

Improvement of maintenance and repair system of internal combustion engines of automotive equipment

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Abstract. The paper analyzes the operating conditions of road transport affecting its reliability. It is concluded that it is necessary to develop scientifically based strategies flexible of AE maintenance based on predicting the failure moment by extrapolating the process of time drift of the informative parameters of the AE at the interval of its intended use. To solve this problem, we propose an approach based on the use of quasi-deterministic models of the time drift of the AE parameters, which allow to obtain analytical expressions for the main reliability indicators - density of the distribution time to failure and the probability of failure - free operation at a given time interval. On the basis of these indicators of reliability in operation, performance indicators have been formed allowing determining of the optimal maintenance frequency. In the final part of the article, the author proposes an algorithm and a methodology that allows organizing flexible strategies for AE maintenance, considering special conditions of its operation.

In modern conditions, road transport is the most important component of the transport system of the Russian Federation, while its reliability depends to a significant extent on natural and climatic, transport and road operating conditions, which include high and low temperatures, dust and humidity, environmental aggressiveness, precipitation, wind load, road conditions, terrain, etc. [1].

At the same time, most of the factors are random in nature, and their combined influence leads to a gradual change in the values of the AE parameters over time and eventually to its failure. In this regard, it is obvious that the decrease in AE reliability during its operation under special conditions should be considered by adjusting the appropriate standards to ensure that the required parameters are maintained within the normal range during a given service life, considering the impact of random external factors, the initial values of the parameters and their changes over time. At the same time, it should be taken into account that the change in AE parameters over time is a random process, and the study of its regularities should be based on the appropriate methods of probability theory and mathematical statistics.

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The importance and relevance of this area is evidenced by a fairly large number of works on this topic, but most of these works, unfortunately, are devoted to the study of only individual issues. They analysed the impact of only strictly de-fined operating conditions on AE reliability, or considered the issues of ensuring the reliability of individual components (aggregates), and only for certain types of cars [2]. The problem of ensuring AE reliability for critical purposes during its operation in special conditions has not been finally solved at present, and the works on this topic are, for the most part, of a private nature and are devoted to the study of only its individual aspects. The lack of elaboration of these issues, in turn, leads to the lack of validity of flexible strategies of AE maintenance. As a result, despite their promising prospects, currently in practice, mainly planned strategies are used, calculated for average conditions and do not fully consider special conditions of its operation. At the same time, the described problem becomes especially relevant in modern conditions.

It is obvious that untimely AE failures are caused by the earlier achievement of the maximum permissible (normalized) values by the parameters of the AE units and aggregates, and to prevent these failures, it is necessary to constantly maintain the AE parameters within the specified limits (established by the regulatory and technical documentation). First of all, this applies to one of the most important units of the AE-ICE. Therefore, for each specific operating conditions, it is necessary to study the patterns of time drift of the ICE parameters and their further analysis in order to prevent their values from exceeding the established limits (failure). This task can be successfully solved by organizing a flexible maintenance strategy with optimal frequency according to the specified criteria. Because of this, when operating AE in special conditions, there is a need to switch from rigid (planned) AE maintenance strategies to flexible maintenance strategies based on the use of probabilistic forecasting methods [3,4].

Thus at present, there is an objective contradiction between the existence of hard-coded parameters and control at planned strategy designed for average conditions and not considering special conditions on the one hand, and the lack of developed flexible strategy and control, which would consider these conditions, and thus would increase the AE efficiency – on the other hand.

This contradiction leads to the fact that the terms of maintenance calculated for typical operating conditions, given in the technical documentation, are often insufficiently justified, which significantly reduces the efficiency of the AE operation when it is operated in special conditions by reducing the availability factor of the vehicle fleet and increasing the unproductive costs of its operation.

The analysis performed has shown that from the total set of informative parameters of the AE ICE, a number of the most important parameters can be identified, which are closely related to the accelerated failure of various units when operating under special conditions. Such parameters specified in the technical documentation that have the greatest impact on the ICE performance are called determining, and the unit itself, the failure of which is most likely under certain operating conditions, is critical. At the same time, it is obvious that depending on certain operating conditions of the AE, both the determining parameters themselves and the critical units can differ significantly [5].

