DOI 10.29042/2019-5227-5232

Helix Vol. 9 (4): 5227- 5232

Automated Modeling System for Internal Combustion Engines

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Received: 23rd July 2019, Accepted: 10th August 2019, Published: 31st August 2019

Abstract
The widespread use of internal combustion engines (ICE) requires continuous improvement of basic technical, economic and operational characteristics. Creating a competitive internal combustion engine involves the use of promising ways to improve the quality of control, the experimental development of the engine, the reduction of development time and the preparation of its serial production.
In the process of developing the software of the automated test system (ATS) of the engine, one of the main tasks is to determine the mathematical model of the engine, which is necessary for setting the parameters of the ATS. Knowledge of the mathematical model of the internal combustion engine also provides the possibility of taking into account the dynamic properties of the engine when developing an automated test system. In addition, these equations can be used to control the operating modes of the internal combustion engine using a computer during bench tests.

Keywords
Modeling; Network; Engine; Automation; System.

Introduction

Mathematical models are widely used in the design and development of microprocessor engine control systems, the development of methods for diagnosing its operation, and in solving a number of other problems [1]. Important aspects of mathematical modeling of the engine are the ability to automate the search for optimal options and, ultimately, the use of mathematical models as a dynamic functional analogue of an object or its element when building an ATS [2].
With the help of mathematical modeling, it is possible to analyze the course of individual working processes and the entire working cycle, to predict the main indicators and characteristics of the engine [3]. At the same time, models cannot be fully adequate to an object and reflect only certain of its properties that are of interest for the purposes of a specific study [4].
The implementation of mathematical models in the ATS program allows the system to operate in real time [5].
The complexity of creating ATS engine software is related to the functioning of systems in real time and the presence of time constraints on the response and processing of various input signals and situations [6]. As a result, the ATS engine software package must ensure that a sufficiently large variety of research, developmental and serial tests of numerous types and modifications of the internal combustion engine is carried out [7].
Therefore, mathematical modeling and the problem of determining the parameters of a mathematical model of the internal combustion engine, as well as the definition of control actions, is one of the urgent problems in the design of ATS [8].
The relevance of the topic is due to the need to automate the engine management function in the process of bench testing - a mass technological operation at the stage of putting the product into operation [9]. The development of ATS software is a necessary stage for solving this problem, and in order to apply CALS technologies in production, it becomes a prerequisite [10].

Methods

The software of an automated engine test system is a combination of mathematical models (MM) and the methods underlying the logic and computational processes that accompany the performance of automated tests [11].
Engines are complex technical systems [12]. At all stages of the life cycle, they are subjected to various kinds of tests, the volume and complexity of which, as practice shows, continuously increase [13]. Tests are among the most responsible and time-consuming stages of the life cycle of the engine [14]. At this stage, the final assessment of the structure is carried out, its compliance with technical and technological parameters is determined [15].
The object of control is a test bench with an installed engine and technological equipment, providing testing [16]. Depending on the type of testing, the composition of the equipment interacting with ATS and the technology of testing can vary [17].
ATS allows to improve the quality and efficiency of design development, reduce the time needed to refine and improve engines while reducing the cost of bench testing [18].
On the basis of the analysis made, a conclusion was drawn that the ATS of the internal combustion engine was more effective on the basis of the graphical tuning method, where the segments representing the acceleration points, constant speed, were chosen as graphic elements or braking (Fig. 1) [19].
The method is reduced to solving a problem that would allow, using the output frequency dependence, to obtain input control parameters to ensure a given mode of engine operation [20]. The movement of the fuel pump rail is taken as a

control. By changing this value, you can set and control the output parameter - the rotational speed of the crankshaft [21]. This task takes the opposite form from the existing one [22].
After analyzing the currently used test methods, it was concluded that such a task is currently considered superficially and has not found practical application, since the equipment used for testing does not allow the use of this technology [23].

