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ANALYSIS OF METHODS OF IN-PLACE DIAGNOSTICS OF AUTOMOTIVE AND TRACTOR DIESEL ENGINES

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Diagnostics and forecasting of the resource is one of the most important factors in managing the efficiency and operational reliability of agricultural machinery. Increasing the requirements for the quality of technical maintenance requires improving approaches to assessing the condition of the engine, which is considered as a system of series-connected elements without redundancy. The purpose of the article is to analyze existing methods for non-disassembly diagnostics of auto-tractor diesel engines and to justify the feasibility of using the pattern recognition method for small deviations of parameters to predict the residual resource. The research methods are based on the analysis of the theory of similarity and dimensions, as well as methods of mathematical statistics and probability theory.

The laws of failure distribution (normal, Weibull, exponential, Rayleigh, gamma distribution) and their application to various types of wear are considered in detail. The research found that classical statistical methods, in particular the normal distribution law, require a large amount of testing, which complicates their use for operational forecasting. The results of the analysis allowed us to substantiate the effectiveness of the pattern recognition method, which allows us to record hidden changes in structural parameters within the tolerance range. The proposed approach allows us to reduce the amount of computational work and increase the accuracy of individual forecasting of the resource of a particular unit.

The results of the work will be useful for engineering and technical workers of the agro-industrial complex in solving the problems of reducing the variability of the resource of engines and their systems, providing the possibility of prompt detection of pre-failure states based on small deviations of parameters for more accurate forecasting of the durability of equipment. The materials of the scientific article are based on the results of the initiative scientific topics 0122U002187 and 0122U002135

Key words: *automotive and tractor diesel engines, in-place diagnostics, resource prediction, reliability theory, probability distribution laws, similarity method, pattern recognition.*

Eq. 21. Fig. 10. Table. 1. Ref. 17.

1. Problem formulation

It is well known that engine reliability is a function of the reliability of its individual mechanisms and systems. From the standpoint of reliability theory, an automotive or tractor diesel engine can be considered as a system consisting of series-connected elements without redundancy, where the failure of any single element leads to the failure of the entire system.

At present, the automotive and tractor industry has achieved relatively high average service lives of engine mechanisms and systems. However, a critical problem remains the significant variability of the service life of these components, which directly affects the overall reliability of the engine. Therefore, an important task is not only to increase the average durability of engines but also to reduce the dispersion of their service lives.

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Diagnostics and forecasting of the residual resource are among the most important factors in managing the efficiency, operational reliability, and longevity of tractors, trucks, combines, and other agricultural machinery. Modern agricultural equipment places increasingly high demands on the quality of maintenance and repair, precision of adjustments of systems and mechanisms, and, consequently, on the improvement of in-place diagnostic methods capable of detecting pre-failure states during operation.

2. Analysis of recent research and publications

Analysis of experimental and operational data [1–5] shows that failures of components, systems, and mechanisms limiting engine reliability are generally described by the normal distribution, the Weibull distribution (over 60%), and the exponential distribution. The application of these probability laws in reliability studies is justified, as they encompass the main types of failures occurring during engine operation.

Failures caused by gradual wear are typically distributed according to the normal law, with a coefficient of variation in the range of $0 < v \leq 0{,}33$.

Failures resulting from extreme loads applied to structural elements, which usually manifest as sudden failures, are described by the exponential distribution, with a coefficient of variation of $0{,}8 \leq v \leq 1{,}0$.

An intermediate position between these two extreme cases is occupied by the Weibull distribution, which can describe both gradual and sudden failures. In this case, the coefficient of variation may range from $0{,}28 \leq v \leq 1{,}0$.

The transition from the normal distribution to the exponential distribution occurs through the Weibull distribution, covering the entire range $0 \leq v \leq 1{,}0$.

To study wear and durability of mating engine components, methods of mathematical statistics and probability theory, including correlation and regression analysis, are widely used [6–10]. Correlation theory makes it possible to establish a stable relationship between wear and operating time, despite the influence of random external factors inherent in experimental data. Regression analysis, in turn, allows determining the functional form of this relationship and estimating statistical durability parameters.

