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EXPERIMENTAL DETERMINATION OF THE PARAMETERS FOR THE MATHEMATIAL MODEL OF MAINTAINING AUTOMOBILE DIESEL FEED SYSTEM FUNCTIONABILITY DURING ITS OPERATION

Parameters have been determined for the mathematical model of the process of maintaining automobile diesel feed system functionability during its operation. On the basis of statistical data failure rate dependences on the kilometrage and operation life have been obtained, probability distribution law concerning failure-free operation of KamAZ-5320 diesel feed system is substantiated.

Key words: *maintenance and repair system, functionability, reliability, failure rate, probability of failure-free operation.*

Introduction

Maintenance and repair (M and R) system occupies an important place in the conception of automobile quality management, particularly in maintaining functionability while performing transport operations. E.g., in the realized aggregative index of automobile quality that falls to the operation sphere, the weight of M and R organization system constitutes 25%. This determines the importance of research work and practical measures on the improvement of M and R system [1].

The existing methods for maintaining an automobile serviceability [2 – 6] are directed mainly towards improvement of the system of diagnostic and informational M and R provision, which will enable switching from the scheduled maintenance strategy to the maintenance according to the current state, which is, undoubtedly, much more efficient. However, a part of automobiles in the production sphere will always be equipped only with the most necessary devices of built-in diagnostics and, therefore, be more affordable. The above-mentioned concerns outdated automobiles of both home (in most cases) and foreign production. As it is known, the average age of the automobiles, used in Ukraine, is 10 – 12 years.

Maintaining serviceability of such automobiles during their operation requires searching for other approaches, particularly, through taking into account additional factors that have essential influence on changes in an automobile condition. This will make it possible to determine optimal maintenance periodicity and the list of works to be performed.

As the previous research has shown, along with kilometrage time, automobile serviceability is influenced by its operation life. As a rule, those factors are not considered separately in literature. However, in terms of M and R organization the difference between calendar time and duration of the intended automobile operation is of considerable importance [7].

Still, at present no research is found on how an automobile technical state is influenced by its operation life along with running time, in particular, the existing M and R system does not fully take into account the influence of both factors.

The methods of maintaining an automobile serviceability during its operation, with the above drawbacks being taken into account, were developed and described in detail in works [8, 9].

The developed methods for maintaining serviceability of an automobile diesel feed system are designed for preventing failures by establishing optimal periodicity of M and R work and of the list of the required operations for the least reliable system elements. To achieve this goal, an algorithm was developed [9] that provides for the fulfillment of a number of logic conditions, solution of certain algebraic equations and expressions and, in fact, is a mathematical model of maintaining serviceability of an automobile diesel feed system.

This mathematical model is a posterior one, because the end result is achieved with input data being calculated by analytical relationships (formulas and distribution laws), obtained as a result of data processing and experimental data analysis.

Therefore, functioning of the mathematical model of maintaining automobile diesel feed system serviceability is possible if posterior parameters are available. Their determination on the basis of processing statistical information about failures of KamAZ-5320 diesel feed system is the goal of this work.

According to the developed procedure, to such parameters belong:

- dependence of the failure rate of the automobile diesel feed system on the automobile kilometrage and operation life;
- the law of failure-free operation probability distribution;
- the lists of maintenance operations for automobile diesel feed system and their grouping according to the types.

Statistical data about the failures of KamAZ-5320 diesel feed system serve as initial information for finding these parameters.

Collection of statistical data on failures of KamAZ-5320 feed system was performed at Vinnytsia motor transport enterprise АТП 10554 and «AUTODIN» enterprise, engaged in diagnostics and repairs of diesel fuel supply equipment including that of KamAZ-5320.

For obtaining the dependences of the failure rate variations on kilometrage and operation life the following statistical data were collected: the date of KamAZ-5320 production, maintenance (or repair) date, and the automobile kilometrage for the moment of maintenance and the feed system failure characteristic.

The entire period of the automobile operation was divided into operation groups: according to operation life – from 0 to 7, from 7 to 14, from 14 to 21 years of operation; according to kilometrage – from 0 to 50000 km, from 50 000 to 100 000 km, etc. up to 350 000, which makes the total of 3×7=21 operation groups of automobiles.

