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SHIP MANAGEMENT INTERNAL COMBUSTION ENGINES WITH REGARD TO ITS TECHNICAL STATE BASED THEORY OF FUZZY SETS

Annotation:The paper presents a fuzzy model of determining the current status of marine internal combustion engine on the basis of criteria established by the manufacturer. Design model and determine the optimal mode of work was carried out by the algorithm of fuzzy inference Mamdani package Fuzzy Logic Toolbox computing environment MATLAB. Using fuzzy logic allows the use of a generalized and formalized experience of a large number of experts in the field of ship diesel power plants, both in the creation of the rule base and to determine the current condition of the engine.
Keywords: fuzzy logic, linguistic variable, membership function, the definition of a technical condition, the ship's engine.

Introduction. Ship internal combustion engines (SICE) are complex systems composed of many subsystems and components, and the failure of at least one of them leads to a loss of efficiency of the engine, which is a threat to the safety of navigation, reduces the efficiency of the engine and extensive material losses. SICE during operation is exposed to moisture, salt, vibration, shock, ambient temperature changes over a wide range, etc. These effects, in addition to the complex physical and chemical processes and energy transformation that occur during operation of the engine, accelerate the process of degradation of parts and assemblies SICE and reduce their reliability.

During operation, the engine plays an important role to ensure the safety of navigation, which is directly related to ensuring the reliability of the engine and its components. To ensure a high level of reliability of the engine of the ship is necessary to carry out continuous monitoring of its technical condition, failure to timely detect and prevent sudden failure of the engine and its systems. The solution to this problem is possible in the presence of a system for assessing the technical condition of the engine in real time. Evaluation of the technical condition of the ship's engine is in operation, provides an opportunity to optimize operating conditions of the engine, focusing on economic performance, environmental standards and the safety of navigation. Additionally, continuous monitoring allows for timely detection of faults, to prevent sudden failure of the engine and its components. This in turn leads to an increase in the interval between repairs and reduce operating costs.

In order to enhance the evaluation of the technical condition of the engine, as well as for early detection of faults are currently using modern methods of simulation and computer tools. At the same time, the use of fuzzy logic allows to make management decisions on the choice of operating conditions of the engine in a fuzzy, incomplete and uncertain information. Since marine engines for use characteristic feature is that the decision on the choice of operating conditions, in most cases, made subjectively only chief engineer, then it is likely that the decision will not be correct. In this regard, the development of methods that could generalize and formalize the experience of a large number of marine engineers and based on them to create a system to support decision-making on the choice of operating conditions in real time, is today an important task of the technical operation of marine SICE.

Analysis of publications. At the present days, there are a variety of means, methods and systems of information on the technical condition of the ship's engine by controlling the structural and functional parameters. For nondestructive testing include:vibroacoustic [1,2], ultrasonic [3], magnetic [4], etc. The basis of integrated assessment put statistical methods [5], methods for determining the technical condition of the engine of complex parameters [6], the methods of diagnosing the parameters of exhaust gases [7]. A method of thermal imaging diagnosis of marine diesel engines [8]. It is not always possible to quickly identify the problem due to the lack of clarity and delays in the collection of objective information about the state of the engine in real time [9]. To solve such problems, widespread system of fuzzy inference, which are based on the theory of fuzzy sets [10-12].

The purpose of the article. The development of models for assessing the technical condition of the engine in real time based on the theory of fuzzy sets.

Main part. Model studies can be represented by the formula

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$$y = f(x_1, x_2, \ldots, x_n), \qquad (1)$$

where y - the value of the technical status (output parameter),

$x_1, x_2, \ldots, x_n$ - the parameters controlled during the operation of marine diesel (input parameters).

To build the model, and determine the optimum mode of operation used a system of fuzzy inference algorithm based on fuzzy inference Mamdani. This choice is determined by the fact that when using the model type Mamdani no difficulty with the content interpretation of the parameters of fuzzy model, as well as an explanation of the inference, so it is more understandable for the operator.

