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METHODS FOR ENSURING THE RELIABILITY AND ECONOMIC EFFICIENCY OF AUTOMOTIVE ENGINES OPERATING IN HOT CLIMATIC CONDITIONS

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Abstract: This study explores methods for ensuring the reliable operation of automotive engines under hot climatic conditions. It emphasizes the importance of balancing reliability with economic factors, particularly through analyzing the relationship between component/system reliability and associated costs. The paper highlights the collaborative role of designers and reliability engineers, noting that traditional design methods alone are insufficient for modern engine development. Key topics include the use of safety factors, the limitations of empirical design approaches, and the need for optimized solutions incorporating new materials and technologies. The research also discusses statistical approaches to stress-strength analysis and the practical challenges posed by cost, time, and rapid technological change.
Keywords (one line):engine reliability, hot climate, safety factor, mechanical components, design optimization, operational analysis, reliability theory, cost analysis,

To ensure a given probability of failure-free operation, one of the main factors is to take into account the condition of minimum costs, for which it is necessary to determine the relationship between reliability and costs for each element and engine system. In practice, it is not always possible to use this condition due to the lack of data on the costs required to ensure a given level of reliability [1].

The creation of reliable elements, systems and engines themselves is possible only if the efforts of designers and operational reliability specialists are combined. At the same time, the main role is assigned to the designer, and the reliability specialist supplements his knowledge by analyzing the reliability of the engine design and statistical analysis of operational data. At the present stage, the principle of ensuring the reliability of engines, based on the simple application of rational design methods, is insufficient to give a given reliability to an engine as a complex system. In this regard, it becomes necessary to single out an independent section in the theory of reliability, which would study the issues of reliability of elements and systems of engines. The following factors may serve as the basis for this [2-5]:

1) insufficient design experience. The pace of technology change is so fast that it is almost impossible for engine designers to complete the design;

2) cost and time constraints. Cost and time are important, so the designer is not able to learn from past mistakes, i.e. trial and error is not acceptable here;

3) the need to optimize resources. The creation of a working engine design must be optimized under constraints on such parameters as cost, reliability, weight, efficiency, performance and dimensions.

Result and discussion. The nature of the change in the distribution of stresses and strength is shown in Fig.3. For convenience, it is assumed that the stress distribution is constant, while the strength distribution changes with time. If the distributions of stresses and strength are known, then according to the results of the relationship between them, it is possible to determine the reliability of the work [6].

When designing the mechanical elements of the engine, a certain margin of safety is chosen, set by arbitrary strength factors. Such an approach to the choice of coefficients in a number of cases makes it possible to obtain a satisfactory design of engine parts, especially if their values are chosen on the basis of experience. But in modern conditions, when creating new engine designs, new approaches, new materials and more consistent methods are required.

In this case, it is important to consider the following indicators[8]:

1. Safety factor. In practice, there are several ways to calculate the safety factor S_f. This factor can be defined as the ratio of the average strength μ_s to the average stress μ_s'. In this case, μ_s is a parameter that determines the appearance of a failure, and μ_s' - causing failure.

$$S_f = \frac{\mu_s}{\mu'_s} \geq 1.$$

If the stress and strength are distributed according to the normal law, the use of the coefficient S_f is very convenient. The method of choosing the safety factor is shown in fig. 4 It should be noted that if the stress and strength have a large range of variability, the coefficient S_f loses its meaning.

