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ARTICLE

INTERNAL COMBUSTION ENGINE FAULT SIMULATION METHOD

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ABSTRACT

This article describes methods of diagnosing of internal combustion engines (ICE). The conclusion is drawn that the majority of modern methods and ICE diagnostic devices don't solve fully a problem of determination of technical condition of the engine, often are labor-consuming and expensive. The choice of a method and mode of diagnosing of ICE on the basis of external speed characteristics is carried out for what the list of sensors and executive mechanisms of a control system of the engine is defined. The choice of a method of training of fuzzy Sugeno systems on the basis of hybrid neural networks is reasonable. The possibility of identification of difficult dependences by the systems of fuzzy sets on the basis of hybrid networks is proved. Разработаны и реализованы алгоритмы обработки информации сигналов датчиков и исполнительных механизмов системы управления для вычисления внешних скоростных характеристик. Possibilities of systems for fuzzy conclusion on identification of dependences are the basis for algorithms. Assessment of influence of external factors on the accuracy of measurements therefore it is established that the maximum error doesn't exceed 5% is carried out. Experimental studies of metrological characteristics of the diagnostic system have been carried out, which showed that the relative errors do not exceed the estimated errors. In this case, speed characteristic was determined in the entire range of engine speed.

KEY WORDS
diesel engine, fault diagnostic, test, information system, neural network.

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INTRODUCTION

The estimation of the general condition of the engine is made on the effective parameters of its operation, which include the effective torque and power on the motor shaft, fuel and air consumption, ignition timing, and harmful emissions in the exhaust gases [1]. The work of systems implementing this approach is based on brake and non-brake methods.

Brake methods involve the use of special loading stands with running drums. This method was not widely used due to the high cost of equipment.

Non-brake methods are simpler and do not require the use of special braking devices [2]. In this case, the angular acceleration is measured when the engine is accelerated without an external load from the minimum stable speed to the maximum due to the sharp opening of the injection pump. This method allows carrying out diagnostics in real operating conditions, and equipping modern ICE with electronic control systems - to increase the number of controlled parameters.

The disadvantages of the systems implementing this approach are to a different degree the low accuracy associated with the need for numerical differentiation of the angular velocity variation function, the incompleteness of the parameters to be determined, and a narrow range of rotation frequencies for the characteristics obtained [3].

In view of what has been said, the task of creating a diagnostic system that makes it possible to evaluate the basic performance of ICE over a wide range of engine speed is urgent and requires the development of original methods that go beyond existing approaches.

METHODS

The main provisions of the theory of fuzzy sets and fuzzy logic are applied. Typical membership functions and operations on fuzzy numbers are used [4]. The concepts of fuzzy and linguistic variables are considered. In this case, the fuzzy variable is determined by the triple <a, X, A>, where a - name of a fuzzy variable, X - the domain of its definition (universe), A - fuzzy set on X, describing the possible values that a fuzzy variable can take.

A generalization of a fuzzy variable is the so-called linguistic variable, defined by a tuple <p, T, X, G, M>, where

- p - name of the linguistic variable,
- T- basic term-set of a linguistic variable or the set of its values (terms), each of which is the name of a separate fuzzy variable,
- X - domain of fuzzy variables that are included in the definition of a linguistic variable,
- G - a syntactic procedure that describes the process of generating new values for a given linguistic variable,
- M – a semantic procedure that allows each new value of a given linguistic variable, obtained by procedure G, to be assigned to each meaningful content by forming the corresponding fuzzy set.

The basic configuration of the fuzzy inference system based on the rules of fuzzy products is used, in which conditions and conclusions are formulated in terms of fuzzy linguistic utterances [5].

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Thus, the problem of identifying data with fuzzy Sugeno systems with membership functions of a Gaussian type reduces mainly to the selection of the number of terms of the input variable. With an increase in the number of terms of the input variable, the errors do not increase [6]. At the same time, with a decrease in the number of terms of the input variable, the smoothing properties of the fuzzy system approximation will be strengthened [7].

The undoubted advantages of fuzzy systems to identify data can be attributed to the fact that not require special selection output system structure and the form of membership functions, unlike parametric identification methods (exponential, logarithmic, exponential, power and other techniques).

RESULTS AND DISCUSSION

To build the speed characteristic, it is enough to process the information contained in the five signals of the control system [8]. These include the signals of the crankshaft position sensor, the mass air flow, the position of the fuel pump rail, the fuel injection and ignition control systems, etc.