In recent years, mathematical models based on the laws of mechanical, physical, gas-dynamic, and chemical processes occurring in diesel engines have been increasingly applied to diagnostic problems. These models consider structural parameters, operating modes, environmental conditions, and diagnostic parameters, which are functionally related and allow assessing engine condition under operating conditions.

3. The purpose of the article

The purpose of this article is to analyze existing methods of in-place (non-disassembly) diagnostics of automotive and tractor diesel engines and to substantiate the feasibility of using the pattern recognition method based on small deviations of diagnostic parameters to predict the residual resource.

The study aims to demonstrate that, in contrast to classical statistical methods requiring large amounts of test data, the pattern recognition approach enables the detection of hidden changes in structural parameters within permissible tolerance ranges. This makes it possible to reduce computational complexity and improve the accuracy of individual forecasting of the residual life of specific engine units under real operating conditions.

4. Results and discussion

To solve the formulated diagnostic and reliability assessment problem, it is necessary to develop a mathematical description of the processes occurring in a diesel engine under operating conditions.

Mathematical models of processes developed based on the laws of mechanical, physical, gas-dynamic, and chemical processes occurring in diesel engines are increasingly used in solving diagnostic problems.

Typically, the following parameters are considered when developing a mathematical model of processes: x_i and $\overset{\circ}{x_i}$, $i = 1, \dots, n$ – are the structural parameters and their nominal values, respectively; y_i and $\overset{\circ}{y_i}$, $i = 1, \dots, h$ – are the parameters characterizing the state of the external environment, respectively; z_i, $i = 1, \dots, s$ – are the parameters characterizing the diesel engine operating mode; Y_i , $\overset{\circ}{Y_i}$ and $\Delta\overset{\circ}{Y_i}$, $i = 1, \dots, m$ – are the diesel engine diagnostic parameters, their average values, and their permissible deviations, respectively; *n*,*m*,*h*,*s* – are the number of corresponding parameters.

A functional relationship has been established between the above parameters, which generally has the form [9]:

$$F_{к}(\vec{x}, \vec{y}, \vec{z}, \vec{Y}) = 0\ , k = 1, \dots, m. \quad (1)$$

where $\vec{x}$, $\vec{y}$, and $\vec{z}$ are vectors, respectively, $\overrightarrow{x} = (x_1, x_2 \dots x_n)$, $\vec{y} = (y_1, y_2 \dots y_h)$, $\vec{z} = (z_1, z_2 \dots z_s)$.

Diagnostics of the technical condition of automotive and tractor diesel engines under operating conditions can be carried out using the similarity method and dimensional theory, the method of mathematical statistics and probability theory, the method of pattern recognition, etc.

The application of the fundamental principles of similarity and dimensional theory to the processing and analysis of experimental data on the wear of automotive and tractor engines allows us to establish patterns in the change in wear rate tg α depending on the engine's adjustment parameters.

There is a functional relationship between the wear rate and the engine's adjustment parameters [9],

$$\frac{tg\,\alpha}{\mathrm{tg}\,\alpha'} = f\left(N_e, P_p, \varphi_{vpr}, N_{\mathrm{en}}, \varphi_{pn}, P_{vpr.n}\right), \tag{2}$$

which, according to the 2nd theorem, can be represented as a relationship between dimensionless complexes.

