph of the i -th technological parameter lies in the first coordinate quarter, in the band bounded by the straight lines: $y = Y_{i\min}$ and $y = Y_{i\max}$.

2. All control programs must start at the zero point in time and end at the same time:

$$t_1 = t_2 = \dots = t_N = 0, \quad (3)$$

where t_i – the start time of the control program of the i -th technological parameter,
 N – number of technological parameters used in the test technology.

$$d_1 = d_2 = \dots = d_N, \quad (4)$$

where d_i – duration of the control program of the i -th technological parameter.,
 N – number of technological parameters used in the test technology.

3. Each time value t corresponds to a single value $f(t)$:

$$\exists! f_i(t) \forall t \in D(f_i). \quad (5)$$

From the single-valued correspondence to each argument of only one value of the function it follows that the graph does not have "loops", ramifications and discontinuities.

4. The permissible rates of change in the values of technological parameters are related to the constructive features of the engine and are limited by physical laws:

$$\frac{df_i(t)}{dt} \geq A_{i_{re}} \quad \forall t \in D(f_i), \tag{6}$$

where $A_{i_{re}}$ – maximum allowed rate of reduction of the i-th technological parameter.

$$\frac{df_i(t)}{dt} \leq A_{i_{incr}} \quad \forall t \in D(f_i), \tag{7}$$

where $A_{i_{incr}}$ – maximum allowed speed of increase of the i-th technological parameter.

Rules are associated with the correct form of graphical figures of process control operations. So consider possible errors:

1. Disruption of the control operation figure of the technological operation [Fig. 1(a)].
2. Control operation figures with the opposite motion along the time axis [Fig. 1(b)].
3. Create two control operation figures for the same operation [Fig. 1(c)].
4. Branching of the control operation figure [Fig. 1(d)].

Error 1 is a gap in the continuous management of the process, which will lead to a malfunction of the system in the interval of the gap. Error 2 is the absence of physical meaning when the system is running, because the time movement is carried out in one direction. Errors 3 and 4 also lead to system failure due to ambiguous control, i.e. at the same time the same control parameter must have different values.

Removing the possibility of these errors will reduce the time spent on developing test technologies and improve the ergonomics of ATS.

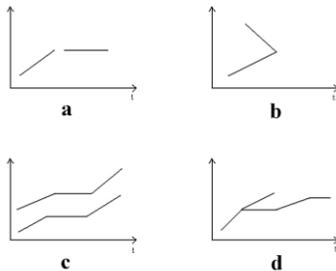


Fig. 1: Possible errors in the development of test technology.

Note that errors 1, 3, 4 arise when the figure of the technological operation is ruptured. Having eliminated the principal possibility of the appearance of a rupture of testing technology in the planning, one can get rid of errors of types 1, 3, 4.

To solve this problem, a method based on the use of nodal points was proposed. It is the fact that the technologist does not work with the graphic images of control operations themselves, but with the nodal points of their conjugation.

Adding a node to the graphic element actually means dividing it into two conjugate elements. Deleting a node means merging two adjacent elements into one. To uniquely define the control operation, it is sufficient to indicate the nodes of the corresponding graphic element. For convenience, the operation setting vectors are also linked to nodes. Thus, the process of setting the test modes is reduced to manipulating the nodes. Obviously, a technology test does not break in this case. This means that when using the node-point method, errors 1, 3, and 4 are fundamentally impossible. Error 2 is eliminated by introducing an additional rule for the movement of nodes: the abscissa of the node must always be not less than the abscissa of the left neighboring node and not greater than the abscissa of the right neighboring node. The [Fig. 2] shows the allowed interval for changing the time coordinate of the node (on the example of the technological parameter "shaft speed").

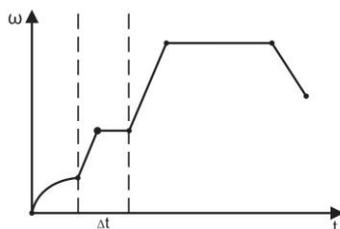


Fig. 2: The allowed interval for changing the abscissa of the node.

At the beginning of the planning the test duration, the initial and final values of all technological parameters are set. For the newly created test technology, they are formed by the one control operation for each technological parameter. The [Fig. 3] shows an example for the technological parameter "shaft speed".

These operations are mandatory, and cannot be deleted. They can only be divided into several sub-operations, the total duration of which is equal to the duration of the original obligate operations. In other words, the test technology always contains at least two nodes, which are set at the beginning of planning.

