PRINCIPLES OF CREATING INVARIANT STANDARDS FOR THE FUNCTIONAL DIAGNOSIS OF MARINE DIESELS

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Abstract text.The principles of constructing invariant standards for the functional diagnosis of marine diesel engines are formulated. An example of the construction of invariant standards for the diagnosis of work processes in the cylinders of a particular engine is given; The results of practical diagnostics of working processes in engine cylinders are given.

Keywords: invariant standard, principles of construction, diagnostic results

Practical difficulties in the functional diagnosis of the main marine diesels are caused by the instability of the propeller characteristics. Under the influence of variable perturbations on the side of the propeller, the possible variations in the engine's energy and economic parameters significantly exceed the deviations caused by changes in the technical state of the systems ensuring the quality of combustion of the fuel in the cylinders. [1,2] For these reasons, direct use of heat engineering parameters to assess the quality of the combustion process in Cylinders of main marine diesel engines does not allow to detect possible violations of the combustion process at an early stage of their development.

The efficiency of functional diagnosing of working processes in the cylinders of the main marine diesels under operational conditions can be significantly improved by using special standards that have the property of invariance with respect to the characteristics of the propeller. The construction of such standards is made in accordance with the following principles [3,4,5].

1. The set of properties incorporated into the design of the engine in the design process and determining its ability to produce mechanical energy with a given quality will be characterized by a field permissible for long-term operation of the regimes. By this field we

mean the part of the coordinate plane $P_e - n$ (effective power - the speed of rotation) bounded to the left and right by the verticals $n_{\min} = const$ and $n_н = const$; Top - the upper limiting characteristic; Below the coordinate axis. The field limited in this way includes the whole set of regimes determining the conditions for the combustion of fuel in the cylinders. The position of the boundaries of the described field is determined only by the properties of the engine and does not depend on the features of the consumer of mechanical energy, i.e. It has the property of invariance with respect to the characteristics of the consumer and therefore is subsequently taken as the standard.

2. It is known that the standards are intended to determine the specific properties of objects or processes. Therefore, in order to assess the quality of combustion of the fuel in cylinders, it is necessary to form quantitative structures, having the property of invariance, on the basis of input into the working cylinders and output from the working cylinders of the parameters, with respect to possible perturbations on the part of the consumer. The input parameters are assumed to be the same for all cylinders; Weekends are different. This ensures that the features of the flow of working processes in the individual cylinders of the engine are taken into account.
3. Quantitative structures that have the property of invariance with respect to the characteristics of consumers of mechanical energy are of practical value only in those cases when the parameters on which they are based are available for operational control in ship conditions.

The sequence of computational operations for a quantitative description of the formulated principles will be demonstrated using the example of the formation of invariant standards for functional diagnostics of the quality of combustion processes in engine cylinders 6 cylinder four stroke turbocharged 25/34-3.
For this purpose, we use the results of bench tests of the engine on a series of load characteristics in the range of rotation frequencies from $n_н = 500\ min^{-1}$ to $n_{min}=350$, with step $\Delta n = 50\ min^{-1}$.
During the testing, the following informative parameters were measured:
t_g - exhaust gas temperature at the exit from the cylinders, ^{0}C;
n - crankshaft speed, min^{-1};
h - position of the load indicator, conventional units.
In the following calculations, we use the dimensionless values of the informative parameters

$$t_g = \frac{t_g}{t_{гн}}; \quad n_0 = \frac{n}{n_н}; \quad h_0 = \frac{h}{h_н}, \tag{1}$$

where $t_{gн}$, $n_н$ u $h_н$ – normalizing parameters, the numerical values of which in this case are taken as follows:

$$t_{gн} = 390\ {}^0C;\ n_н = 500\ мин^{-1};\ h_н = 4{,}9.$$

The use of dimensionless informative parameters excludes the question of the dimensions of the input and output parameters of invariant standards. In addition, informative parameters are expressed by numbers of the same order, which increases the stability of the computational process.