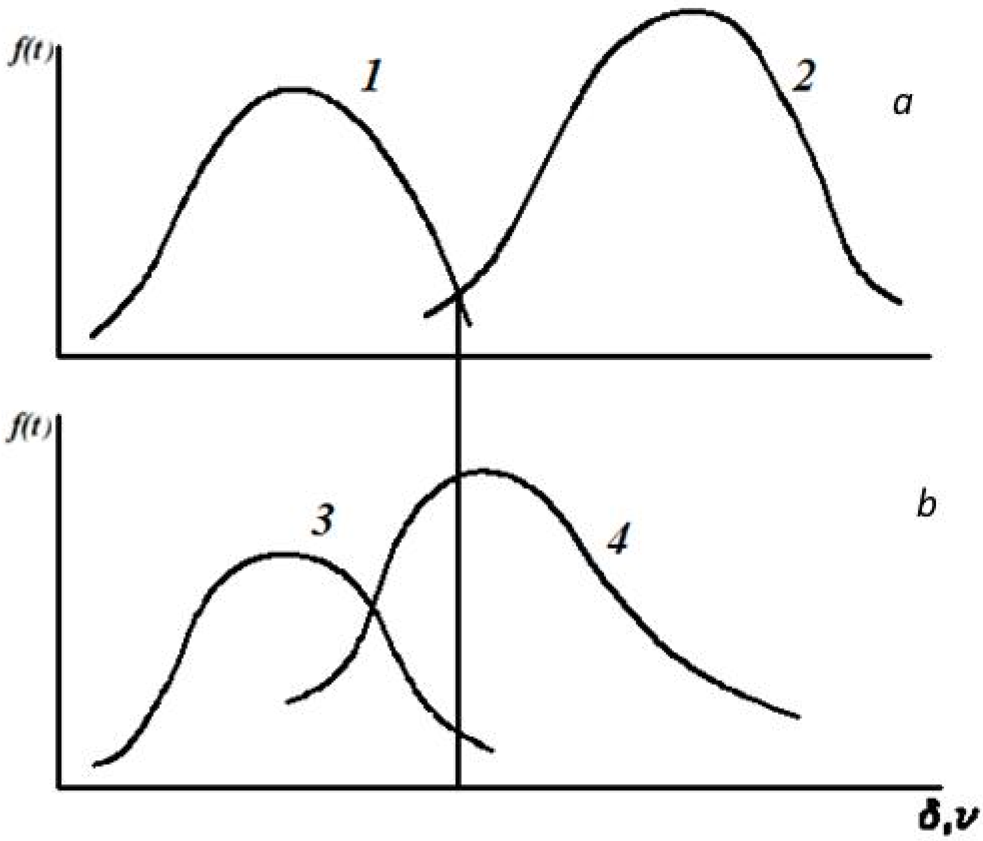
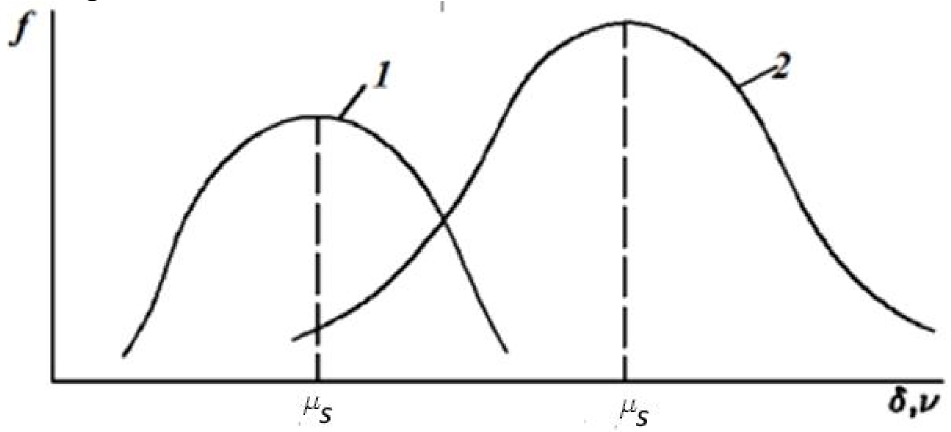


Figure 1. Distribution of stresses (b) and strength (v) depending on the time (t) of work:
a - at time t_1; b - at time t_2; 1 - stress distribution; 2 - strength; 3 - constant distribution of stresses; 4— strength distribution over time interval (t_2—t_1)

2. Margin of safety. It is determined by the formula Sm \ u003d S_f-1.

Coefficient Sm as S_f is a random variable, it reflects the idea of the need to separate the average values of stress and strength.