As the membership functions for the input parameters used Gaussian function, which is its advantage continuously differentiable on its domain, and the fact that the shape of the curve is determined by only two parameters, making it easy to configure the system:

$$gaussmf(x, \sigma, c) = e^{-\left(\frac{x-c}{\sigma}\right)^2}, \qquad (2)$$

where c - the maximum coordinate of the curve, and σ - concentration factor, the value of which defines the area of the curve accessories.

For output parameter used triangular membership function of fuzzy sets:

$$trimf(x, a, b, c) = \max\left(\min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0\right), \qquad (3)$$

where the parameters *aиc* define the coordinates of the base of the triangle, the parameter b determines the coordinates of the vertices. This feature allows you to get the required accuracy defuzzification by the fixed domain of definition.

Formation of the rule base of fuzzy inference is carried out in an ordered list of agreed fuzzy production rules of the form:

IF "Condition 1" THEN "Conclusion 1".

The aim is to establish the stage of fuzzification correspondence between the specific values of the individual input variable fuzzy inference system and membership functions corresponding to the value of her term input linguistic variable.

Aggregation is a procedure for determining the degree of truth conditions for each of the fuzzy inference rules of the system. Are the levels of "cut-off" for each of the prerequisites rules using operation min:

$$\alpha_k = \bigwedge_{i=1}^{n}\left[\mu^{a_i^k}(x_i)\right] \quad (4)$$

Activation is the process of finding the truth degree of each of the fuzzy inference rules podzaklyucheny, ie definition truncated membership functions of fuzzy sets:

$$\mu'_k = \left(\alpha_k \wedge \mu_k(D)\right), \quad (5)$$

where μ(D)- truncated membership functions for input variables - truncated membership functions for the fuzzy rules.

Accumulation is the process of finding the membership function of a fuzzy subset of the final output for the variable:

$$\mu_\Sigma(D) = \bigvee_{k=1}^{m}\left[\mu'_k(D)\right] \quad (6)$$

Defuzzification systems fuzzy inference is the process or the process of finding a conventional (non-fuzzy) values for each of the output linguistic variables. Defuzzification carried out by the center of gravity. Clearly the value of the output variable is defined as the center of gravity of the resulting accumulation of figures:

$$Y = \frac{\int_{\min}^{\max} x \cdot \mu(x)\,dx}{\int_{\min}^{\max} \mu(x)\,dx} \quad (7)$$

where Y - the result of defuzzification, x - variable corresponding to the output linguistic variable - membership function of the fuzzy set corresponding to the output variable after stage accumulation, min, and max - the left and right points of the interval considered medium fuzzy set output variable.

Practical implementation of the work of the proposed model was implemented for marine engines Wärtsilä6L46C package Fuzzy Logic Toolbox computing environment MATLAB, equipped with special means of fuzzy modeling, which allows the full range of research on the development and application of fuzzy models [13-14].

The formalization of input and output parameters are presented in Table 1.

In the set of parameters describing the technical condition of marine diesel was allocated seven. Their choice is due to the fact that it is for them, developers of the engine Wдrtsilд6L46C identified critical to triggering the alarm [15].

The range of changes was based on the design parameters of auxiliary systems registered in the engine manual.

Table 1

Baths, boundaries and range of the linguistic variables

Linguistic variables	Bathslinguisticvariable	Range
x_1 – «air temperature after air cooler», K	norm	(313,15...343,15)
	allowable	(343,15...348,15)
	inadmissible	(348,15...373,15)
x_2 – «pressure before engine (lubricating oil system)», MPa	norm	(0,3...0,4)
	allowable	(0,2...0,3)
	inadmissible	(0...0,2)
x_3 – «prelubricating pressure», MPa	norm	(0,078...0,08)
	allowable	(0,05...0,078)
	inadmissible	(0...0,05)
x_4 – «temperature before engine», K	norm	(336,15...351,15)
	allowable	(351,15...353,15)
	inadmissible	(353,15...373,15)
x_5 – «pressure before engine (hight temperature cooling water system)» , MPa	norm	(0,32...0,48)
	allowable	(0,2...0,32)
	inadmissible	(0...0,2)
x_6 – «temperature after cylinders(hight temperature cooling water system)», K	norm	(355,15...378,15)
	allowable	(378,15...383,15)
	inadmissible	(383,15...403,15)
x_7 – «pressure before engine (low temperature cooling water system)» , MPa	norm	(0,32...0,44)
	allowable	(0,2...0,32)
	inadmissible	(0...0,2)
y -«technical state»	a good	0,8...1,0
	acceptable	0,5...0,8
	allowable	0,3...0,5
	inadmissible	0...0,3