Applying the zero-dimensional method, we find that the dimensionless wear rate $P = tg\,\alpha\,/\,tg\,\alpha_n$ in the case under consideration is a function of the following criteria:

$$\frac{tg\,\alpha}{tg\,\alpha_{\text{н}}} = f\left[\frac{N_e}{N_{en}}, \frac{\varphi_p}{\varphi_{pn}}, \frac{P_{vpr}}{P_{vpr.n}}\right] \tag{3}$$

By introducing the designations of the criteria: $P_1 = N_{\mathrm{e}}/N_{en}$, $P_2 = \varphi_p/\varphi_{pn}$, $P_3 = P_{vpr}/P_{vpr.n}$, $P = tg\,\alpha\,/\,tg\,\alpha_n$, we obtain:

$$P = f(P_1, P_2, P_3). \tag{4}$$

First, the influence of criteria P_1 and P_2 on the dimensionless wear rate P is determined at $P_3 = 1$. For this purpose, dimensionless dependencies $P = f(P_1)$ for different values of the simplex P_2 are plotted in logarithmic coordinates ($lg\,P_1$, 0 , $lg\,P_2$). The processing is carried out using the least squares method.

Analysis shows that the influence of criteria P_1 and P_2 on the relative wear rate P is quite complex, and that determining these criteria requires numerous experiments. Therefore, this method has not found widespread practical application for determining the service life and predicting the longevity and reliability of automotive and tractor engines.

The wear and durability of automotive and tractor engine mating components can be studied using mathematical statistics and probability theory, using correlation theory [8, 9, 10].

Correlation theory allows us to establish a consistent relationship between wear and operating time, despite the fact that we are investigating this relationship using experimental data where other factors, with their variability, distort the relationship under study. In this case, we solve two main problems:

We determine the closeness of the relationship between the studied quantities (correlation analysis), which characterizes the degree of influence of operating time on wear under given operating conditions.

We establish the form of the relationship between the studied quantities (regression analysis), i.e., we determine the form of the function $\overline{Y_x} = f(x)$ or $\overline{X_y} = \varphi(y)$, where $\overline{Y_x}$ is the average wear value for a given operating time and $\overline{X_y}$ is the average operating time for a given wear.

Solving these two problems makes it possible to determine the wear process dynamics and the statistical parameters of durability.

The main objective of reliability theory is to predict (predict with varying probability) various indicators of failure-free operation, durability, service life, etc. This is related to determining probabilities.

The Monte Carlo method has recently begun to be used to study complex probabilistic processes. The Monte Carlo method, also known as statistical modeling or statistical testing, is a numerical method for solving complex problems. It is based on the use of random numbers that model probabilistic processes. The results of solving the method allow us to establish empirical relationships between the processes under study. The mathematical basis of the method is the law of large numbers, developed by P. L. Chebyshev, which is formulated as follows: for a large number of statistical tests, the probability that the arithmetic mean of a random variable tends to the mathematical expectation is equal to 1:

$$\lim P\left\{\left|\frac{\sum x_i}{n} - m(x)\right| < \varepsilon\right\} \to 1, \tag{5}$$

where ε – is any small positive number.

With a normal distribution, the accuracy of the results obtained by the Monte Carlo method can be estimated using the formula

$$P|\bar{x}| - m(x) < \frac{3\sigma}{\sqrt{n}}\ . \tag{6}$$

Monte Carlo method problem solving is effective only with high-speed computers.

Probability theory uses the following distribution laws for random variables: normal, exponential, Rayleigh, Weibull, gamma, Poisson, binomial, and others.

The normal distribution law is exceptionally important and occupies a special position among other laws, being the most frequently encountered in practice (especially in engineering). The main feature that distinguishes the normal distribution law from other laws is that it is a limiting law, approached by other distribution laws under frequently encountered typical conditions.

The normal distribution law applies to components and assemblies subjected to wear testing until all or most of them fail. The main characteristics of this law are reliability, failure probability, and the probability density of the failure time of an element or assembly.

The normal distribution function for the time to failure is written as

$$F(t) = P[T \leq t] = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{t} e^{-\frac{(t_i-\bar{T})^2}{2\sigma^2}} \cdot dt, \tag{7}$$

where T – is a random variable (lifetime), hour; t_i – is its value (failure time of the *i*-th element), hour; $\bar{T}$ – is the arithmetic mean of the random variable (average lifetime), hour; σ – is the standard deviation of the random variable.