In cases where reliability is assessed according to the established distributions of stress and strength parameters, traditional methods such as the Lagrange multiplier method, integer, linear and dynamic programming methods can be used to optimize the reliability of the mechanical elements of the engine.



Rice. 2. Choice of safety factor (S $_f$) depending on the ratio between stress distributions (b) and strength (ν):

1 - stress distribution; 2 - strength

At the same time, reliability characteristics can be optimized under restrictions on costs, weight and dimensions (volume).

Below is a method for optimizing the reliability of the mechanical elements of the engine with a normal distribution of stress and strength parameters. In this case, the probability of failure-free operation is defined as:

$$R=\int_{-n}^{\infty}\frac{1}{\sqrt{2\pi}}e^{-y^2/2}dy,$$

where $n=\left(S_п-S_н\right)(\sigma^2{}_{S_п}th+\sigma^2{}_{S_н}t)^{-1/2}$; $S_н$— average voltage;

Sn is the average strength; $\sigma_{S_п}th'$ $\sigma_{S_н}t$ are the standard deviation of strength and stress, respectively. In this case, stress and strength are statistically independent quantities.

To increase the probability of failure-free operation, the lower limit of integration should be as small as possible. Then the minimization of total costs for a given value of R can be represented as

$$R=R_1\left(S_п\right)+k_2\left(\sigma_{S_п}th\right)+R_3\left(S_н\right)+R_4\left(\sigma_{S_п}t\right),$$

under the restriction $(S_п-S_н)(\sigma_{S_п}t)$]1/2 ≥ y , k - total costs; k(Sп) is the function of the cost of providing medium strength (monotonically increasing function); $R_3(S_н)$ is the stability cost function against the average stress value (monotonically decreasing function; $k_2(\sigma_{S_п}th)$ is the cost function of maintaining a given strength standard deviation, $k_4\left(\sigma_{S_н}t\right)-$ the stability cost function is within the stress standard deviation; y is the value determined by the coupling equation for the required level of probability of no- failure operation. Lagrange equation in this case takes the form

$$F\left(S_пS_н\sigma_{S_п}th,\sigma_{S_н}t,\lambda\right)=k+\lambda\left[S_п-S_н-y(\sigma^2{}_{S_п}th+\sigma^2{}_{S_н}t)\right]^{1/2}$$

To determine the optimal solution of this_equation, we differentiate it with respect to each variable λ, $S_п$, $S_н$, $\sigma_{S_п}th,\sigma_{S_н}t,$ and equating each derivative to zero, we get:

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$$S_п - S_н - y\left(\sigma^2{}_{S_п th} + \sigma^2{}_{S_н}\right)^{\frac{1}{2}} = 0;$$

$$k_4\left(\sigma_{S_н t}\right) = \frac{\lambda y \sigma s_н t}{\sqrt{\sigma s_п th + \sigma^2{}_{S_н t}}};$$

$$k_2\left(\sigma_{S_п th}\right) = \frac{\lambda y \sigma_{S_п th}}{\sqrt{\sigma_{S_п th} + \sigma_{S_н t}}};\ k_3\left(S_н\right) = \lambda,\ \ k''_1\left(S_п\right) = -\lambda.$$

Here, the dot denotes the partial derivative with respect to $\sigma_{S_н t'}$, the dash with respect to $S_н$, two dots with respect to $\sigma_{S_п th}$, and two dashes with respect to $S_п$. By solving a system of equations, one can find the values of $S_п$, $S_н$, $\sigma_{S_п th}$, λ, K for locally optimal conditions. To determine the general extremum of the objective function, it is necessary to find the values of the objective function for all locally optimal solutions.

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