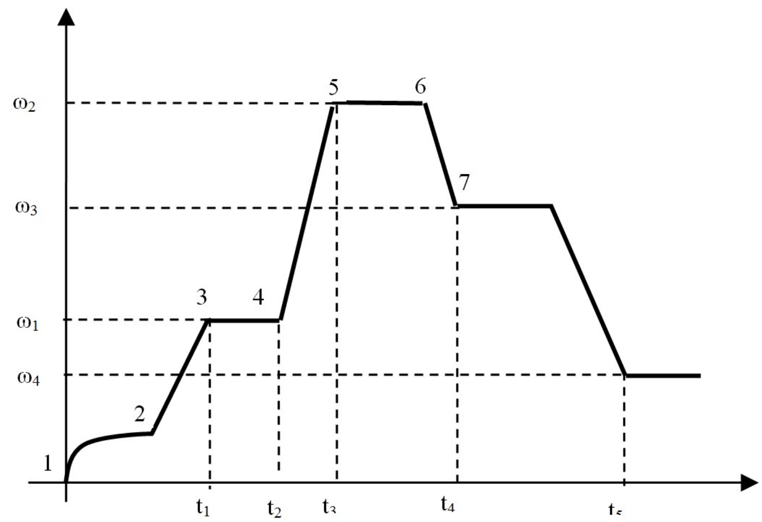

Fig.1: Image of the Dependence of the Angular Frequency on Time

The task leads to the definition of mathematical dependencies describing the internal combustion engine, with respect to the controlled value - the movement of the fuel pump rail [24]. The solution of this equation will allow to obtain the dependence of the shaft rotation frequency on the movement of the fuel pump rail.
The purpose of the evaluation of the technical condition of the engine is to determine the values of the structural parameters that directly characterize the technical condition of the engine, its assemblies and parts [25]. Determining the necessary and sufficient number of parameters that would allow to reliably assess the technical condition of the engine as a whole, its systems, mechanisms and individual parts, is based on an analysis of the physical processes occurring in the engine and the patterns of their development.
To set up ATS engines, it is proposed to use a graphical interface, which includes an integrated programming environment based on a database of graphic modules of operations, based on the principle of FBD-blocks of SCADA-systems [26]. The graphic element of the technology carries the settings. To determine the number and types of graphic elements of the technology, the real technological process is divided into a set of technological operations, i.e. it is decomposed, typical operations are distinguished, and the graphic form of their representation in the system is determined.
As one of the typical control operations considered a mathematical model of the engine, which provides the possibility of taking into account the dynamic properties of the engine [27]. An overly detailed mathematical description that takes into account the properties of elements that are not essential for a given task, complicates the solution of the problem and may even make it insoluble. Excessive simplification of the mathematical description, the adoption of unfounded assumptions is unacceptable, since this can be missed essential qualities of the elements and, consequently, processes in the system.
If the ATS sets the test modes in the form of the required characteristics, which in our case are the output parameters of the engine, then the system itself must develop control actions. This is impossible without the development of a model of the control object, which is necessary for setting the parameters of the ATS of the internal combustion engine.
ICE without pressurization, as a controlled object at the frequency of rotation of the crankshaft ω is described by a linear differential equation:

$$T_D \frac{d\omega(t)}{dt} + K_D \omega(\mathrm{t}) = h(t) - T_C M_C(t)$$

where $\omega(t)$ - crankshaft speed; $h(t)$ - position of the fuel pump rail; $M_C(t)$ – load value; t – time; T_D, K_D, T_C – constant values, depending on the design features of the engine.
Moving the rail $h(t)$ we obtain from the relation:

$$h(t) = T_D \frac{d\omega(t)}{dt} + K_D \omega(t) + T_C M_C(t)$$

When testing, it is necessary to transfer the internal combustion engine from one state to another, then for t_i and ω_i we take the specific state of the test mode, which takes place during the transition from one engine state to another, and i is the transition point number.

Frequency change sites at specified intervals can be expressed from the equation of a straight line, where ω_i is the required initial value of the motor shaft rotation frequency at the time t_i, ω_{i+1} is the final required value of the motor shaft rotation frequency at the time t_{i+1}.

The dependence $\omega(t)$ will look like

$$\omega(t) = \frac{\omega_{i+1} - \omega_i}{t_{i+1} - t_i} \cdot t - \frac{t_i(\omega_{i+1} - \omega_i)}{t_{i+1} - t_i} + \omega_i$$

where $i = \overline{1,n}$; n – the number of ICE transition points from one state to another.