For a random variable T distributed according to the normal law with mean $\bar{T}$ and standard deviation σ, we have

$$F(t) = \varphi\left(\frac{t_i - \bar{T}}{\sigma}\right) \tag{8}$$

Fig. 1 shows a graph of the cumulative distribution function of a continuous random variable.

The probability density function of a normal distribution is bell-shaped, symmetrical about the mean, and is determined by the formula:

$$(t) = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(t_i-\bar{T})^2}{2\sigma^2}} = \frac{1}{\sigma} \cdot \varphi \cdot \left(\frac{t_i - \bar{T}}{\sigma}\right). \tag{9}$$

The probability of failure-free operation, or the probability that a non-recoverable system will perform a required function at a given time t, can be written as

$$P(t) = 1 - \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(t_i-\bar{T})^2}{2\sigma^2}} = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{t} e^{-\frac{(t_i-\bar{T})^2}{2\sigma^2}} \cdot dt, \tag{10}$$

is graphically represented as follows (Fig. 2) [11].

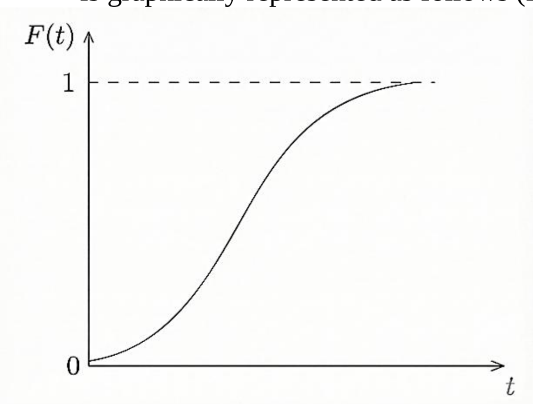

Fig. 1. Graph of the integral distribution function of a continuous random variable.

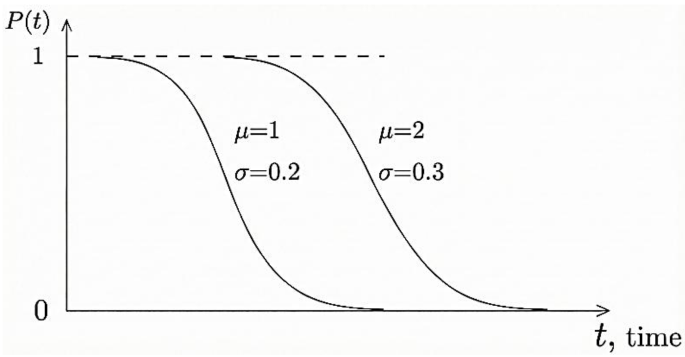

Fig. 2. Probability of failure-free operation with normal distribution of time to failure

If the random variable T (time to failure) has a distribution density *f(t)*, then

$$1 - F(t) = P(t). \tag{11}$$

In the case of a normal distribution, the failure rate is a monotonically increasing function of time (Fig. 3) [12] and is determined by the formula:

$$\lambda(t) = \frac{f(t)}{1 - F(t)} = \frac{1}{6} \cdot \frac{\varphi\left(\frac{t_i - \bar{T}}{\sigma}\right)}{\phi\left(\frac{\bar{T} - t_i}{\sigma}\right)}. \tag{12}$$

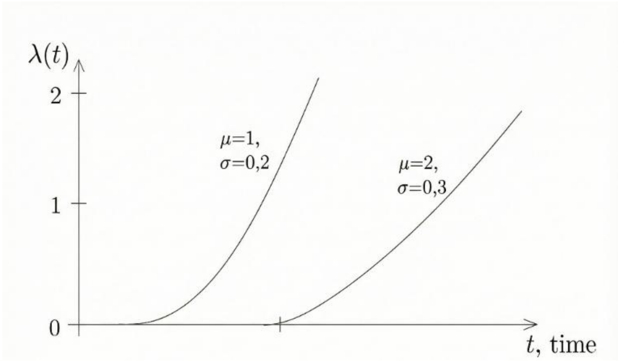

Fig. 3. Failure rate with normal distribution of time to failure

The service life of components and the engine as a whole is affected by their service life. When selecting parameters, the degree of influence of service life is taken into account by the Weibull distribution, a reliability law based on the Weibull distribution. The Weibull distribution is applicable to studying the service life of mechanical devices that have been in operation for a certain period of time.