This circumstance allows to conclude that it is necessary to develop scientifically based flexible strategies for the maintenance of AE ICE, based on the prediction of the moment of failure by extrapolating the random process of time drift of its informative parameters. At the same time, in practice, it is often possible to group the same type of equipment with similar operating conditions and go to the group forecasting of its reliability. The final result of such probabilistic (as opposed to individual) forecasting will be the most complete (exhaustive) characteristics of the random time when the parameters reach their maximum

permissible values, namely, the distribution density of time to failure and the probability of failure-free operation at a given time interval [6].

These characteristics, in turn, allow to form performance indicators that depend on the maintenance frequency, and then on their basis – to determine the optimal (according to a particular criterion) frequency of maintenance, reduce the cost of AE operation and increase its reliability.

At the same time, attention was paid, first of all, to the reliability indicators of the AE. This is due to the fact that for AE, which refers to long-term operation systems, the most important property is to maintain a working state during a certain operating time; if the system does not have the required reliability, then it loses its purpose, and other components of reliability (maintainability, durability and conservability) are no longer so important [7].

In this regard, as a generalized efficiency indicator, the so-called specific readiness indicator was used, depending on the values of maintenance and control periodicity (formula 1), which, in turn, can be obtained on the basis of partial indicators.

As the first particular indicator, the readiness indicator was chosen, which characterizes the AE readiness for use for its intended purpose at an arbitrary time and depends on the values of the periodicity of maintenance and control [1, 8]:

$$K_{\text{nr}}(\tau) = \frac{\overline{t_{\text{op}}}}{\tau + \tau_{\text{k}} + P_{\text{otk}}(\tau) \cdot \tau_{\text{b}}}, \quad (1)$$

Where is $\overline{t_{\text{op}}} = \int_0^{\tau} P(t) dt$ the average uptime of the AE on the interval τ ;

τ_{k} and τ_{b} - the average duration of monitoring and restoring the operation of the AE, respectively, $P_{\text{otk}}(\tau)$ - the probability of AE failure in the interval τ .

As a second particular indicator, it is advisable to use the average relative unproductive costs for the operation of AE:

$$C(\tau) = \frac{C_{\text{k}} \cdot \tau_{\text{k}} + P_{\text{otk}}(\tau) \cdot (C_{\text{otk}} \overline{t_{\text{otk}}} + C_{\text{b}} \cdot \tau_{\text{b}})}{P_0(\tau) \cdot C_{\text{p}} \cdot \overline{t_{\text{op}}} + P_{\text{otk}}(\tau) \cdot (C_{\text{otk}} \cdot \overline{t_{\text{otk}}} + C_{\text{b}} \cdot \tau_{\text{b}}) + C_{\text{k}} \tau_{\text{k}}}, \quad (2)$$

Where C_{k} , C_{otk} , C_{v} – the average cost of operating AE in the maintenance mode, in the failure mode and in the recovery mode, respectively; C_{f} – the average cost of operating the AT with its trouble-free operation; $\overline{t_{\text{otk}}} = \tau - \overline{t_{\text{op}}}$ - the average time of failure of the AE in the interval τ , τ_{k} and τ_{b} - the average duration of monitoring and restoring the AE operation, respectively.

It is obvious that the first of the entered indicators should be reduced to the maximum, and the second - to the minimum. In other words, the optimality criteria for the entered indicators when setting and solving the direct and inverse research problems can be presented in the form of systems (3) and (4), respectively:

$$\begin{cases} K_{\text{nr}}(\tau_{\text{opt}}) = \sup_{\tau_{\text{opt}} \in T_c} K_{\text{nr}}(\tau), \\ C(\tau) \leq C_{\text{дон}}. \end{cases} \quad (3)$$

$$\begin{cases} C(\tau_{\text{опт}}) = \inf_{\tau_{\text{опт}} \in [0; T_{\text{ин}}]} C(\tau), \\ K_{\text{нр доп}}(\tau) \geq K_{\text{нр доп}}, \end{cases} \quad (4)$$

Where $C_{\text{доп}}(\tau)$ – the permissible value of the cost of operating the AE;

T_s – the set of possible values of the frequency of AE maintenance and control, at which the condition $C(\tau) \leq C_{\text{доп}}$ is met;

[0; TPG] - the interval of possible values of maintenance and control periodicity (the area of suitability), formed when the condition $K_{\text{нр}}(\tau) \geq K_{\text{нр зад}}$ is met.