The causal connection between the values of the parameters and the technical condition of the engine formalized as a set of fuzzy logic rules. To build a base of fuzzy rules was carried out expert evaluation of combinations of input variables with simultaneous evaluation of membership functions. Weighting factors of all the rules were set to 1.

Since the totality of these rules describes the strategy for managing the system, when drafting them was paid special attention to their consistency. Computational experiments have shown that the approximation gives the smallest error base consisting of 366 rules.

Fuzzy equations between the membership function of input and output variables are as follows:

$$\mu^{1(n)}(y) = \mu^{n}(x_1) \wedge \mu^{n}(x_2) \wedge \mu^{n}(x_3) \wedge \mu^{n}(x_4) \wedge \mu^{n}(x_5) \wedge \mu^{n}(x_6) \wedge \mu^{n}(x_7) \quad (8)$$

$$\begin{aligned}
&\mu^{0,8(n)}(y) = \\
&\left[\mu^{a}(x_1) \wedge \mu^{n}(x_2) \wedge \mu^{n}(x_3) \wedge \mu^{n}(x_4) \wedge \mu^{n}(x_5) \wedge \mu^{n}(x_6) \wedge \mu^{n}(x_7)\right] \vee \\
&\left[\mu^{n}(x_1) \wedge \mu^{a}(x_2) \wedge \mu^{n}(x_3) \wedge \mu^{n}(x_4) \wedge \mu^{n}(x_5) \wedge \mu^{n}(x_6) \wedge \mu^{n}(x_7)\right] \vee \\
&\left[\mu^{n}(x_1) \wedge \mu^{n}(x_2) \wedge \mu^{a}(x_3) \wedge \mu^{n}(x_4) \wedge \mu^{n}(x_5) \wedge \mu^{n}(x_6) \wedge \mu^{n}(x_7)\right] \vee \\
&\left[\mu^{n}(x_1) \wedge \mu^{n}(x_2) \wedge \mu^{n}(x_3) \wedge \mu^{a}(x_4) \wedge \mu^{n}(x_5) \wedge \mu^{n}(x_6) \wedge \mu^{n}(x_7)\right] \vee \qquad (9) \\
&\left[\mu^{n}(x_1) \wedge \mu^{n}(x_2) \wedge \mu^{n}(x_3) \wedge \mu^{n}(x_4) \wedge \mu^{a}(x_5) \wedge \mu^{n}(x_6) \wedge \mu^{n}(x_7)\right] \vee \\
&\left[\mu^{n}(x_1) \wedge \mu^{n}(x_2) \wedge \mu^{n}(x_3) \wedge \mu^{n}(x_4) \wedge \mu^{n}(x_5) \wedge \mu^{a}(x_6) \wedge \mu^{n}(x_7)\right] \vee \\
&\left[\mu^{n}(x_1) \wedge \mu^{n}(x_2) \wedge \mu^{n}(x_3) \wedge \mu^{n}(x_4) \wedge \mu^{n}(x_5) \wedge \mu^{n}(x_6) \wedge \mu^{a}(x_7)\right]
\end{aligned}$$

In step defuzzification linguistic variables inputs have been converted into a numerical value representing the technical condition of the ship's engine.

As a result of fuzzy inference obtained surface "input - output", showing the dependence of the technical condition of the engine from the input values (Figure 1).

During the test the system, changing input parameter values ithin a predetermined range causing a change of the output variable in accordance with the actual situation. The results of the system are presented in Table 2. As for the first case, when the values x_1 = 325; x_2 = 0,35; x_3 = 0,078; x_4 =345; x_5 = 0,415; x_6 = 368; x_7 = 0,398, which corresponds to the normal value of the output variable y = 0,893, which, according to experts, this estimate corresponds to the technical status at the given values of the input parameters.