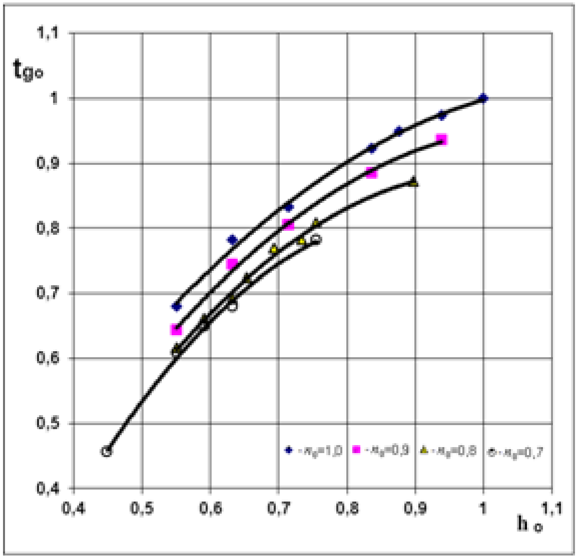

Fig.1. Load characteristics of the first engine cylinder 6 cylinder four stroke turbocharged 25 / 34-3 in the coordinates $t_{go}=f(h_o)$

In Fig. 1. The load characteristics of the first cylinder of the engine 6 cylinder four stroke turbocharged 25 / 34-3 in the coordinate system $t_{go} = f\,(h_o)$

It can be seen that these are monotonous curves, therefore each of them with a high degree of reliability ($R^2 \geq 0{,}99$) can be approximated by a second-order polynomial of the form

$$t_{go} = x_1\,(n_o)\cdot h_o^2 + x_2\,(n_o)\cdot h_o + x_3\,(n_o), \tag{2}$$

and/but the entire series of load characteristics, the system of the following polynomials:

$$
\begin{aligned}
&t_{go}= -0.8732\cdot h_o^2 + 2.0501\cdot h_o -0.1789, && n=1.0;\\
&t_{go}= -1.0884\cdot h_o^2 + 2.3587\cdot h_o -0.3218, && n=0.9;\\
&t_{go}= -1.316\cdot h_o^2 + 2.6532\cdot h_o -0.449, && n=0.8;\\
&t_{go}= -1.6797\cdot h_o^2 + 3.073\cdot h_o -0.6827, && n=0.7.
\end{aligned}
\qquad (3)
$$

The system of polynomials (3) allows us to determine the patterns of change in the parameters to be determined $x_i = f\,(n_o)$.

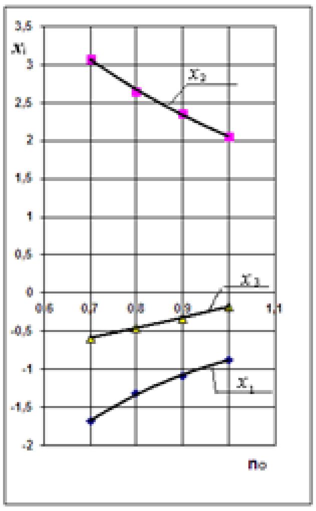

Fig.2. Graphical representation of dependencies $x_1=f(n_0)$, $x_2=f(n_0)$, $x_3=f(n_0)$

In Fig.2. Graphical representation of the dependencies $x_1 = f\,(n_o)$, $x_2 = f\,(n_o)$, $x_3 = f\,(n_o)$. It is seen that these are also monotonous curves, so with a high degree of certainty ($R^2 \geq 0,99$) they are approximated by polynomials of the second order

$$
\begin{aligned}
&x_1(n_o) = -3.8625\cdot n_o^2 +9.2073\cdot n_o -6.2251;\\
&x_2(n_o) = 2.78\cdot n_o^2 -8.0892\cdot n_o +7.3663;\\
&x_3(n_o) = 0.23\cdot n_o^2 + 0.9476\cdot n_o -1.3576.
\end{aligned}
\qquad (4)
$$

Substitution of (4) into (2) yields the equation of the surface formed by the successive displacement of the segment of the monotone curve $t_{go}=f\,(h_o)$ of the first cylinder in the range of rotation speed change $0.7\leq n_o \leq 1.0$

$$
t_{gop}^{\,1} = (-3.8625 \cdot n_o^2 + 9.2073 \cdot n_o -6.2251)\cdot h_o^2 + (2.78\cdot n_o^2-8.0892\cdot n_o+7.3663)\cdot h_o + (0.23\cdot n_o^2+0.9476\cdot n_o-1.3576) \;. \qquad (5)
$$