After statistical information is collected the next step is calculation of the automobile feed system failure rates for each operation group according to the kilometrage and operation life.

$$\omega(L) = \frac{\sum_{i=1}^{n} r_i(L)}{n \cdot L}, \left[\frac{1}{km}\right], \qquad (1)$$

where n is the number of automobiles in the group being investigated; $r_i(L)$ – the number of failures occurred in the i-th automobile within the kilometrage range of L.

Failure rate values, calculated from the statistical formula (1), have made it possible to obtain graphical relationships presented in fig. 2.

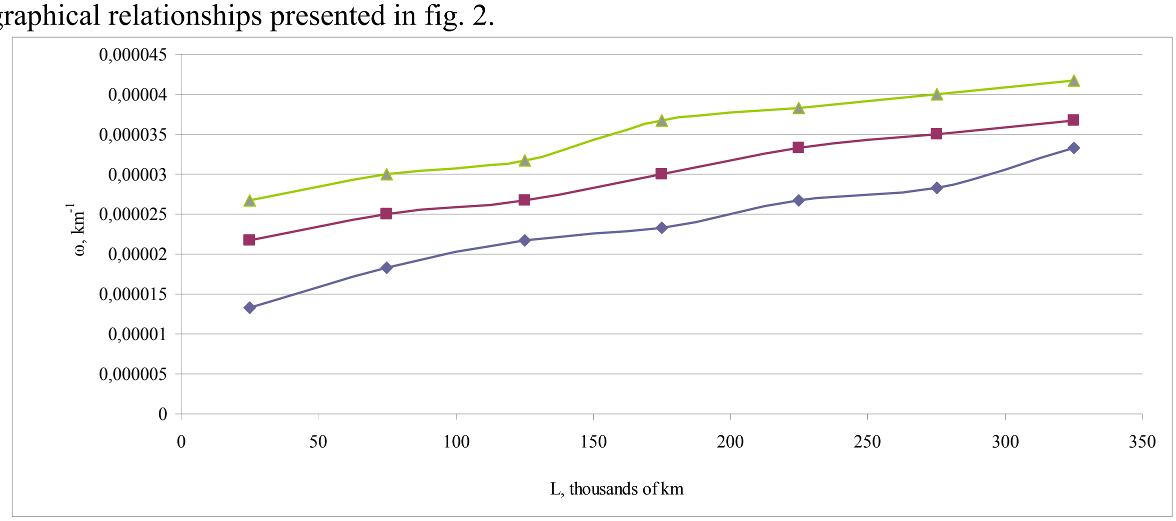

Fig. 1. Graphic dependence of Kamaz-5320 diesel feed system failure rate ω on kilometrage L and operation life T: T_1 – less than 7 years of operation; T_2 – from 7 to 14 years of operation; T_3 – from 14 to 21 years of operation.

Determination of the analytical dependences of KamAZ-5320 diesel feed system failure rate variations on the kilometrage and operation life

To obtain analytical dependence of KamAZ-5320 diesel feed system failure rate on kilometrage L and operation life T it is necessary to approximate failure rate dependences, found on the basis of statistical data about failures.

Bifactorial equation $\omega = f(L,T)$ was generated by sequential approximation [12]. At the first stage graphic dependences of the failure rate on the kilometrage $\omega = f(L)$ were approximated (fig. 2).

