METHOD FOR DETERMINING REMAINING LIFE OF ENGINE BY DYNAMIC CHARACTERISTICS

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Abstract. Currently, methods of direct measurement of design parameters of technical condition are used to determine the remaining life of the engine. This requires complete or partial disassembly of the engine, which implies its decommissioning and subsequent placement on repair sites. The main argument in favor of such methods is the reliability of the results obtained, although this increases the labor intensity and cost of this process. The article proposes a method for non-selective evaluation of the residual life of the engine by the transient functions of its systems. The estimated parameters are the transient functions for fuel consumption, air consumption, and crankshaft speed. Quantitative indicators for transient functions are the intensity of changes in the selected parameters when the load is applied. Depending on the technical condition of the internal combustion engine, they have a high, medium and low level. To make a final decision about the technical condition of the engine, the Bayes algorithm on conditional probabilities is used. In case of an unfavorable combination of factors, this algorithm allows to assess the need for work to restore the engine resource with a certain probability. To improve the adequacy of the results obtained, it is necessary to use statistical data that reflect the relationship between the design parameters of the technical condition and the engine running time. The dependence of the selected diagnostic parameters on the technical condition of the engine is reflected in regression equations. Increasing the sample size of available data increases the accuracy of the diagnosis.

Keywords: residual resource of engine , transition function, basic wear parts.

Introduction

Determining the remaining life of internal combustion engines allows to correctly select the standards of technical operation, adjust the structure and content of maintenance and repair operations, which will ultimately lead to a reduction in operating costs. To date, in the scientific and technical literature, such developed methods of in-line engine diagnostics as the vibro-acoustic diagnostic method [1], a method for analyzing the composition and quantity of engine exhaust gases [2-5], and a method for measuring the oil flow rate are given [6; 7]. The method currently used for determining the residual life of the engine is based on its assessment through the resources of the basic parts and is well covered in the works [8; 9]. In accordance with the provisions of the normative and technical documentation, the cylinder block and crankshaft are taken as the basic parts of the internal combustion engine. In accordance with this, the possibility is considered of evaluating the remaining life of the engine as a whole through the current technical condition of its cylinder block.

Status of the issue

According to the manufacturer's recommendations, the need to restore the resource of the cylinder block is determined by finding its controlled parameters in the range of maximum permissible values of the design parameters of the technical condition. These parameters under average operating conditions vary smoothly and continuously with different intensities (Fig. 1), it is shown that with an increase in the operating time l and a decrease in compression in the cylinders k, the probability of an operational state of the engine $P(k, l)$ decreases [10].

The intensity of changes in the design parameters is determined by both the engine operating mode and the quality and timeliness of the performed maintenance operations. The residual life of the engine can be estimated (Fig. 2) [11, 12].

Assessment of the current technical condition of the internal combustion engine by its design parameters is the most adequate and reasonable option, when choosing a decision on the need to restore the resource of its basic parts. However, this option is also the most time-consuming and expensive. Therefore, we propose a solution, where the current state of the engine is evaluated based on the selected indirect diagnostic parameters, which are the transient functions of the engine and its component systems [10].

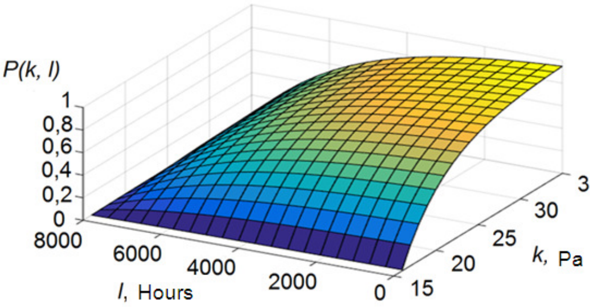

Fig. 1. **Probability of good condition of CPG depending on the compression and the operating time**

