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ARTICLE

# THE CONCEPT OF MAINTAINING THE EFFICIENCY OF AUTOMOBILE ENGINES METHODS TRIBODIAGNOSTICS

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## ABSTRACT

*The article presents an analysis of the process of changing of technical state of the automobile engine mobile interfaces from the beginning of operation until depletion of established service life in the form of life ageing structure that includes a complex of repair and maintenance cycles. During the operational phase, periodic multiple repetition of cycles of deterioration and stepwise recovery of the technical state occurs. Within a single cycle, deterioration of technical state forms a monotonic and relatively slow wear of the parts and their aperiodic sudden failures. If within a single maintenance cycle there is a complex of working cycles that include engine operation at startup, idle and under load, and maintenance itself, the regularity of the technical state change will be determined by wear rate at each of these modes. Consideration of this "micro level" in the structure of wear is a feature and novelty of the described here repair and maintenance cycle of engine. According to this structure, taking into account the assumptions and limitations made, the dependence between the mobile interface lifetime and the lifetime of the lubricating layer under the influence of a complex of operational factors: torque, crankshaft speed, modes and duration of run-in phase, duration of operation at start-up, idling, under load is received. The objective function of an automobile engine durability improvement is proposed. The results of calculations show that the mobile interfaces lifetime is significantly increased if the maximum lifetime of the lubricating layer is provided during run-in, start-up, idle and under load conditions. Thus, based on the idea of regularity of the technical state change of mobile interfaces in operation, the scientific concept of maintaining the automobile engine efficiency in operation is proved. The concept is presented in the form of a structure containing the goal, criteria, limitations, scope, stages, technical and organizational solutions. The novelty of the concept is that conditions for limiting the crankshaft bearings wear during the operating cycles are created in the structure of repair and maintenance cycle of an automobile engine, due to the development of the lubrication control system.*

**KEY WORDS**
*engine, efficiency, crankshaft, tribodiagnostics, lubrication process.*

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## INTRODUCTION

An essential factor for increasing the competitiveness of automobile transportation is minimizing costs of ensuring working capacity of vehicles and their components. Engine is one of the major automobile component, which determine both its operation efficiency and the amount of maintenance costs. The efficiency of the automobile engines operation is determined by a variety of factors - constructive, road, natural-climatic, operational, etc. [1-3]. At the same time, a wide range of opportunities for increasing the efficiency of its operation provides management of operational factors.

At the stages of production and technical operation of automobile engines, there is a change in parameters of the technical state of its units, mechanisms and systems, initial indicators values of which are formed during production [2]. During running-in of new or overhauled engine, change in parameters is directed towards improvement, however, during subsequent operation time, a multiple repetition of cycles of technical state deterioration and its stepwise recovery through repair is carried out with a regularity of maintenance. Within a single maintenance cycle, the regularity of change in the technical state forms a monotonic and relatively slow wear of mobile interfaces and aperiodic sudden failures.

Strict adherence to periodicity and volume of maintenance work, timeliness of repair performance slows the monotonous deterioration of the technical state parameters. At the same time, the authors concluded that there is a significant reserve in maintaining the automobile engines performance if additional measures are taken to reduce the rate of technical state deterioration within a single cycle.

Based on Cause and Effect Analysis of the factors of changes in the technical state of mobile interfaces in operation, it is concluded that the control of the technical condition is associated with the control of the lubrication process [4, 5]. Preconditions of such control were studied based on the study of scientific publications and practical developments in the field of maintaining of automobile engines efficiency in operation [6 -12].

It is established that the common problem holding back quality improvement of run-in, technical state definition and prediction, minimization of starting and operational wear of mobile interfaces, is insufficiently developed operational, reliable, low-cost and available methods and tools for evaluating the lubrication process.

Analysis of the present situation showed that the problem of increasing the automobile engine durability could be solved by controlling the lubrication process in mobile interfaces. However, the effective practical implementation of such operational method of maintaining the automobile engine efficiency is currently hindered due to insufficient development of theoretical and methodological provisions of the lubrication management system. Therefore, development of methods for effective maintenance of automobile engines performance based on the lubrication process management helps to reduce costs of resources and losses during operation.

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In this regard, research aimed at developing methods and instruments to maintain the automobile engine performance are relevant.

## METHODS

The main scientific propositions and results presented in the article are based on the developed theoretical background and results of experimental studies of the operational reliability of automobile engines, the use of tribo diagnostics and study of regularities of change in the automobiles and aggregates technical state [13].

Change process of mobile interfaces technical state from beginning of operation until depletion of established service life is complex, and it can be more simply represented as the structure of operational wear process. It includes a set of repair and maintenance cycles, formed by stages of repair and operation [14].

If within a single maintenance cycle there is a complex of working cycles that include engine operation at startup, idle and under load, and maintenance itself, the intensity of the technical state change will be determined by regularities of wear at each of these modes. Consideration of working cycles in the structure of wear is a feature and novelty of the repair and maintenance cycle of engine.

According to the accepted structure, the current diametral clearance $\Delta$ in the mobile interface is formed by the clearance value after mounting (assembly) $\Delta_M$ and the total current operational wear $I^{\Sigma}$ generated by wear during the running-in $I^{ОБ}$ and current operational wear $I^{Э}$, which, in turn, consists of wear at start-up $I^{П}$, when the engine is idling $I^{X}$ and under load IH:

$$\Delta=\Delta_M + I^{\Sigma}=\Delta_M + I^{ОБ} + I^{Э}=\Delta_M + I^{ОБ} + I^{П} + I^{X} + I^{H}. \quad (1)$$

Based on this, the objective function of operational wear can be represented as following:

$$I^{\Sigma}=I^{ОБ} + I^{П} + I^{X} + I^{H}\rightarrow min.$$

Linear wear I of the rubbing surfaces is equal to:

$$I = i_h \cdot \tau , \quad (2)$$

where ih – wear rate, $\mu m / h$; $\tau$ - duration of friction, h.