In the developing system, the definition of speed characteristic is based on the non-brake method. The engine is accelerated by changing the position of the fuel injection pump rail. The signals of the engine control system are continuously measured.

The choice of the diagnostic mode is reduced to providing such engine operating conditions, in which its properties are presented most fully. This mode corresponds to the mode of full fuel supply, when the fuel pump rail is opening as much as possible [9]. This is due, first of all, to the maximum wide frequency range of the engine and the maximum work of inertial forces and frictional forces. In addition, in the real conditions of the diagnosis, to ensure the permanence of the position of the rail (different from 100% of the opening of the rail) is problematic enough.

The hardware of the AIS includes a cable-splitter of the signals of the control system, a coupling device, an input module for analog signals, and a computer. To provide mobility as a computer, a portable personal computer of the "notebook" type was chosen. This makes it possible to carry out diagnostics while the vehicle is moving, when the load is the mass of the car, driven to the crankshaft via the transmission [10]. As an analog input module, an external ADC / DAC E14-440 module from L-card was selected, which was added to the State Register of measuring instruments. The module interacts with the computer via the USB bus, the ADC has a bit capacity of 14 bits, the maximum conversion frequency is 400 kHz [11]. This solution allows for diagnostics in real operating conditions. The software part manages the data collection and processing of the engine control system signals. Processing algorithms are based on the use of fuzzy inference systems as part of hybrid networks, which ensures high accuracy and repeatability of the results of experimental tests in a wide range of engine speed.

On the basis of the previously obtained knowledge base of fuzzy rules [12], we will formulate a methodology for testing and diagnosing diesel engines in accordance with GOST 18509-88 "Diesel tractors and combine harvesters. Test methods». The given standard assumes measurement of parameters of the engine in a stationary mode at a step equal to 200 min-1. The fuel consumption is selected as low as possible, which makes it possible to realize an economical operating mode, and the torque according to its characteristics will be selected to coincide with the corresponding speed.

The next stage is the presentation of this testing method in the form of images, which are formed according to the methodology for designing testing techniques for diesel engines., described at [13].
The figures for ω, MH and GT are shown in the [Fig. 1,2,3].

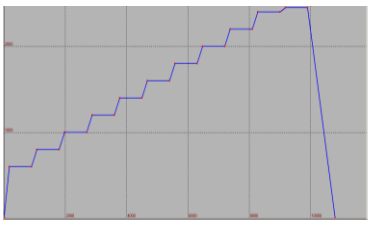

Fig. 1: The figure for the engine speed.

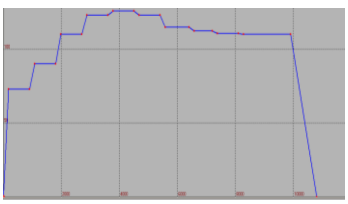

Fig. 2: Figure for moment of loading.

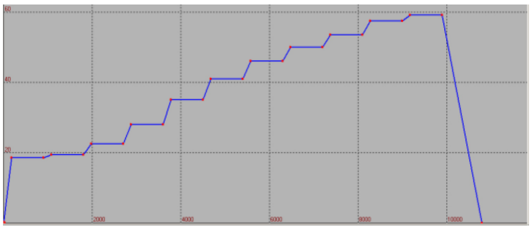

Fig. 3: Figure for fuel consumption.

The use of graphical representation of data is convenient for humans, for computer processing it is better to have numeric data. Therefore, the next step is to convert the images into a summary table of parameters.

This data is saved in the summary table of parameters [Table 1].

Table 1: Summary table of parameters

№	Test time, min.	Figure for ω, min^{-1}	Figure for M_H, Nm	Figure for G_T, kg/hour
1.	Engine start			
2.	15	600	73	18,6
3.	30	800	90	19,5
4.	45	1000	110	24
5.	60	1200	123	30
6.	75	1400	125,8	35
7.	90	1600	123	41
8.	105	1800	115	46
9.	120	2000	112,5	50
10.	135	2200	110,8	53,5
11.	150	2400	110	57,5
12.	165	2450	110	59,2
13.	180	600	73	18,6
14.	Engine stop			

At the next stage, fuzzification is carried out, that is, the conversion of values of the input variables A_i into fuzzy B_i, by linguistic variable [14]. Such transformation is in fact a kind of valuation necessary to translate the given data into subjective estimates. Linguistic variables for translating a value into fuzzy are stored in the knowledge base of fuzzy logic. The result of the work at this stage will be a converted summary table of parameters, in which instead of clear values the membership functions will be located. The result of this stage is shown in the [Fig. 4].