This distribution law allows, by selecting the parameters β (shape parameter) and γ (scale parameter), to approximate statistical data on failures, taking into account the degree of influence of the service life of a component or unit.

For $\beta = 1$, this law transforms into an exponential distribution law, and for $\beta > 1$, it approaches the normal distribution law. The main characteristics of the Weibull distribution law are summarized in Table 1 and shown in Figs. 4–6 [13, 14].

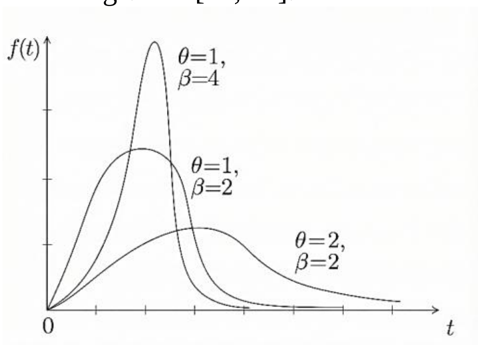

Fig. 4. Distribution density of time to failure according to Weibull's law.

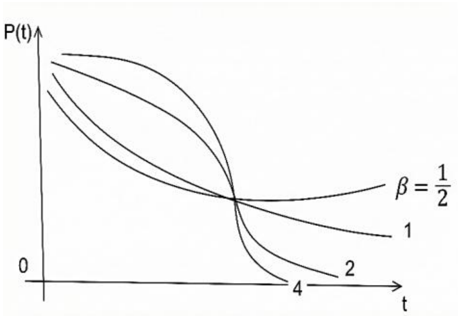

Fig. 5. Probability of failure-free operation when distributing work per failure according to Weibull's law

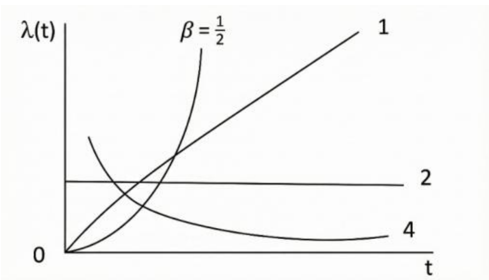

Fig. 6. Intensity of failures in the distribution of working hours to failure according to Weibull's law

The probability distribution of reliable operation can be expressed according to Rayleigh's law as [10]:

$$\mathrm{P(t)} = e^{-\psi(t)} = e^{-\frac{t^2}{2\sigma_0^2}}, \tag{13}$$

where $\psi(t) = \frac{t}{2\sigma_0^2}$ - is the parameter of the law.

The probability density of the element's failure time is determined by the equation

$$f(t) = \frac{t}{\sigma_0^2} \cdot e^{-\frac{t^2}{2\sigma_0^2}} \tag{14}$$

Table. 1

Probability distribution laws of failure-free operation and their reliability characteristics