With the well-known mathematical model and the specified values of the frequency change, it is necessary to determine the control value $h(t)$, leading to the required values.

The result of the calculation is the dependency:

$$h(t) = T_D \frac{\omega_{i+1} - \omega_i}{t_{i+1} - t_i} + K_D \frac{\omega_{i+1} - \omega_i}{t_{i+1} - t_i} \cdot t - K_D \frac{t_i(\omega_{i+1} - \omega_i)}{t_{i+1} - t_i} + K_D \omega_i + T_C M_C(t)$$

where $i = \overline{1,n}$.

The ICE model with autonomous independent gas turbine supercharging is described by a linear differential equation:

$$T_2^2 \frac{d^2\omega(t)}{dt^2} + T_1 \frac{d\omega(t)}{dt} + T_0\omega(t) = T_h \frac{dh(t)}{dt} + K_h h(t) - T_M \frac{dM_C(t)}{dt} - K_M M_C(t)$$

where $\omega(t)$, $h(t)$, t – are the same values of the parameters as in the previous section. T_2, T_1, T_0, T_h, K_h, T_M, K_M are constant values depending on engine design features.

If we consider the internal combustion engine with respect to the change in the displacement of the pump rail, then some assumptions can be made due to the linearity of the dependence of the rotational speed ω on time. Initial conditions are taken based on the values of the model parameters in the vicinity of the equilibrium state of the engine.

Applying the method of indefinite coefficients and the Laplace transform, we get:

$$\begin{aligned} h(t) = {} & \frac{T_0 \cdot (\omega_{i+1} - \omega_i)}{K_h (t_{i+1} - t_i)} \cdot t + \Big(\frac{T_1(\omega_{i+1} - \omega_i)}{K_h (t_{i+1} - t_i)} - \frac{T_0 \cdot t_i(\omega_{i+1} - \omega_i)}{K_h (t_{i+1} - t_i)} + \\ & + \frac{K_M M_C}{K_h} - \frac{T_0 \cdot T_h(\omega_{i+1} - \omega_i)}{K_h^2 (t_{i+1} - t_i)} \Big) + \Big(\frac{T_0 \cdot T_h(\omega_{i+1} - \omega_i)}{K_h^2 (t_{i+1} - t_i)} - \\ & - \frac{T_1(\omega_{i+1} - \omega_i)}{K_h (t_{i+1} - t_i)} + \frac{T_0 \cdot t_i(\omega_{i+1} - \omega_i)}{K_h (t_{i+1} - t_i)} - \frac{K_M M_C}{K_h} \Big) \cdot e^{-\frac{K_h}{T_h} \cdot t}, \end{aligned}$$

where $i = \overline{1,n}$.

If we consider the internal combustion engine with respect to the change in load, then, applying also the method of uncertain coefficients and the Laplace transform, we obtain:

$$\begin{aligned} M_C(t) = {} & -\frac{T_0 \cdot (\omega_{i+1} - \omega_i)}{K_M (t_{i+1} - t_i)} \cdot t + \Big(\frac{T_1(\omega_{i+1} - \omega_i)}{K_M (t_{i+1} - t_i)} - \frac{T_0 \cdot t_i(\omega_{i+1} - \omega_i)}{K_M (t_{i+1} - t_i)} + \\ & + \frac{K_h \cdot h}{K_M} - \frac{T_0 \cdot T_M(\omega_{i+1} - \omega_i)}{K_M^2 (t_{i+1} - t_i)} \Big) - \Big(\frac{T_0 \cdot t_i(\omega_{i+1} - \omega_i)}{K_M (t_{i+1} - t_i)} + \\ & + \frac{T_1(\omega_{i+1} - \omega_i)}{K_M (t_{i+1} - t_i)} - \frac{T_0 \cdot T_M(\omega_{i+1} - \omega_i)}{K_M^2 (t_{i+1} - t_i)} - \frac{K_h \cdot h}{K_M} \Big) \cdot e^{-\frac{K_M}{T_M} \cdot t}, \end{aligned}$$

where $i = \overline{1,n}$.