The next step is the formation of an approximate fuzzy result in the output block. To do this, fuzzy rules stored in the knowledge base of fuzzy logic were applied.

The next stage is defuzzification. Defuzzification means the procedure for converting fuzzy values obtained as a result of fuzzy inference into clear ones, on the basis of which it is possible to conduct engine tests. For defuzzification we use the fuzzy derivation of Sugeno. This is because it is highly accurate and easy to use this algorithm will reduce the processing time of information.

The results of fuzzy inference are control vectors in linguistic variables ω, MH and GT.
F_ω= (0; 2,99; 6,48; 11,13; 16,13; 21,1; 26; 30,98; 36; 43,53; 50);
F_{Mh}=(0; 3,04; 7,37; 12,5; 15,17; 21,43; 28, 31,25; 36; 45; 50);
F_{Gt}=(0; 1; 5,7; 10,39; 14,3; 19,32; 24,12; 28,97; 33,97; 41,11; 48).

We calculate the total result vector by three parameters ω, MH and GT based on averaging the average value and the method of ranking the characteristics. The result of the control vector over the averaged value will have the form:

F_S=(0; 2,34; 6,52; 11,34; 15,2; 20,62; 26,4; 30,4; 35,3; 43,21; 49,33).

The control vector by the method of paired comparisons will have the following form:

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F_R=(0; 2,27; 6,42; 11,2; 15,21; 20,53; 25,81; 30,31; 35,26; 43,01; 49,27).

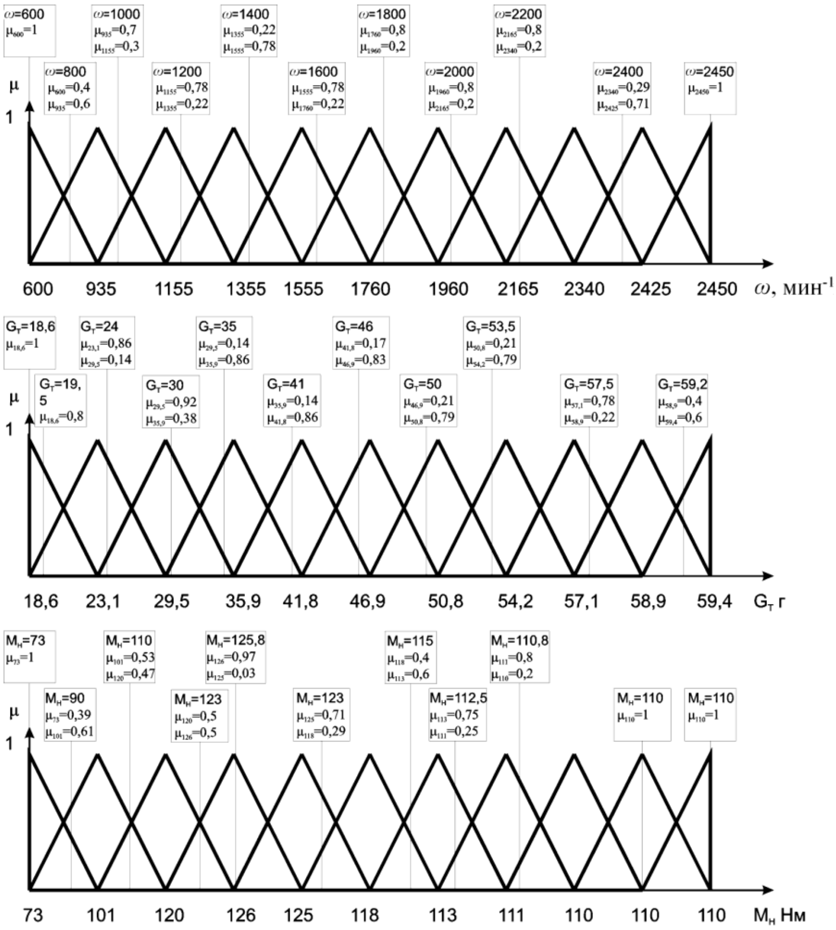

Fig. 4: Fazzification of data.