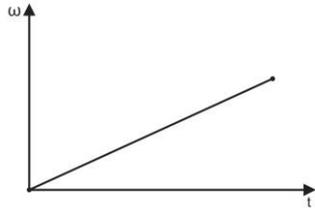


Fig. 3: Mandatory operation.

Further, the test technology is tuned in the desired way by adding and removing nodes and setting the parameters of the adjustment vectors. The [Fig. 4] shows the generated program for controlling the technological parameter on the example of shaft speed.

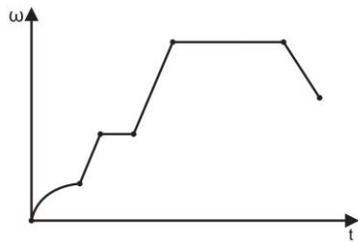


Fig. 4: Generated program for controlling the shaft speed.

The main function of the graphical interface is to convert data from internal representation to graphic form and back. The work of the ATS interface is based on the mathematical apparatus of analytic geometry. In computer memory, information about graphic elements is stored in the internal coordinate system. Its display on the display, which uses its screen coordinate system, is associated with the conversion of the internal coordinate system to the screen system. This transformation is performed by formulas (8) and (9):

$$x_s = \frac{x_{int}}{k_x} \quad (8)$$

$$y_s = h_s - \frac{y_{int}}{k_y} \quad (9)$$

where x_s – screen coordinate x,

x_{int} – internal coordinate x,

k_x – scale on the axis X,

y_s – screen coordinate y,

y_{int} – internal coordinate y,

k_y – scale on the axis Y,

h_s – distance between the origin of the screen and the internal coordinate system.

The inverse transformation is carried out by the formulas (10) and (11):

$$x_s = x_s \cdot k_x \quad (10)$$

$$y_s = (h_s - y_{int}) \cdot k_y \quad (11)$$

As it was said above, we will use graphic elements of three types: linear, exponential and harmonic.

Linear elements are straight lines and are described by the equation of a straight line passing through two points - the ends of a segment:

$$\frac{y - y_1}{y_2 - y_1} = \frac{x - x_1}{x_2 - x_1} \quad (12)$$

or

$$y = \frac{y_2 - y_1}{x_2 - x_1} \cdot x + \frac{y_1 \cdot x_2 - x_1 \cdot y_2}{x_2 - x_1} \quad (13)$$

where x_1 - abscissa of the beginning of the segment,
 y_1 - ordinate of the beginning of the segment,
 x_2 - abscissa of the end of the segment,
 y_2 - ordinate of the end of the segment.

Exponential elements do not have a single equation. There are four types of exponential graphic elements, each of which is described by its equation. They differ from each other by increasing / decreasing and curvature of the arc (positive / negative). The [Fig. 5-6] show these four types.

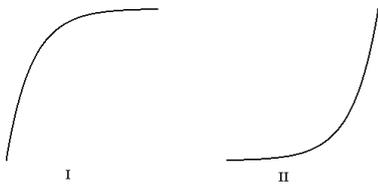


Fig. 5: Growing exponentials.

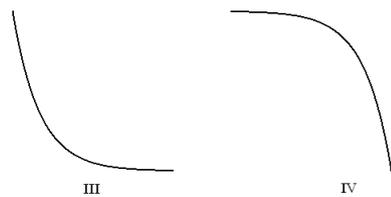


Fig. 6: Decreasing exponentials.

Graphic elements of I-IV types are described by equations (14 - 17), respectively:

$$y = a - e^{-kx+b} \quad (14)$$

$$y = a + e^{kx+b} \quad (15)$$

$$y = a + e^{-kx+b} \quad (16)$$

$$y = a - e^{kx+b} \quad (17)$$

where a and b - coefficients that affect the displacement of the graph with respect to the coordinate axes,
 k - coefficient that affects the curvature of the graph.

In a generalized form, formulas (14) and (15) can be written in the form of formula (18), and formulas (16) and (17) in the form (19):

$$y = a + s \cdot e^{skx+b} \quad (18)$$

$$y = a + s \cdot e^{-skx+b} \quad (19)$$

where $s = \pm 1$.

The technologist sets only s and k coefficients. The coefficients a and b are calculated by the program.

For the exponent described by equation (18) and passing through two nodes (x_1, y_1) and (x_2, y_2) , the system (20) takes place:

$$\begin{cases} y_1 = a + s \cdot e^{skx_1+b} \\ y_2 = a + s \cdot e^{skx_2+b} \end{cases} \quad (20)$$

This is a system of two equations and two variables. We solve it with respect to a and b.