As a result of the calculations, relations have been obtained that allow the test object to be controlled by two input parameters: the displacement of the fuel pump rail and the change in the load on the motor shaft.

Results and Discussion

Using the method of D-splitting in the plane of two parameters, the areas of stability of mathematical dependencies describing the internal combustion engine without pressurized and with autonomous gas turbine supercharging are determined, and the range of change of the studied coefficients is determined. These coefficients are T1 and T2. When changing them in the range from -0.02 to ∞, the system will always be stable.

In the process of conducting an experimental test of the engine KamAZ 740.60 data were obtained, which were filmed according to GOST 8670-80 at stand KI-15711-01 and used to build characteristics. Tests of the engine were carried out according to the international standard 1585 in stationary modes.
The graph of the transient process of the KamAZ 740.60 engine indicators with a load increase is shown in Fig. 2.

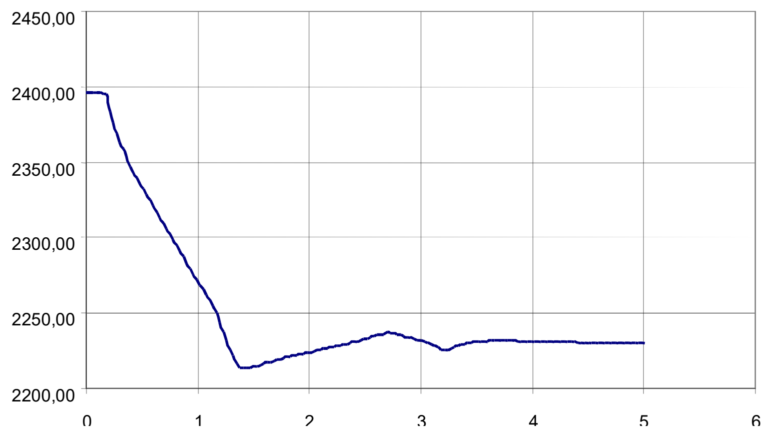

Fig 2: Characteristics of the Internal Combustion Engine when the Load on the Motor Shaft

Summary
To determine the simulation error, we perform the imposition of an experimental characteristic and a simulated one. Figure 3 presents the characteristics obtained.

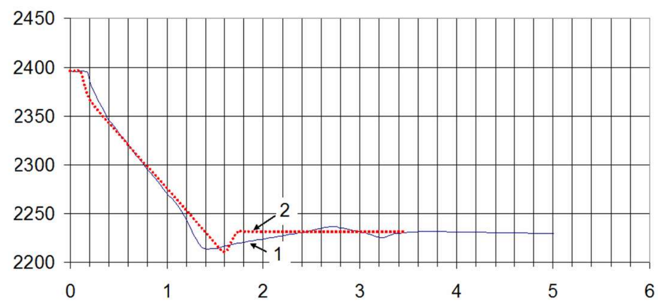

Fig 3: Transient Characteristics of the Internal Combustion Engine (Experimental and Simulated)

According to the graph representing the combined characteristics, it is clear that the modeling error is in the region of 5%.
The block diagram allows to investigate the control system simultaneously using two input parameters.
Thus, the constructed model of the ATS makes it easy to draw an analogy with the operation of the test object. Having set the necessary initial parameters of the work, it is possible to investigate various modes of engine operation in real time.
If a change in the displacement of the rail h, as well as the change in the load on the motor shaft to the maximum value at which the simulation process was carried out, is submitted to the system input, then the test process specified by the characteristic, the output of the system will be as follows (Fig. 4).
The model obtained as a result of solving differential equations with respect to input parameters makes it possible to control the testing process.
Based on the above studies, a device has been developed that ensures the movement of the fuel pump rail.