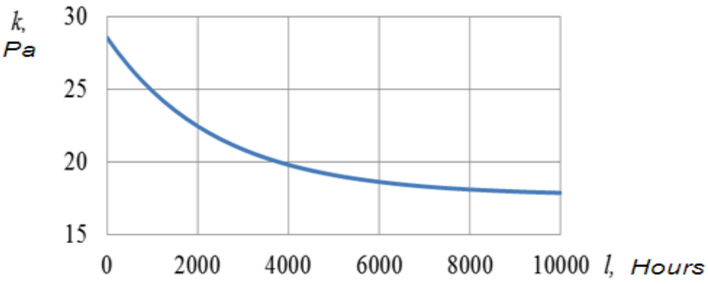

Fig. 2. **Change in compression in the cylinder k depending on the operating time l**

Proposed solution

According to the established requirements set out in [6], indirect diagnostic parameters must have linear characteristics with high sensitivity and have stability over the entire range of changes in operating modes. The choice of diagnostic parameters of working processes is considered particularly attractive, since they allow to assess the technical condition of the internal combustion engine. In this case, the researcher should be able to establish a statistical or functional dependence of the wear parameters with the current values of the diagnostic parameters.

In this paper, it is proposed to use the diagnostic parameters proposed in [13]. These include: the intensity of changes in the engine performance during a stepwise change in the position of the tuning knob φ, that is, the transition functions in terms of fuel and air consumption, as well as in the frequency of rotation of the crankshaft x_j, $j = 1 \div 3$ (Fig. 3.4):

1. intensity of change in the speed of rotation of the crankshaft – T_n;
2. intensity of change in the cyclic feed – $T_{gц}$;
3. intensity of change in the air flow – $T_{Gв}$.

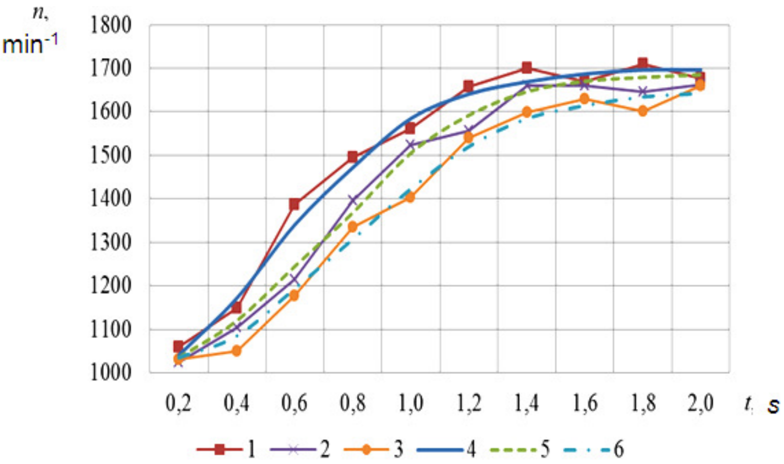

Fig. 3. **Transitional functions of the rotational speed n depending on the compression *k* of the D-243 engine. Experimental and approximating data:** 1,4 – with compression of 2.7 MPa; 2, 5 – with compression of 2.4 MPa; 3, 6 – with compression of 2.1 MPa.

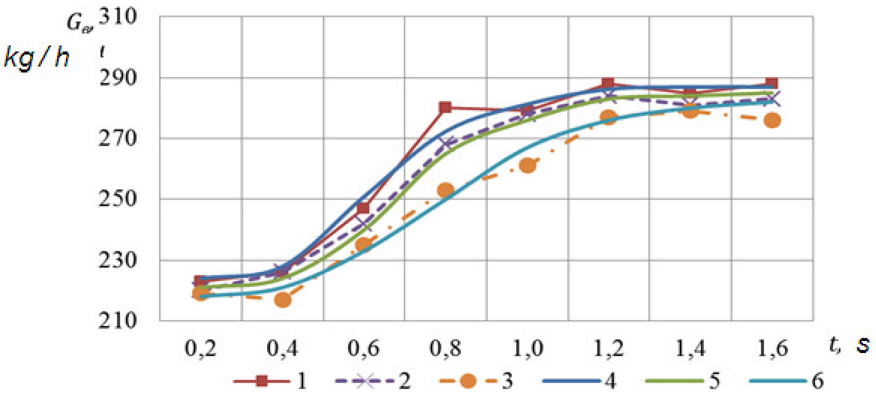

Fig. 4. **Transitional functions of the air flow *Gв* depending on the compression k of the D-243 engine:** 1,4 – with compression of 2.7 MPa; 2, 5 – with compression of 2.4 MPa; 3, 6 – with compression of 2.1 MPa