Distribution	Distribution function *F(t)*	Distribution function *f(t)*	Probability of failure-free operation *P(t)*	Failure rate $\lambda(t)$	Mathematical expectation *M(t)*	Dispersion $\sigma^2(t)$
Normal	$\frac{1}{\sigma\sqrt{2\pi}}\int_{-\infty}^{t} e^{-\frac{(t_i-}{2}} \cdot dt = \phi(\frac{t_i-\bar{T}}{\sigma})$	$\frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(t_i-\bar{T})^2}{2\sigma^2}} \cdot dt = \frac{1}{\sigma}\varphi(\frac{t_i-\bar{T}}{\sigma})$	$\frac{1}{\sigma\sqrt{2\pi}}\int_{t}^{\infty} e^{-\frac{(t_i-\bar{T})^2}{2\sigma^2}} \cdot dt = \phi(\frac{\bar{T}-t_i}{\sigma}))$	$\frac{f(t)}{P(t)} = \frac{1}{6} \cdot \frac{\varphi(\frac{t_i-\bar{T}}{\sigma})}{\phi(\frac{\bar{T}-t_i}{\sigma})}$	$\bar{T}$	σ^2
Weibull	$1-e^{-(\frac{t_i}{V})^\beta}$	$\frac{\beta}{V} \cdot (\frac{t_i}{V})^{\beta-1} \cdot e^{-(\frac{t_i}{V})^\beta}$	$e^{-(\frac{t_i}{V})^\beta}$	$\frac{\beta}{V} \cdot (\frac{t_i}{V})^{\beta-1}$		
Exponential	$1-e^{-\psi t}$	$\psi e^{-\psi t}$	$e^{-\psi t}$	$\frac{1}{\bar{T}} = \psi$	$\frac{1}{\psi}$	$\frac{1}{\psi}$

The Poisson distribution is used in the analysis of many random discrete processes. The probability of occurrence of events x = 1, 2, 3... per unit time is expressed by the Poisson law (Fig. 7).

$$P(x) = \frac{m^x}{x!}e^{-m} = \frac{(\lambda t)^x}{x!}e^{-\lambda t}, \quad (15)$$

where: x – is the number of events in a given time interval; λ is the density, i.e., the average number of events per unit time; λt is the average number of events over time t, $\lambda t = m$.

The Poisson distribution is used for rare events, i.e., *P(x)* is the probability that an event will occur x times during a given test period given a very large number of measurements m.

For Poisson's law, the variance is equal to the mathematical expectation of the number of occurrences of an event over time t, i.e., $\sigma^2 = m$.

When studying processes associated with a gradual decrease in parameters (deterioration of material properties over time, structural degradation, aging processes, wear-related failures in machines, etc.), the gamma distribution law is used (Figs. 8-10) [15].

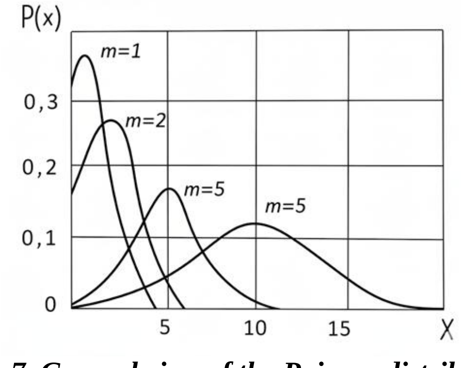

Fig. 7. General view of the Poisson distribution curve

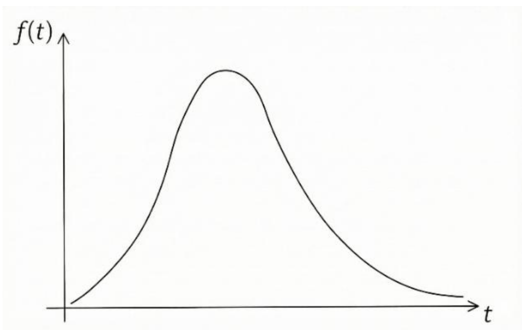

Fig. 8. General view of the distribution curve

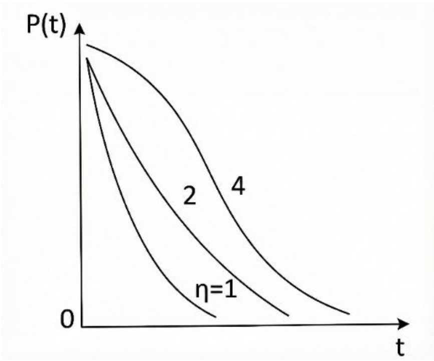

Fig. 9. Probability of trouble-free operation with a gamma distribution of time to failure (λ=1)