According to the above algorithm, the equations of surfaces obtained by the successive displacement of load characteristics of the remaining engine cylinders are obtained. 6 CHN 25 / 34-3:

$$t_{gop}^{II}= (-11.287 \cdot n_o^2 + 23.087 \cdot n_o - 12.32)\cdot h_o^2 + (12.336\cdot n_o^2 - 25.275\cdot n_o + 14.441)\cdot h_o + \\ + (-3.2025\cdot n_o^2 + 6.8727\cdot n_o - 3.5649);$$

$$t_{gop}^{III}= (-8.8975 \cdot n_o^2 + 17.977 \cdot n_o - 9.7956)\cdot h_o^2 + (10.085\cdot n_o^2 - 20.396\cdot n_o + 12.105)\cdot h_o + \\ +(-2.665\cdot n_o^2 + 5.6359\cdot n_o - 3.666); \qquad (6)$$

$$t_{gop}^{IV}= (-7.91 \cdot n_o^2 + 17.174 \cdot n_o - 9.6694)\cdot h_o^2 + (6.86\cdot n_o^2 - 16.026\cdot n_o + 10.408)\cdot h_o + \\ +(-0.7625\cdot n_o^2 + 2.8269\cdot n_o - 1.8519);$$

$$t_{gop}^{V} = (-16.197 \cdot n_o^2 + 35.987\cdot n_o - 19.943)\cdot h_o^2 + (14.125\cdot n_o^2 - 35.074\cdot n_o + 21.775)\cdot h_o + \\ +(-1.5\cdot n_o^2 + 6.355\cdot n_o - 4.5003);$$

$$t_{gop}^{VI} = (-16.395 \cdot n_o^2 + 35.273 \cdot n_o - 19.498)\cdot h_o^2 + (12.93\cdot n_o^2 - 31.331\cdot n_o + 19.994)\cdot h_o + \\ + (-0.69\cdot n_o^2 + 4.3364\cdot n_o - 3.6266).$$

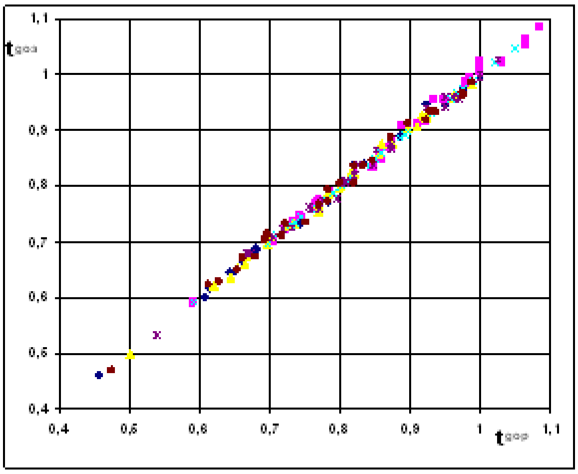

Fig.3. Single invariant standard of the engine 6ЧН25/34-3

On the basis of (5) and (6), through the representation $t_{go\text{э}} = f(t_{gop})$, a single invariant standard of the engine 6ЧН25 / 34-3, presented in Fig.3, can be formed.

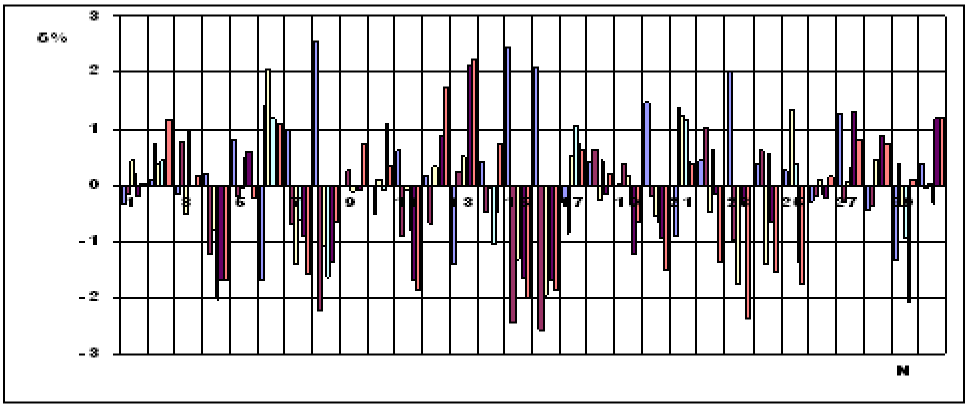

Fig.4. Distribution histogram of calculation errors for the entire set of input data