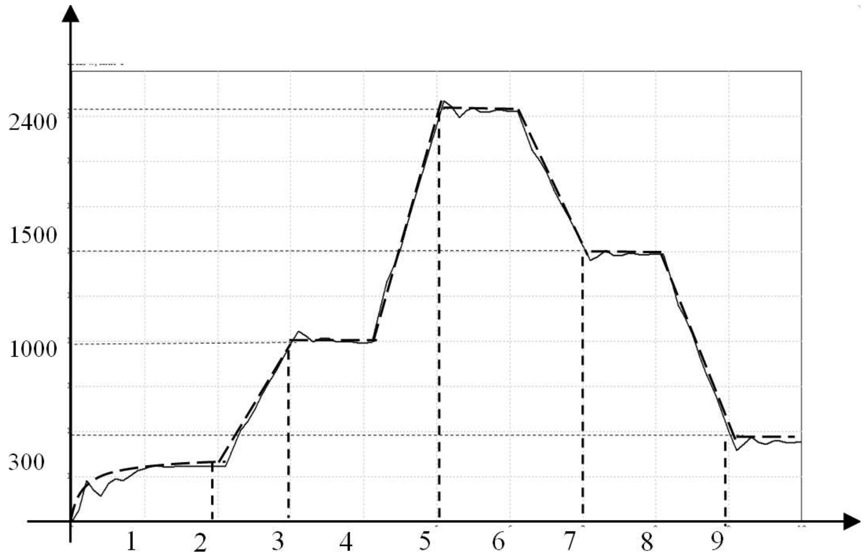

Fig 4: The Combination of a Given and Simulation Characteristics

Conclusions

A method has been developed for setting model parameters using graphic characteristics representing acceleration, constant deceleration moments in order to study various engine operating modes in real time, as well as the ability to analyze the influence of such factors as load, temperature, fuel composition affecting engine operation.

Acknowledgements

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

References

[1] X. Li, F. Yu, H. Jin, J. Liu, Z. Li, X. Zhang, “Simulation platform design for diesel engine fault,” 2011 International Conference on Electrical and Control Engineering, ICECE 2011 - Proceedings, art. no. 6057562, pp. 4963 - 4967, 2011.

[2] L. Guihang, W. Jian, W. Qiang, S. Jingui, “Application for diesel engine in fault diagnose based on fuzzy neural network and information fusion,” 2011 IEEE 3rd International Conference on Communication Software and Networks, ICCSN 2011, art. no. 6014398, pp. 102 - 105, 2011.

[3] Lenar A. Galiullin; Rustam A. Valiev, “Internal combustion engine fault simulation method,” IIOAB OURNAL, №9, pp. 91-96, 2018.

[4] M. Shah, V. Gaikwad, S. Lokhande, S. Borhade, “Fault identification for I.C. engines using artificial neural network,” Proceedings of 2011 International Conference on Process Automation, Control and Computing, PACC 2011, art. no. 5978891, 2011.

[5] Lenar A. Galiullin; Rustam A. Valiev, Khairullin A. Haliullovich, “Method for modeling the parameters of the internal combustion engine,” IIOAB JOURNAL, №9, pp. 83-90, 2018.

[6] Lenar A. Galiullin; Rustam A. Valiev, “Control vector for ice automated test and diagnostic system,” DILEMAS CONTEMPORANEOS-EDUCACION POLITICA Y VALORES, №6 SI, article №95, 2018.

[7] Y. Yu, J. Yang, “The development of fault diagnosis system for diesel engine based on fuzzy logic,” Proceedings - 2011 8th International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2011, 1, art. no. 6019556, pp. 472 - 475, 2011.

[8] R.A. Valiev, A.Kh. Khairullin, V.G. Shibakov, “Automated Design Systems for Manufacturing Processes,” Russian Engineering Research, 35(9). pp. 662 – 665, 2015.

[9] L.A. Galiullin, R.A. Valiev, “An automated diagnostic system for ICE,” (2018) Journal of Advanced Research in Dynamical and Control Systems, 10 (10 Special Issue), pp. 1767-1772.

[10] R. Isermann, “Model-based fault-detection and diagnosis - Status and applications,” Annual Reviews in Control, 29 (1), pp. 71-85, 2005.

[11] D. Wei, “Design of Web based expert system of electronic control engine fault diagnosis,” BMEI 2011 - Proceedings 2011 International Conference on Business Management and Electronic Information, 1, art. no. 5916978, pp. 482 - 485, 2011.