All the entered AE indicators are dimensionless, normalized to one, have the same order and depend on maintenance and control frequency. At the same time, the efficiency of the AP functioning in the work was understood as the degree of achievement of the above-mentioned requirements for the indicator of readiness and for operating costs, and the assessment of the optimality of the selected maintenance and control periodicity was made by changing the efficiency of the AE functioning, i.e. by the degree of satisfaction of the specified requirements [5].

In practice, as a generalized indicator of efficiency, it is quite convenient to use the so-called specific indicator of AE readiness, which depends on the values of maintenance and control periodicity, which can be obtained on the basis of previously introduced partial indicators ($K_{\text{пг}}$ and C) and has the following form:

$$K_{\text{г}}^{\text{уд}}(\tau) = \frac{K_{\text{нр}}(\tau)}{C(\tau)}, \quad (5)$$

where τ is the frequency of maintenance and control of the parameters of the AE units.

It is obvious that the generalized indicator of the type (5) depends on control and maintenance period, while in the practical operation of the AE under special conditions, it is often necessary to determine the optimal periodicity $\tau_{\text{опт}}$, at which a predetermined value of the AE readiness indicator is provided at the lowest possible operating costs.

For the calculation using formulas (1 - 4), analytical dependences for the time-to-failure distribution density are required, which, in turn, can be obtained by probabilistic forecasting. At the same time, for such forecasting in practice, it is quite convenient to use the so-called quasi-deterministic (quasi-random) models of a random process, which are a combination of a deterministic function that reflects the drift pattern, and random coefficients that specify the process. Various deterministic functions can be used as basic functions for such models, each of which can describe the regularity of the time drift of parameters under different operating conditions and has random coefficients distributed according to one of the known laws (Table 1).

In this case, the problem of forecasting is reduced to determining the distribution density of the time when the parameters reach their maximum permissible values, i.e., to find the density of the function distribution according to a given distribution of its arguments.

The distribution density obtained with the help of these models is an exhaustive characteristic of a continuous random variable – the AE uptime, which fully characterizes it from a probabilistic point of view, and allows to calculate the probability of uptime at any current moment or, on the contrary, to find the point in time at which the probability of uptime will meet the specified requirements. At the same time, in relation to certain special operating conditions, the optimal frequency of maintenance can be found [9], at which the maximum possible value of the availability coefficient is achieved while reducing the cost

of its operation. The procedure for determining such an optimal periodicity is presented in the form of an appropriate algorithm (Fig.1).

Table 1 - Forecasting CD models of the time drift of the IP AE and the results of the calculation of the LWD before their values exceed the permissible limits

Type of model of time drift of IP AE	Random coefficients of the model	$\omega(\tau_{np})$ - PRV before the IP goes beyond the permissible limits in general form
Linear $\Pi(t) = \Pi_0 - a_1 t$	a_1	$\omega(\tau_{np}) = \frac{\Delta\Pi}{\tau_{np}^2} \cdot \omega\left(\frac{\Delta\Pi}{\tau_{np}}\right)$
	$\Delta\Pi = \Pi_0 - \Pi_{np}$	$\omega(\tau_{np}) = J_{\Delta\Pi} \cdot \omega(\psi_{\Delta\Pi}) = a_1 \cdot \omega(a_1 \tau_{np})$
	a_1 и $\Delta\Pi$	$\omega(\tau_{np}) = \int_{-\infty}^{\infty} \omega_2(\Delta\Pi) \omega_1\left(\frac{\Delta\Pi}{\tau_{np}}\right) \frac{\Delta\Pi}{\tau_{np}^2} d(\Delta\Pi)$
Logarithmic $\Pi(t) = \Pi_0 - \Pi_0 \cdot \ln\left(1 + \frac{a_1 t}{\Pi_0}\right)$	a_1	$\omega(\tau_{np}) = \omega(a_1) \cdot \frac{\Delta\Pi}{\tau_{np}^2} \cdot \left(1 - \exp^{-\frac{\Delta\Pi}{\Pi_0}}\right)$
	a_1 и $\Delta\Pi$	$\omega(\tau_{np}) = \int_{-\infty}^{\infty} \omega_2(a_1) \cdot \omega_1\left(\frac{\Delta\Pi}{\Pi_0}\right) \frac{\Delta\Pi}{\tau_{np}^2} \left(1 - \exp^{-\frac{\Delta\Pi}{\Pi_0}}\right) d\Delta\Pi$
Exponential $\Pi(t) = \Pi_0 \cdot e^{-\frac{a_1 t}{\Pi_0}}$	a_1	$\omega(\tau_{np}) = \omega(a_1) \cdot \frac{\Delta\Pi}{\tau_{np}^2} \cdot \ln\left(\frac{\Pi_0}{\Pi_{np}}\right)$
	a_1 и $\Delta\Pi$	$\omega(\tau_{np}) = \int_{-\infty}^{\infty} \omega(a_1) \cdot \frac{\Delta\Pi}{\tau_{np}^2} \cdot \ln\left(\frac{\Pi_0}{\Pi_{np}}\right) \omega(\Pi_0) d\Delta\Pi$