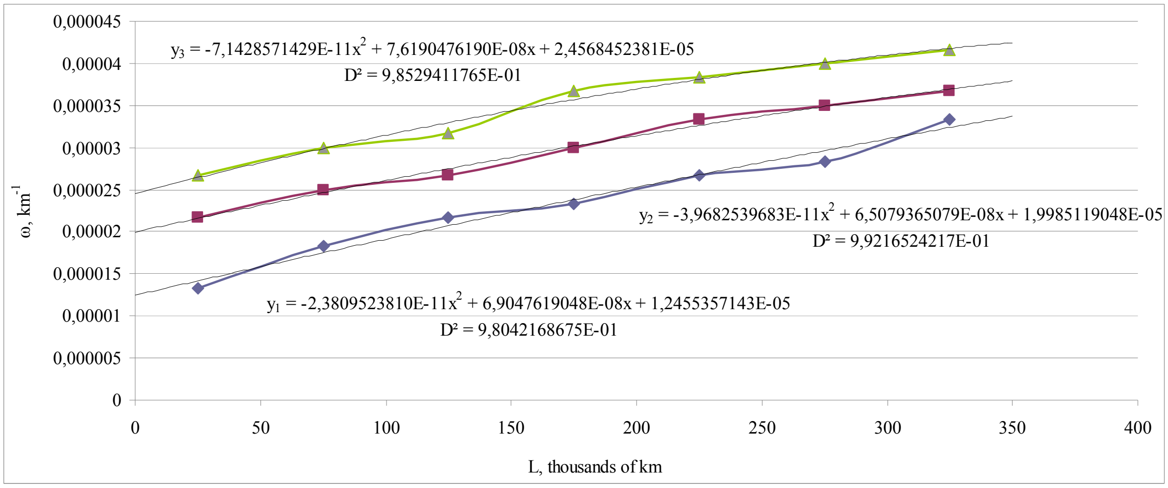

Fig. 2. Approximation curves of KamAZ-5320 diesel feed system failure rate ω on kilometrage L and operation life T: T_1 – under 7 years of operation; T_2 – from 7 to 14 years of operation; T_3 – from 14 до 21 years of operation. D^2 – quantity that characterizes the validity of approximation

The obtained numerical values of the coefficients from the approximation equations of KamAZ-5320 feed system failure rate dependence on the automobile operation life are presented in table 1.

Table 1

Coefficients of the approximation equations of KamAZ-5320 feed system failure rate dependence on the automobile operation life

Automobile operation life, years	Coefficients		
	$a_0, \frac{1}{km}$	$a_1, \frac{1}{km^2}$	$a_2, \frac{1}{km^3}$
From 0 to 7	$1{,}2455 \cdot 10^{-5}$	$6{,}9048 \cdot 10^{-8}$	$-2{,}381 \cdot 10^{-11}$
From 7 to 14	$1{,}9985 \cdot 10^{-5}$	$6{,}5079 \cdot 10^{-8}$	$-3{,}9683 \cdot 10^{-11}$
From 14 to 21	$2{,}4568 \cdot 10^{-5}$	$7{,}6191 \cdot 10^{-8}$	$-7{,}1429 \cdot 10^{-11}$

At the second stage, according to the numerical values of the coefficients $\alpha_к$ of approximation equations, their graphic dependences on the automobile operation life T are built (fig. 3).

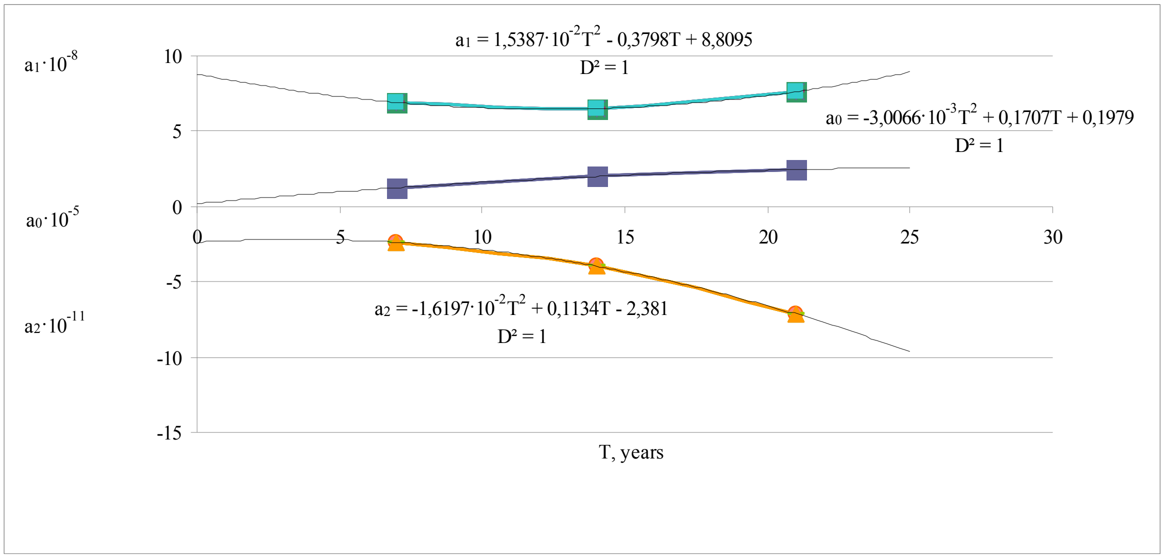

Fig. 3. Relationships of the coefficients $a_к = f_k(T)$ of the approximation equations describing KamAZ-5320 feed system failure rate dependence on the automobile operation life *T*