However, it should be borne in mind that the intensity of the change in speed is determined by the increment of the engine torque, which in turn depends on the state of the CPG, the parameters of fuel and air supply. Therefore, a prerequisite is to evaluate the fuel and air supply systems and the degree of compression in the engine cylinders.

Then, in accordance with the recommendations [10], the formulas are used to determine the residual resource θ and variance D$\{\theta\}$:

$$\theta_j = \frac{x_j^* - x_{jn}}{k_{j1}}, \tag{1}$$

$$k_{j1} = \frac{x_{j1} - x_{j2}}{t_{j1} - t_{j2}}, \tag{2}$$

$$D_j\{\theta_j\} = \frac{(x_j^* - x_{jn}) \cdot k_{j2}}{k_{j1}^3} + \frac{\theta_j^2}{k_1^2} D_j\{k_{j1}\}, \tag{3}$$

$$k_{j2} = \frac{1}{l}\sum_{i=1}^{l} \frac{I^0_{j1,n}}{V_{j1,n}}, \tag{4}$$

$$I^0_{j\,k,n} = \sum_{t=1}^{n} \frac{t^k_{1,n}}{I^2(t_1)}, \tag{5}$$

$$V_{j\,k,n} = \sum_{t=1}^{n} \text{И}^k(t_1), \tag{6}$$

where $x_1, ..., x_2$ – the results of measuring the indirect controlled parameter j at moments $t_1, ..., t_n$.

It is considered that the *limit* value of wear $E_{limit\ j}$ and the corresponding value of the indirect controlled x_j^* parameter have a functional relationship:

$$x_j^* = f(\grave{E}_{limit\,j}). \tag{7}$$

The value of $\Delta(t)$ changes during the accumulation of damage to the wear surfaces, leading to a monotonous process of changing the diagnostic parameters of T_n, T_{gu}, $T_{Gв}$.

In the first approximation, we can consider the increments of T_n, T_{gu}, $T_{Gв}$, Δ independent [13]. This gives reason to use the Markov approximation when describing T_n, T_{gu}, $T_{Gв}$, Δ.

Thus, we assume a priori that T_n, T_{gu}, $T_{Gв}$, Δ represent normal non-stationary processes with mathematical expectations:

- $k_0^{T_n} + k_1^{T_n} \cdot t^{1,57}$ – for the intensity of change in the cyclic feed $T_n(t)$;

- $k_0^{T_{gц}} + k_1^{T_{gц}} \cdot t$ – for the intensity of changes in the air flow $T_{gц}(t)$;
- $k_0^{T_{Gв}} + k_1^{T_{Gв}} \cdot t$ – for the intensity of changes in the speed of rotation of the crankshaft $T_{Gв}(t)$;
- $k_0^{\Delta} + k_1^{\Delta} \cdot t$ – for the process of increasing wear $\Delta(t)$;
- $k_0^{T_n}, k_0^{T_{gц}}, k_0^{T_{Gв}}, k_0^{\Delta}$ – initial random variables equal to the values $T_n(t)$, $T_{gц}(t)$, $T_{Gв}(t)$, $\Delta(t)$ at the end of running – in t°.

The variances of the processes under consideration are equal:

$$D\{T_n(t)\} = k_2^{T_n} \cdot t^{1.57}, \tag{8}$$

$$D\{T_{gц}(t)\} = k_2^{T_{gц}} \cdot t + D\{k_0^{T_{gц}}\}, \tag{9}$$

$$D\{T_{Gв}(t)\} = k_2^{T_{GB}} \cdot t + D\{k_0^{T_{Gв}}\}, \tag{10}$$

$$D\{\Delta(t)\} = k_2^{\Delta} \cdot t + D\{k_0^{\Delta}\}. \tag{11}$$

Coefficients $k_1^{T_n}, k_1^{T_{gц}}, k_1^{T_{Gв}}, k_1^{\Delta}, k_2^{T_n}, k_2^{T_{gц}}, k_2^{T_{Gв}}, k_2^{\Delta}$ are constants and determined experimentally.