[12] L.A. Galiullin, R.A. Valiev, “Automation of Diesel Engine Test Procedure,” IEEE 2016 2ND International Conference on Industrial Engineering, Applications And Manufacturing (ICIEAM), Published: 2016.

[13] L.A. Galiullin, R.A. Valiev, “Method for neuro-fuzzy inference system learning for ICE tests,” (2018) Journal of Advanced Research in Dynamical and Control Systems, 10 (10 Special Issue), pp. 1773-1779.

[14] L.A. Galiullin, “Development of Automated Test System for Diesel Engines Based on Fuzzy Logic,” IEEE 2016 2ND International Conference on Industrial Engineering, Applications And Manufacturing (ICIEAM) Published: 2016.

[15] R. Ahmed, M. El Sayed, S.A. Gadsden, J. Tjong, S. Habibi, “Automotive internal-combustion-engine fault detection and classification using artificial neural network techniques,” IEEE Transactions on Vehicular Technology, 64 (1), № 6803044, pp. 21-33, 2015.

[16] L.A. Galiullin, R.A. Valiev, “Diagnostics Technological Process Modeling for Internal Combustion Engines,” 2017 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM) Published: 2017.

[17] L.A. Galiullin, R.A. Valiev, “Modeling of internal combustion engines by adaptive network-based fuzzy inference system,” (2018) Journal of Advanced Research in Dynamical and Control Systems, 10 (10 Special Issue), pp. 1759-1766.

[18] L.A. Galiullin, R.A. Valiev, L.B. Mingaleeva, “Method of internal combustion engines testing on the basis of the graphic language,” Journal of Fundamental and Applied Sciences, Volume: 9, Special Issue: SI, Supplement: 1, Pages: 1524-1533, Published: 2017.

[19] J. Chen, R. Randall, N. Feng, B. Peeters, H. Van Der Auweraer, “Automated diagnosis system for mechanical faults in IC engines,” 10th International Conference on Condition Monitoring and Machinery Failure Prevention Technologies, CM 2013 and MFPT 2013, 2, pp. 892-903, 2013.

[20] N. McDowell, G. McCullough, X. Wang, U. Kruger, G.W. Irwin, “Application of auto-associative neural networks to transient fault detection in an IC engine,” Proceedings of the 2007 Fall Technical Conference of the ASME Internal Combustion Engine Division, pp. 555-562, 2008.

[21] L.A. Galiullin, R.A. Valiev, “Optimization of the parameters of an internal combustion engine using a neural network,” (2018) Journal of Advanced Research in Dynamical and Control Systems, 10 (10 Special Issue), pp. 1754-1758.

[22] R.B. Randall, “The application of fault simulation to machine diagnostics and prognostics,” 16th International Congress on Sound and Vibration 2009, ICSV 2009, 8, pp. 5042-5055, 2009.

[23] J. Chen, R. Randall, B. Peeters, W. Desmet, H. Van Der Auweraer, “Neural network based diagnosis of mechanical faults in IC engines,” Institution of Mechanical Engineers - 10th International Conference on Vibrations in Rotating Machinery, pp. 679-690., 2012.

[24] Lenar A. Galiullin, Rustam A. Valiev, “Diagnosis System of Internal Combustion Engine Development,” Revista Publicando, Volume: 4, Issue: 13, Pages: PR128-PR137, Part: 2, Published: 2017.

[25] Lenar A. Galiullin, Rustam A. Valiev, Lejsan B. Mingaleeva, “Development of a Neuro-Fuzzy Diagnostic System Mathematical Model for Internal Combustion Engines,” HELIX, Volume: 8, Issue: 1, Pages: 2535-2540, Published: 2018.

[26] D. Danfeng, M. Yan, G. Xiurong, “Application of PNN to fault diagnosis of IC engine,” 2009 2nd International Conference on Intelligent Computing Technology and Automation, ICICTA 2009, 2, № 5287738, pp. 495-498, 2009.

[27] JLenar A. Galiullin, Rustam A. Valiev, “Mathematical modelling of diesel engine testing and diagnostic regimes,” Turkish Online Journal of Design Art and Communication, Volume: 7, Pages: 1864-1871, Published: DEC 2017.