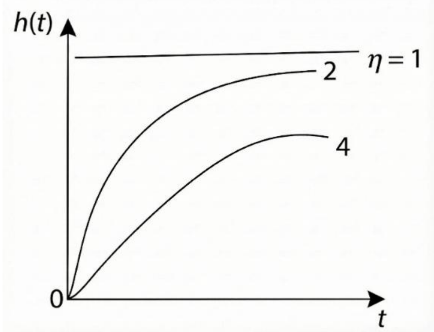

Fig. 10. Failure rate with gamma distribution of time to failure (λ=1)

For this distribution law we have:

$$F(t)=\int_0^t \frac{\lambda\eta}{\Gamma(\eta)}\tau^{\eta-1}e^{-\lambda\tau}\cdot d\tau, \tag{16}$$

where η – is the shape parameter; λ – is the scale parameter.

$$f(t)=\frac{\lambda^{\eta}}{\Gamma(\eta)}t^{\eta-1}e^{-\lambda t}, t\geq 0, \eta>0, \lambda>0. \tag{17}$$

If η is an integer, then by successive integration by parts it can be shown that

$$F(t)=\sum_{K=\eta}^{\infty}\frac{(\lambda t)^K \exp(-\lambda t))}{K!}; \tag{18}$$

$$P(t)=1-F(t)=\sum_{K=0}^{\eta-1}\frac{(\lambda t)^K \exp(-\lambda t))}{K!}; \tag{19}$$

$$h(t)=\frac{f(t)}{P(t)}=\frac{\frac{\lambda^{\eta}}{\Gamma(\eta)}t^{\eta-1}e^{-\lambda t}}{\sum_{K=0}^{\eta-1}\frac{(\lambda t)^K exp(-\lambda t))}{K!}}; \tag{20}$$

$$f(t)=\frac{\lambda^{\eta}}{\Gamma(\eta)}t^{\eta-1}e^{-\lambda t}. \tag{21}$$

The gamma distribution can also be used to describe the time to the *n*th failure of a system if the underlying mean-time-to-failure distribution is exponential. This means that if the random variable x_i has an exponential distribution with parameter $\theta=1/\lambda$, then the random variable $t=x_1+x_2...+x_n$ has a gamma distribution with parameters λ and *n*.

Choosing a mean-time-to-failure distribution is a difficult problem from a practical standpoint. Without a large body of test data, it is difficult to determine which distribution is best suited for a given case. The analyzed distribution laws generally provide a good fit to experimental data in the middle part of the random variable domain, but they differ from each other in the region of large deviations.

The small-deviation pattern recognition method is a fundamentally new approach to diesel engine diagnostics [16, 17].

Analysis of distribution laws has shown that diagnosing anзd predicting the remaining service life of automotive and tractor diesel engines, regardless of their type, requires extensive testing. At the same time, the small-deviation method significantly reduces computational effort when determining the multifactorial nature of parameter relationships, while ensuring a sufficiently high accuracy of results.

A real opportunity to optimize the solution to the problem of diagnosing the technical condition and predicting the remaining service life of diesel engines is the combined use of pattern recognition theory and small-deviation theory. Pattern recognition theory is an attempt to systematically study one of the classic problems of applied mathematics: how, based on limited, incomplete, distorted, probabilistic information about an object, system, or process, can one form an understanding of its internal structure, determine whether it possesses a certain set of properties, predict its behavior, etc.

As noted above, classical statistical methods (normal law, Weibull distribution) operate with average service life indicators T and standard deviations σ. However, for operational reliability management of a specific engine under operating conditions, knowledge of the average service life is insufficient. A transition from failure detection to pre-failure state recognition is necessary.

In this context, the method of pattern recognition based on small parameter deviations is based on the analysis of functional dependence (1), where the technical condition of a diesel engine is considered as a vector in an *n*- dimensional parameter space. The physical essence of the method is that any significant failure (both sudden and gradual) is preceded by a stage of hidden changes in the structural parameters x_i from their nominal values $\mathring{x}_i$.