The controlled parameters listed Δ, T_n, $T_{gц}$, $T_{Gв}$ depend on the technical condition of the engine and change monotonously as the resource is developed. The loss of engine performance leads to an increase in the values Δ, T_n, $T_{gц}$, $T_{Gв}$ compared to preliminary data.

Discussion of results

Consider the proposed method for estimating the residual life of the d-243 engine. Using the equipment and methodology given in [14], we obtain changes in the evaluation parameters depending on the operating time and technical condition of the engine.

Analysis of the reasons for changing the parameters Δ, T_n, $T_{gц}$, $T_{Gв}$ shows that the reason for changing all the monitored parameters Δ, T_n, $T_{gц}$, $T_{Gв}$ is the wear of the elements on which the gap depends. In that case, if the random factor will dominate in the formation of values Δ, T_n, $T_{gц}$, $T_{Gв}$ over other random factors, then a regression relationship may appear between the parameters $\Delta = f(T_n, T_{gц}, T_{Gв})$ we look for the function f in the form:

$$\Delta = c_1 T_{gц} + c_2 T_n + c_3 T_{Gв} + c_4, \tag{12}$$

where c_1, c_2, c_3, c_4 – constant unknown coefficients.

Reducing the square shape by c_1, c_2, c_3, c_4:

$$\sum_{i=1}^{N} \left[\Delta_i - c_1 T_{gц_i} - c_2 T_{n_1} - c_3 T_{Gв_i} - c_4\right]^2, \tag{13}$$

where N – number of dimensions.

For unknown constants, we get the following values $c_1 = 4{,}5$; $c_2 = 0{,}1$; $c_3 = 3{,}2$; $c_4 = -570$; $N = 81$.

When using the obtained regression dependence to predict the remaining engine life by wear, the following situations may occur.

1. The lack of direct measurements Δ.

Regression dependence used

$$\Delta = 4.5 \cdot T_{gц} + 0.1 \cdot T_n + 3.2 \cdot T_{Gв} - 570, \tag{14}$$

It is necessary for each time of measurement $\{T_n, T_{gц}, T_{Gв}\}_i$ get the appropriate value $\Delta(t_i)$.

Using least squares (OLS) processing, the following parameters are determined k_1^{Δ}, k_2^{Δ}.

The following formula is used to determine the remaining resource θ and variance:

$$\theta = \frac{E_{limit} - 4.5 \cdot T_{gц} + 0.1 \cdot T_n + 3.2 \cdot T_{GB} - 570}{k_1^{\Delta}}, \tag{15}$$

$$D\{\theta\} = \frac{E_{limit} \cdot k_2^{\Delta}}{\left(k_1^{\Delta}\right)^3}, \tag{16}$$

where $T_{гц}(t_n), T_п(t_n), T_{Gв}(t_n)$ – the last measurements $T_{гц}, T_п, T_{Gв}$

2. The amount of wear after running-in Δ* is known.

Refining the c_3 coefficient in the regression relationship

$$\tilde{n}_{3(refining)} = \Delta * -4.5 \cdot T_{гц} + 0.1 \cdot T_п + 3.2 \cdot T_{Gв}, \tag{17}$$

where $T_{гц}, T_п, T_{Gв}$ – measured after running-in.

Replacing c_3 with $c_{3(refining)}$, define θ, $D\{\ \theta\ \}$.

Conclusions

It should be noted that the measured parameters at a real time have a random component in real operating conditions. To improve the adequacy of the decision on the technical condition of the engine, as well as its remaining life , it is desirable to take into account statistical data on the results of real measurements. This approach is well implemented in the Bayes algorithm diagnostic method.

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