By the least squares method graphic relationships are approximated by the second-order equations:

$$a_m = (b_{0m} + b_{1m}T + b_{2m} \cdot T^2) \cdot k_m, \qquad (2)$$

where k_m is dimension factor: $k_0 = 1,[\frac{1}{км}]$; $k_1 = 1,[\frac{1}{км^2}]$; $k_2 = 1,[\frac{1}{км^3}]$.

Constant coefficients b_{0m} of the approximation equations are dimensionless values, dimensionality of the approximation equation coefficients b_{1m} and $b_{2m} - \frac{1}{year}$ and $\frac{1}{year^2}$.

At the third stage we generate general analytical dependence of the automobile failure rate $\boldsymbol{\omega}$ on the kilometrage L and operation life T:

$$\omega = \alpha_0(f_0(T)) + \alpha_1(f_1(T)) \cdot L + ... + \alpha_m(f_m(T)) \cdot L^m, [\frac{1}{км}] \qquad (3)$$

where $\alpha_m = f_m(T)$ – analytical dependences of the approximation equation coefficients on the automobile operation life; *m* – degree of the approximation equation.

Relationships of the coefficients $a_m = f_m(T)$ of the approximation equations for KamAZ-5320 diesel feed system failure rate dependence on the automobile operation life *T* have the following form:

$$a_0 = -3,0066 \cdot 10^{-3}T^2 + 0,1707 \cdot T + 0,1979$$
$$a_1 = 1,5387 \cdot 10^{-2}T^2 - 0,3982T + 8,8095$$
$$a_2 = -1,6197 \cdot 10^{-2}T^2 + 0,1134T - 2,381.$$

The values of the approximation equation constant coefficients b_{jm} for each automobile feed system brand are calculated separately.

The usage of the second-order approximation equations ensures the required accuracy, maximal mean square deviation of the calculated data from the statistical data being 2 %.

Determination of the probability distribution law for the failure-free operation of KamAZ-5320 diesel feed system

While evaluating the probability of failure-free operation of the system that operates with the replacement of the damaged elements, the failure rate in the time interval under consideration is assumed to follow Poisson law. Such supposition is true if probability distribution laws for failure-free system elements operation are exponential, i.e. $P(I) = e^{-\omega \cdot L}$, where ω=const. Besides, according to Palm's limit theorem, this supposition can be considered to be practically true for any laws of probability distribution for failure-free operation of the system elements if their number in the system is sufficiently large [10].

As the analysis of KamAZ-5320 diesel feed system failures has shown, the overwhelming majority of them is caused by gradual wear and therefore, the probability distribution laws for failure-free operation of the system elements will be quite different from the exponential ones. According to the calculation results, the number of the replaceable elements of KamAZ-5320 diesel feed system is relatively small and the fact that the conditions of failure rate belonging to Poisson flow are not [10] satisfied is the evidence of that.

In such case it is feasible to introduce a correction to Poisson approximation. For this it is necessary to determine the function first that describes the probability k of failures in the considered kilometrage range:

$$\left.\begin{aligned} R_\kappa &\approx \psi(\kappa, a) + \varepsilon \nabla^2 \psi(\kappa, a); \\ \varepsilon &= \frac{1}{2}(Д - a), \end{aligned}\right\} \tag{4}$$

where a – mathematical expectation (or average number of failures), $a = \omega \cdot L = \frac{\sum_{i=1}^{n} r_i(L)}{n \cdot L} \cdot L = \frac{\sum_{i=1}^{n} r_i(L)}{n}$; $\psi(\kappa, a)$ – Poisson approximation for the probability R_κ to be found; $\nabla^2 \psi(\kappa, a)$ – correction to Poisson approximation that is equal to the second derivative function $\psi(\kappa, a)$; Д – dispersion of the number of failures in the kilometrage range under consideration; ε – factor that takes into account deviation of the failures number dispersion for the given flow from the dispersion of corresponding Poisson flow (that is equal to a).