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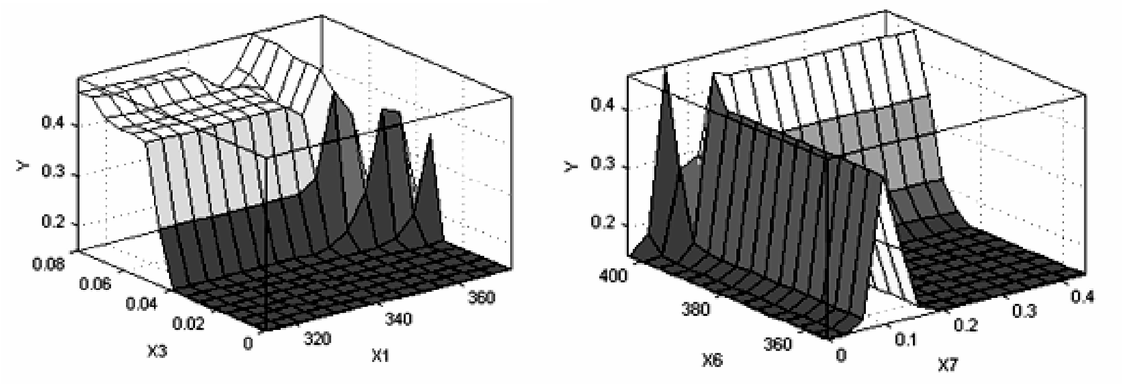

a) b)

Figure 1 - Dependence of the technical condition of the engine on the values of the input parameters:a) x_3 – «prelubricating pressure», x_1 – «air temperature after air cooler»; b) x_6 – «temperature after cylinders (hight temperature cooling water system)», x_7 – «pressure before engine (low temperature cooling water system)»

In the second case, the value was not within the normal range, as in other settings, as was the value in the range of acceptable values. At the same time the output of the y already had a much smaller compared to the first case of a numerical value that indicates the deterioration of the technical condition of the ship's engine.

The results of the system under the conditions of change of input values in the range of "normal" and "acceptable" are shown in the cases 3-6.

Experiments were conducted under conditions of an unacceptable value of one of the input parameters, regardless of the range in which there were other parameters. In the case of 7, when the parameter is invalid, and other parameters are within the normal range at the output of $y = 0{,}158$, which corresponds to "inadmissible" in the real world in such situations is considered critical to the operation of the engine, the engine room alarm is triggered. Similarly, in the case of 8, when he had an invalid value, and all other parameters were within the acceptable range, the value of $y = 0{,}15$, which is also critical in the engine.

Table 2

Results of the system

№	x_1	x_2	x_3	x_4	x_5	x_6	x_7	y
1.	325	0,35	0,078	345	0,415	368	0,398	0,893
2.	325	0,35	0,06	345	0,415	368	0,398	0,887
3.	313	0,25	0,058	350	0,38	356	0,349	0,768
4.	320	0,25	0,079	352	0,26	360	0,36	0,688
5.	346	0,24	0,063	353	0,3	379	0,22	0,491
6.	342	0,35	0,05	351,5	0,2	365	0,2	0,407
7.	318	0,3	0,78	350	0,1	367	0.38	0,158
8.	344	0,25	0,025	352	0,26	380	0,28	0,15

Conclusions. On the basis of these examples show that the most simple model for assessing the current technical condition required for use in controlling the operation of the ship's diesel engines can be built on the basis of the developed framework of the rules of fuzzy logic.

When you change the input values from min to max, the output parameter varied from 1.15 to 0.893, and is adequate for each case.

Presented fuzzy model allows to determine the technical condition of the ship's engine in real-time by changing the values of the input parameters.

To use the model provided by the operator does not need to have some additional skills, and the data obtained at the output can be easily interpreted.

This model is easy to adjust to any ship internal combustion engine.

A further area of research is the creation of an integrated system of marine engine diagnostics based on neural network technology.

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