SUMMARY

Using the vector Fω, which characterizes the engine speed, we will check the degree of adequacy of the control model to the real parameters of the engine. The results of the averaged value of the error of the engine tests are shown in the [Fig. 5].

As can be seen from the figure, the maximum absolute error is 19,4 min-1, which corresponds to a relative error of 2,4% at 800 min-1, which is explained by the high non-linearity of this characteristic in this section. To this value it is necessary to add the error of the test stand, equal to 0,5%. From these values, we can conclude that the error in controlling the diesel engine based on the model as a knowledge base of fuzzy rules will not exceed 2.9%.

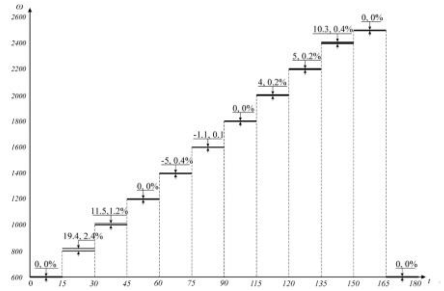

Fig. 5: Calculated and experimental data of the engine speed.

Using the resulting values of ω, MH and GT we construct speed characteristics with these parameters [Fig. 6, 7]. In these figures, [Fig. 1] indicates a calculated characteristic, and [Fig. 2] indicates an experimental characteristic. The maximum error at the moment of engine load is 3% at 1800 min-1, and the maximum error in fuel consumption is 5% at 1400 min-1.

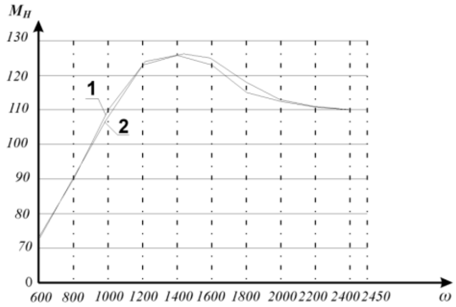

Fig. 6: Speed characteristic for engine load moment.

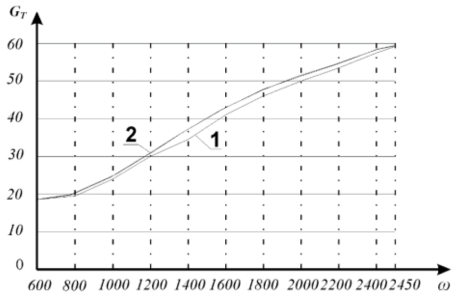

Fig. 7: Speed characteristic for fuel consumption.

Calculation of the speed characteristic for MH and GT showed that the error of control based on the model using fuzzy logic on these characteristics does not exceed five percent, which satisfies the requirements of GOST 18509-88 « Diesel tractors and combine harvesters. Methods of bench tests».

The accuracy of the methods for obtaining the resulting control vectors with concern to the three parameters ω, MH and GT, is determined using the averaging of the mean value and the ranking of the reference parameters based on the testing of diesel engines. The results of the experiment are shown in [Fig. 8].

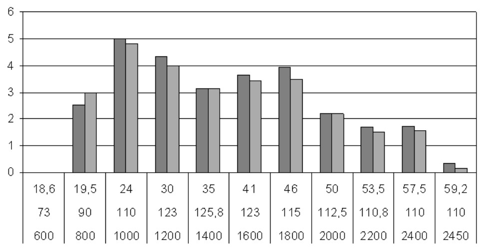

Fig. 8: The error in the methods for determining the resulting vector.

[Fig. 8] shows the relative error of the tests: dark color - by the average value, and light - by the method of paired comparisons. As can be seen from the figure, the second method is more accurate, in addition to the value of 800 min-1, which is explained by the large nonlinearity in this section of the engine speed.

CONCLUSION

As a result of the work, a hardware-algorithmic complex was developed that makes it possible to carry out experiments to obtain the speed characteristics of an internal combustion engine. This system makes it possible to carry out tests of both a working engine and an engine with various malfunctions in real operating conditions. It can be seen that the average value of the relative deviation for the tests performed does not exceed the estimated relative error.

CONFLICT OF INTEREST

There is no conflict of interest.

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FINANCIAL DISCLOSURE

None

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