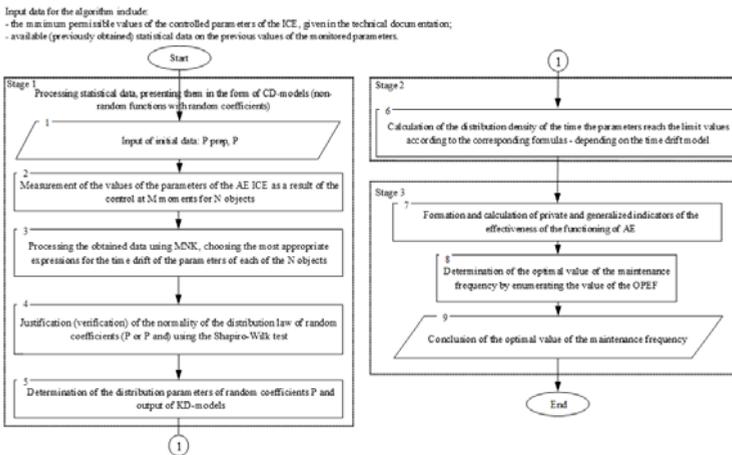


Fig. 1. Block diagram of the algorithm for determining the optimal periodicity of ICE maintenance.

At the first stage of the algorithm, based on statistical data, the approximation polynomials are calculated for the time drift of the parameters for each of the AE types, the law of distribution of the random coefficients of the models is justified, and the distribution parameters of the random coefficients included in them are determined. Next, the density of the distribution of the time for the parameter to reach the limit value is calculated, depending on the selected model and the number of random coefficients, after which the performance indicators are formed and the optimal period of maintenance and control is determined according to the entered criteria.

The optimal values of the maintenance and control periodicity obtained using the algorithm, in turn, can be used to develop a method for monitoring AE aggregates under special conditions (Fig.2), which allows to organize a flexible strategy for AE maintenance in relation to certain special conditions of its operation. The initial data for the implementation of this technique are the values of the parameters of critical aggregates obtained during previous measurements (for example, during routine maintenance and previous maintenance sessions), as well as the algorithm and models discussed earlier.

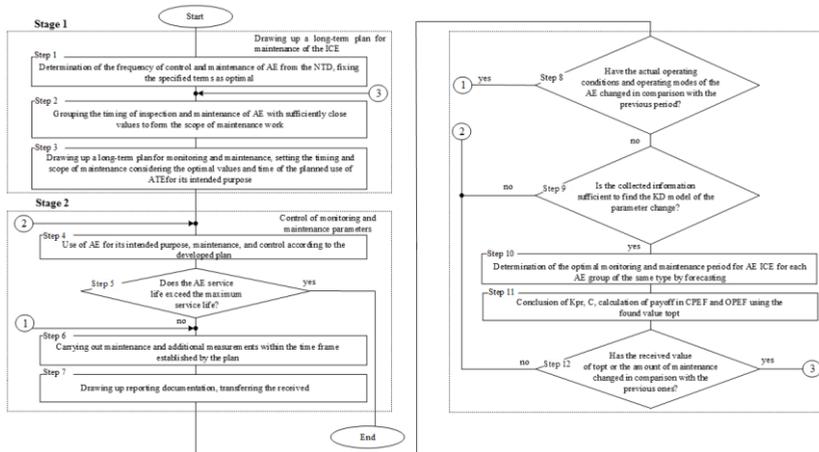


Fig. 2. Method of control and maintenance of the AE ICE in special conditions of its operation.