$$\psi(\kappa, a) = \frac{a^\kappa}{\kappa!} e^{-a};$$

$$\nabla^2 \psi(\kappa, a) = \psi(\kappa, a) - 2\psi(\kappa - 1, a) + \psi(\kappa - 2, a),$$

As failure-free operation probability P is of interest to us, or the probability of occurrence 0 of failures R_0, i.e. κ=0 and $R_0 = Đ$, we will have:

$$\psi(0, a) = \nabla^2 \psi(0, a) = e^{-a},$$

wherefrom we obtain a formula for the probability of the absence of failures in the kilometrage range under consideration:

$$P \approx [1 + \varepsilon] \cdot e^{-a}. \tag{5}$$

Analysis of the application sphere of the calculation method for the Poisson flow correction has shown that formulas (4) and (5) can be used if the maximal correction value is less than the half of the corresponding Poisson approximation, i.e. when $\varepsilon < 1/2$ [10].

The calculations have shown that this method can be used to determine the correction to Poisson flow. In other cases a profound analysis of the system failures is required – of their character and peculiarities in order to establish the dependence of the probability distribution law on the kilometrage and then to verify the supposition using the agreement criteria.

The value of the calculated maximal correction turned to be several orders less than Poisson approximation itself, which allows for its value not to be taken into account.

In case when the average number of failures a >15, the functions $\psi(\kappa, a)$ and $\nabla^2\psi(\kappa, a)$ become close to the corresponding functions for normal distribution. Therefore, for a >15, calculations are performed by the formula:

$$P_0 \approx \frac{1}{\sqrt{a}}\varphi\left(-\sqrt{a}\right) + \frac{\varepsilon}{a\sqrt{a}}\varphi''\left(-\sqrt{a}\right), \tag{6}$$

where

$$\varphi(x) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2} \tag{7}$$

According to the experimental investigation, the maximal value of the average failures number is below 15.

Determination of the list of maintenance operations for KamAZ-5320 diesel feed system and their grouping according to the types requires the analysis of the obtained statistical data about the feed system failures in terms of:

failure distribution over the feed system elements, which will make it possible to distinguish the less reliable among them;

frequencies of occurrence of different failure types – this will enable failure distribution according to servicing types and forming the lists of control-diagnostic works for each type of servicing operations in the order of diminishing probability of each subsequent failure.

Types and lists of control-diagnostic servicing operations for the automobile diesel feed system are established for each operation group. This is explained by different influence of the kilometrage and operation life on the changes in the technical state of individual elements. And really, with the increasing operation life of the automobile a part of failures, caused by the loss of properties of industrial rubber articles, could differ as compared with the automobiles of another age.

It is important to analyze average kilometrage for each type of failures. This will enable more accurate formation of the lists of control-diagnostic servicing operations for the automobile diesel feed system through avoiding the repetition of such failure removal operation, the kilometrage for which is less than the kilometrage from the moment when this operation was performed last.

The results of the analysis of KamAZ-5320 diesel feed system failures are planned to be described in the form of the procedure for defining the lists and their grouping according to the types of maintenance operations for the automobile diesel feed system.

Conclusions

On the basis of experimental determination of the parameters for the mathematical model of maintaining KamAZ-5320 diesel feed system functionability during its operation, for the first time analytical relationships were obtained that describe the dependence of KamAZ-5320 diesel feed system failure rate variations on kilometrage L and operation life T. The above relationships will make the basis of the given mathematical model. It was found that the probability of failure-free operation of KamAZ-5320 changes in time according to the exponential law. i.e. $P(I) = e^{-\omega \cdot L}$, where ω=const – feed system failure rate; L – kilometrage, thousands of km.

Mathematical model will enable convenient, simple and operative maintaining of KamAZ-5320 diesel feed system serviceability at real enterprises and in organizations engaged in automotive transportation.

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