In Fig. 4. the distribution histogram of calculation errors for the entire set of input data is resulted. It can be seen that equations (5) - (6) reproduce the experimental data with an error not exceeding ± 3%.

Diagnosis of work processes in engine cylinders by means of models (5) - (6) and a single invariant standard is performed according to the following algorithm.

1. In an arbitrary period of operation, the values of the informative parameters t_{go}, n and h are recorded in 4-5 modes belonging to the region accepted as the standard.
2. By the relations (1), the dimensionless values of the informative parameters t_{go}, n_o and h_o. are determined.
3. From the equations (5) - (6), the calculated values of the temperature of the exhaust gases along the cylinders t_{gop} are determined.
4. Dependencies $t_{go\text{э}} = f\ (t_{gop})$, corresponding to the actual conditions of fuel combustion in the cylinders, are constructed.
5. Taking into account the real deviations of the constructed dependences from the standard, a conclusion is made about the quality of the functioning of the cylinders.

The results of the practical diagnosis of the engine 6 cylinder four stroke turbocharged 25 / 34-3 according to the described algorithm are shown in Fig. 5 and 6.

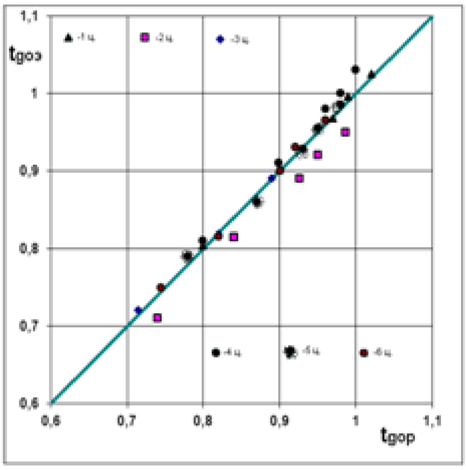

Fig. 5 Results of practical testing of experimental - theoretical models. Malfunctions: 1 cylinder - injection pressure of fuel reduced to 7.5 MPa; 2 cylinder - injection pressure of fuel reduced to 5 MPa; 3 cylinder - the gaps in the valve drive are increased to 1 mm; 4 cylinders - the gaps in the valve actuator are increased to 1.5 mm

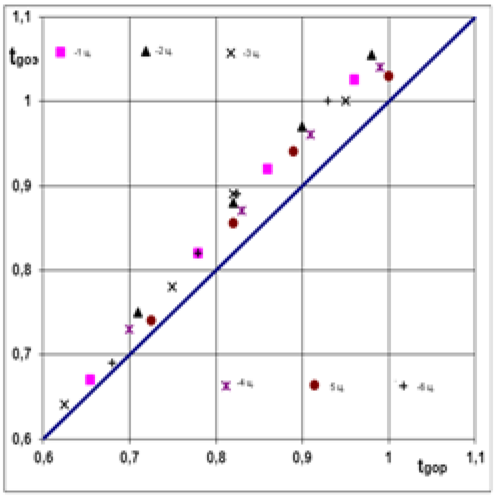

Fig. 6 Results of the practical testing of experimental and theoretical models. The fault is reduced by 50% of the flow cross section of the air filter

The diagnostic results shown in Fig. 5 correspond to the conditions of the engine tests with misaligned injectors of the first and second cylinders and increased clearance in the valve actuator of the third and fourth cylinders.