At the first stage of the methodology (steps 1-3), a long-term (preliminary) plan for conducting maintenance and control is provided. At the second stage (steps 4 to 12), the control and maintenance parameters are managed (i.e., the volume and frequency of operations performed). Thus, the various methodology stages are implemented throughout the entire life cycle of the AE. The proposed approach allows to organize a flexible strategy of maintenance and control of parameters, in which a pre-set value of the AE readiness indicator is achieved while reducing the cost of its operation. At the same time, in contrast to the existing approaches to ensure reliability, individual features of the time drift of the parameters of specific types of AE are considered, taking into account certain special conditions of its operation, and in general, the solution of the problem formulated in the work is provided.

Testing of the developed algorithms was carried out by conducting an experiment on the basis of car parks. As a result of the experiment, statistical data on the values of the parameters of the AE KamAZ at the corresponding moments of measurement were obtained.

After determining the corresponding CD model, the law and the parameters of the distribution of its random coefficients, in accordance with the specified algorithm, the density of the time distribution was determined until the AE parameter exceeds the

permissible limits. After that, the formation of indicators of the AE functioning quality was carried out, then the calculation of the CPEF and the determination by the method of iteration of the optimal period of the AE maintenance using a computer.

Considering the found optimal values of the maintenance frequency, a variant of the organization of a flexible strategy of maintenance of AE of the type KamAZ was developed.

The results of calculations of the dependences of the PRV, R_{br} , and OPEF on the frequency of maintenance of the AE ICE for the AE of the KamAZ-43114 type are shown in Figures 3-5.

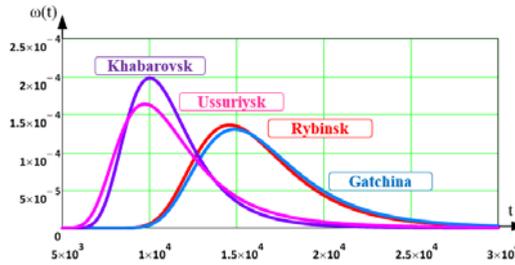


Fig. 3. Results of calculating the time distribution density before the output of the values of the compression value of the KAMAZ-43114 ICE for regions with different natural and climatic conditions (linear drift model).

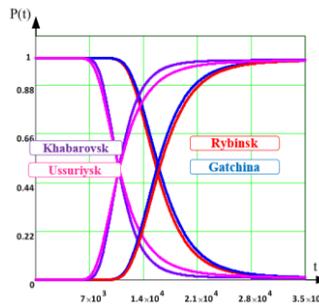


Fig. 4. The probability of the out-of-limiting compression value of the ICE KamAZ-43114 exceeding the permissible limits when operating in different regions.

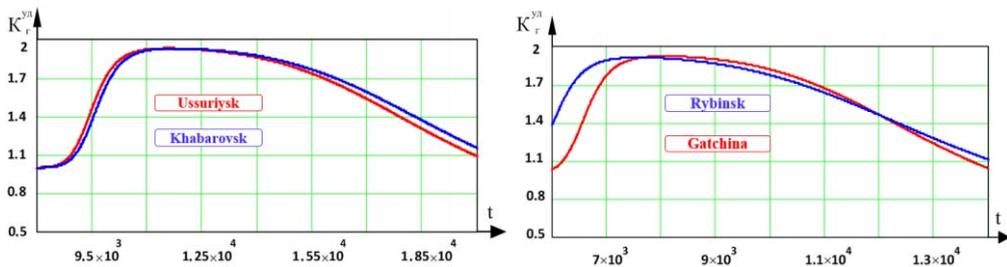


Fig. 5. Results of calculation of the dependence of the specific availability coefficient of AE of the KAMAZ-43114 type on maintenance and control frequency during its operation in various conditions.

The effect obtained from the application of the developed flexible strategy in comparison with the existing planned (rigid) maintenance system in practice is achieved by increasing the specific readiness index from 2.5 to 9.6 %).

Conclusion

The disadvantage of the approach proposed in this paper is the need for preliminary collection of statistical data on the values of the controlled parameters at various points in time, i.e., the gain on the entered indicators is achieved due to a certain decrease in efficiency (an increase in the number of operations) during maintenance and control. To eliminate this drawback, circuit solutions can be used to increase the efficiency and accuracy of monitoring the values of the parameters of the AE ICE [10, 11].

Thus, the application of the obtained results will allow to determine the optimal values of the maintenance and control of the AE ICE in special conditions of its operation, and ultimately - to organize a flexible strategy of maintenance and control, which allows to increase the AE reliability, while reducing the cost of its operation.

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