We subtract the first from the second equation:

$$y_2 - y_1 = s \cdot e^b (e^{skx_2} - e^{skx_1})$$

We express from this equation e^b :

$$e^b = \frac{y_2 - y_1}{s \cdot (e^{skx_2} - e^{skx_1})}$$

From here we can find b:

$$b = \ln \frac{y_2 - y_1}{s \cdot (e^{skx_2} - e^{skx_1})} \quad (21)$$

Knowing b, we can find a from the first equation:

$$a = y_1 - s \cdot e^{skx_1+b} \quad (22)$$

For the exponent described by equation (19) and passing through two points (x_1, y_1) and (x_2, y_2) , the system will have the following form (23):

$$\begin{cases} y_1 = a + s \cdot e^{-skx_1+b} \\ y_2 = a + s \cdot e^{-skx_2+b} \end{cases} \quad (23)$$

Solving it in a similar way, it can be established that the calculated formulas for a and b will have the form (24) and (25), respectively:

$$b = \ln \frac{y_1 - y_2}{s \cdot (e^{-skx_2} - e^{-skx_1})} \quad (24)$$

$$a = y_1 - s \cdot e^{-skx_1+b} \quad (25)$$

The harmonic element is described by equation (26):

$$y = A \cdot \sin(\omega \cdot x + \varphi) + k \cdot x + b \quad (26)$$

where A - the amplitude,
 ω - frequency,
 φ - phase shift,
 k - coefficient of slope,
 b - distance from the abscissa.

In addition to the formulas for describing graphic elements, ATS uses some other formulas.

To verify that the node (x^*, y^*) of a neighborhood of a linear graphic element with origin at node (x_1, y_1) and end at node (x_2, y_2) belongs to formula (27):

$$|y^* - kx^* - b| < \varepsilon, \tag{27}$$

where ε – number describing the extent of the neighborhood.

To verify that the node (x^*, y^*) of a neighborhood of an exponential graphic element with origin at the node (x_1, y_1) and end at point (x_2, y_2) belongs to formula (28):

$$|y^* - a - s \cdot e^{skx^* + b}| < \varepsilon \tag{28}$$

where ε – number describing the extent of the neighborhood.

To verify that the node (x^*, y^*) of the neighborhood of the harmonic graphic element with the origin at the node (x_1, y_1) and the end at node (x_2, y_2) is used, the formula (29):

$$|y^* - A \cdot \sin(\omega x^* + \varphi) - k \cdot x^* - b| < \varepsilon \tag{29}$$

SUMMARY

[Fig. 7] shows an algorithm for planning test technologies using a method based on the use of nodal points.

The planning begins with the choice of the engine. At this stage the technologist chooses the technological parameters that will be included in the newly created test technology. This determines the choice of the mathematical model that will be used in calculating the control signal.

After that control programs for all the necessary technological parameters are created. The technologist manipulates with nodal points (adds, deletes, changes parameters). Each of its actions is checked by the system for correctness – compliance with the rules of the graphic language.

Incorrect actions by the system are not allowed. When the single-parameter control program takes the desired form, the technologist proceeds to create the next program.

The planning of the test technology is completed when the control programs for all technological parameters are created.

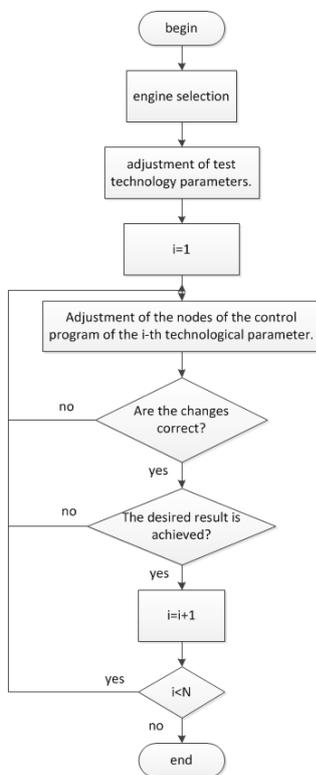


Fig. 7: Algorithm for planning testing technology.

CONCLUSION

As a model for tuning the ICE test modes, the dependence on the engine speed versus time was taken to adjust the engine to the required test mode. In the case of obtaining a universal dependence, which will allow controlling and adjusting the obtained model, it will be possible to talk about the creation of an adaptive control system for testing ICE. The solution of this problem will allow simplify, and also qualitatively improve the level of the ICE tests.

CONFLICT OF INTEREST

There is no conflict of interest.

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None

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