The fuel injection pressure of the injector of the first cylinder was 5.0 MPa, i.e. Was more than four times less than the nominal. Here, the effect of excessive reduction of the injection pressure on the flow of the working process in the cylinder is manifested in accordance with the condition tgoe <tgop, i.e. The actually measured values of the temperatures of the exhaust gases on all the investigated regimes are less than the calculated ones. Apparently in this case, the combined influence of the factors determining the fineness of fuel spraying and the range of fuel flares is manifested in such a way that part of the injected fuel enters the walls of the combustion chamber and does not participate in the combustion process. With prolonged exposure, it is this manifestation of the malfunction of the fuel equipment set that can lead to the most severe consequences. Not burnt fuel flushes the lubricant from the cylinder walls and cokes at the bottom of the piston, i.e. In the cylinder, the system conditions for the heating of the piston are created. Ultimately, the impact of these factors can lead to wedging of the piston. For the reasons stated, in cases where the measured values of the temperature of the exhaust gases on a cylinder are less than the calculated ones, the malfunction in the complete set of fuel equipment of this cylinder should be immediately rectified.

The fuel injection pressure of the second cylinder injector was 7.5 MPa. It can be seen that all the modes of this cylinder with a spread that does not exceed the error in measuring the temperature of the exhaust gases are stacked on the standard. Obviously, this injection pressure is close to the minimum allowable, at which no noticeable deterioration of the mixture formation occurs.

During the operation of the engine, the valve timing does not remain unchanged. The main reasons for their change are the wear of the paddles and the increase in the gaps in the valve drive. As a result, the duration of the valve opening phases is shortened, the cleaning is reduced and the air charge of the cylinders is reduced. According to the results obtained, an increase in clearance in the valve drive to 1.0 mm (third cylinder) has little effect on the quality of the combustion process in the range of loads studied. We can say that the level of this influence does not exceed the errors in measuring the temperature of the exhaust gases. When the gap is increased to 1.5 mm (the fourth cylinder), in modes close to the nominal one, the tendency of deviation of the measured values of the temperature of the exhaust gases from the calculated ones is quite clearly shown in accordance with the condition $t_{go\text{э}} > t_{gop}$.

The list of faults that occur in the elements of the air-gas tract of marine diesel engines is quite diverse. However, the most common are faults associated with the appearance on virtually all elements of the tract of various types of deposits and contaminants. As a result, the degree of consistency between the characteristics of the diesel engine and the turbocharger, achieved in the design and refinement, is partially violated, the air excess ratio during combustion decreases, the heat stress of the cylinder-piston group parts increases, the reliability and economy indicators deteriorate.

The described mechanism for the manifestation of faults in the elements of the air and gas tract suggests that the reaction of the invariant standard to these faults must be monotonous, i.e. For a single or joint action, the actual operating conditions of individual cylinders must be shifted in accordance with the condition $t_{goэ} > t_{gop}$.

Figure 6 shows the results of an engine test with a 50% cut-through section of the air filter. It can be seen that in the investigated range of loads this malfunction is manifested on all cylinders approximately in the same measure in accordance with the condition $t_{goэ} > t_{gop}$.

In connection with the results of practical diagnostics, it is appropriate to discuss in more detail certain features and diagnostic possibilities of invariant standards.
First of all, attention is drawn to the fact that none of all the factors considered that caused a change in the conditions for the combustion of fuel in cylinders are explicitly included in equations (5) - (6), but nevertheless, their influence on the work process is revealed In the engine cylinders. This fact testifies to the fact that in the structure of the standards (5) - (6) there is a parameter that is inherently generalized, the role of which is fulfilled by the temperature of the exhaust gases along the cylinders.

Indeed, equations (5) - (6) can be regarded as identities in which only the definite, unique numerical values of the solutions xi = f (no) can be assigned to the given values of the parameters tgo, no and ho, which are independent variables in the statement of the problem, , I.e. Values that are dependent variables. This strictly unambiguous relationship between independent variables and solutions is possible only for certain conditions for the combustion of fuel in cylinders. If the combustion conditions change, the uniqueness of the relations between independent variables and solutions is violated and the dependence tgoe = f (tgop), corresponding to the new conditions, deviates from the standard.

In conclusion, it should be noted that in the presence of technical means for the operational control of the average indicator pressure on the cylinders, invariant standards can be constructed in which the temperature of the exhaust gases is replaced by an average indicator pressure [3].

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