These changes form a vector of "small deviations" of diagnostic parameters ΔY_i, which is an individual "image" of the system's current state. Unlike statistical testing, which requires collecting a large amount of failure data to construct distribution density curves *f(t)*, the small deviation method allows for changes in the system's state to be detected even at a stage when the parameter values are within tolerance, but the state vector has already deviated from the reference "image" of a healthy engine.

This allows us to solve the key problem identified in reliability analysis: reducing resource variability by individually predicting the remaining life of a specific unit without having to wait for the onset of limiting states characteristic of the Weibull or exponential distributions.

5. Conclusion

1. The similarity method and dimensional theory allow us to establish patterns in wear rate changes tgα depending on engine adjustment parameters. However, this requires numerous experiments, making it impractical for determining the service life and predicting the performance of automotive and tractor engines.

2. The most practical method for determining the remaining service life of automotive and tractor engines is the method of mathematical statistics and probability theory, and, in particular, the normal distribution law. However, determining the service life of engines using this law also requires extensive testing.

3. Therefore, at the current stage of scientific and technological progress in automotive and tractor manufacturing, it is necessary to seek other methods that are more practically acceptable and that facilitate determining the service life of machines with maximum reliability in a shorter time and without extensive testing. These conditions are met by the diagnostic method of pattern recognition based on small parameter deviations.

In this study, the diagnostic method of pattern recognition based on small deviations of diagnostic parameters is adopted as the primary approach for assessing and predicting the service life of automotive and tractor engines.

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АНАЛІЗ МЕТОДІВ БЕЗРОЗБІРНОГО ДІАГНОСТУВАННЯ АВТОТРАКТОРНИХ ДИЗЕЛЬНИХ ДВИГУНІВ

Діагностування та прогнозування ресурсу є одним із найважливіших чинників управління ефективністю та експлуатаційною надійністю сільськогосподарської техніки. Підвищення вимог до якості технічного обслуговування потребує удосконалення підходів до оцінки стану двигуна, який розглядається як система послідовно з'єднаних елементів без резервування. Метою статті є проведення аналізу існуючих методів безрозбірного діагностування автотракторних дизельних двигунів та обґрунтування доцільності використання методу розпізнавання образів за малими відхиленнями параметрів для прогнозування залишкового ресурсу. Методи досліджень ґрунтуються на аналізі теорії подібності та розмірностей, а також методів математичної статистики та теорії ймовірностей.

Детально розглянуто закони розподілу відмов (нормальний, Вейбулла, експоненціальний, Релея, гамма-розподіл) та їх застосування до різних видів зношування. В ході досліджень встановлено, що класичні статистичні методи, зокрема нормальний закон розподілу, вимагають проведення великого обсягу випробувань, що ускладнює їх використання для оперативного прогнозування. Результати аналізу дозволили обґрунтувати ефективність методу розпізнавання образів, який дає змогу фіксувати приховані зміни структурних параметрів ще в межах допуску. Запропонований підхід дозволяє скоротити обсяг обчислювальної роботи та підвищити точність індивідуального прогнозування ресурсу конкретного агрегату.

Результати роботи будуть корисними для інженерно-технічних працівників агропромислового комплексу при вирішенні завдань зниження варіативності ресурсу двигунів та їх систем, забезпечуючи можливість оперативного виявлення передвідмовних станів за малими відхиленнями параметрів для більш точного прогнозування довговічності техніки. Матеріали наукової статті засновані на результатах ініціативних наукових тематик 0122U002187 та 0122U002135.

Ключові слова: *автотракторні дизельні двигуни, безрозбірна діагностика, прогнозування ресурсу, теорія надійності, закони розподілу ймовірностей, метод подібності, розпізнавання образів.*

Ф. 21. Рис. 10. Табл. 1. Літ. 17.

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