It is assumed that the wear rate ih is proportional to frictional work and, accordingly, to duration of the contact interaction (in case of lubricating layer absence) of friction surfaces, torque M and crankshaft speed n:

$$i_h = A(1-E_g)M\, n\, K_{\partial} , \quad (3)$$

where A - coefficient of proportionality, depending on the physical-mechanical and geometric properties of friction surfaces; Eg - parameter of the lubricating layer lifetime in the mobile interface; $K_{ä}$ - coefficient of the mode dynamism taking into account an increase in wear intensity during an unsteady mode of the engine operation in comparison with the steady one.

The operational wear is summarized from the wear values at each mode: start-up $I_l^{Ï}$ , idling $I_l^{Õ}$ and under load $I_l^{Í}$ in all operating cycles:

$$I^{Ý} = \sum^{l=L_{\acute{y}}} (I_l^{Ï} + I_l^{Õ} + I_l^{Í}) = A^{Ï} \sum^{l=L_{\acute{y}}} \sum^{j=T_{Ï}} (1-E_{glj}^{Ï}) Ì_{lj}^{Ï} n_{lj}^{Ï} \tau_{lj}^{Ï} \hat{E}_{älj}^{Ï} +$$
$$+ A^{Õ} \sum^{m=T_{Õ}} (1-E_{glm}^{Õ}) Ì_{lm}^{Õ} n_{lm}^{Õ} \tau_{lm}^{Õ} \hat{E}_{älm}^{Õ} + A^{Í} \sum^{l=L_{\acute{y}}} \sum^{k=T_{Í}} (1-E_{glk}^{Í}) Ì_{lk}^{Í} n_{lk}^{Í} \tau_{lk}^{Í} \hat{E}_{älk}^{Í} . \quad (4)$$

where $T_{П}$, $T_X$, $T_H$ -$\tau_{lj}^{П}$ - the number of start-up, idling and load modes in one operating cycle respectively; $\tau_{lj}^{П}$ - duration of the engine operation in l-th cycle on the j-th operating mode at start-up, h; $\tau_{lm}^{X}$ - duration of the engine operation in the l-th operating cycle on the m-th operating mode at idle, h; $\tau_{lk}^{H}$ - duration of the engine operation in the l-th operating cycle on the k-th operating mode under load, h;

LE - number of working cycles in operation; $(Ì_{lj}^{Ï}, n_{lj}^{Ï}), (Ì_{lm}^{Õ}, n_{lm}^{Õ}), (Ì_{lk}^{Í}, n_{lk}^{Í})$ , - parameters of loading modes in each working cycle; $E_{glj}^{Ï}, E_{glm}^{Õ}, E_{glk}^{Í}$ , - parameter of the relative lifetime of the lubricating layer in each working cycle for each stage; $\hat{E}_{älj}^{Ï}, \hat{E}_{älm}^{Õ}, \hat{E}_{älk}^{Í}$ , is the dynamic factor in each working cycle for each stage.

Duration $\tau_{lk}^{H}$ of the engine operation under load is determined by an automobile mileage $L_{lk}$ (km) with an average speed $V_{lk}$ (km/h) according to the formula:

$$\tau_{lk}^{Í} = \frac{L_{lk}}{V_{lk}} \qquad (5)$$

The maximum permissible operational wear will be:

$I^{Э.ПР} = \Delta_{ПР} - \Delta_{M} - I^{ОБ}$, (6)

where $\Delta_{ПР}$ – maximum permissible value of diametal clearance in mobile interface.

On the assumption that parameters in the groups ($\tau_{lj}^{П}$, $\tau_{lm}^{Õ}$, $\tau_{lm}^{Í}$), [$(\grave{I}_{lj}^{Ï}, n_{lj}^{Ï})$, $(\grave{I}_{lm}^{Õ}, n_{lm}^{Õ})$, $(\grave{I}_{lk}^{Í}, n_{lk}^{Í})$], ($E_{glj}^{Ï}, E_{glm}^{Õ}, E_{glk}^{Í}$), ($\hat{E}_{älj}^{Ï}, \hat{E}_{älm}^{Õ}, \hat{E}_{älk}^{Í}$) have the same values, wear at running-in will be:

$$I^{OÁ} = \grave{A}^{\hat{I}Á}(1-E_g^{OÁ})\grave{I}^{OÁ} n^{OÁ} \grave{O}^{OÁ} \hat{E}_{ä}^{\hat{I}Á}, \qquad (7)$$

maximum permissible operational wear will be:

$$I^{Ý.ÏÐ} = \grave{A}^{Ï}(1-E_g^{Ï})\grave{I}^{Ï} n^{Ï} L_{Ý} T^{Ï} \hat{E}_{ä}^{Ï} + \grave{A}^{Õ}(1-E_g^{Õ})\grave{I}^{Õ} n^{Õ} L_{Ý} T^{Õ} \hat{E}_{ä}^{Õ} + \grave{A}^{Í}(1-E_g^{Í})\grave{I}^{Í} n^{Í} \frac{L_l}{V_l} \hat{E}_{ä}^{Í}, \qquad (8)$$

where $T^{ОБ}$, $T^{П}$, $T^{X}$, $T^{H}$ - total operation time at run-in, start-up, idling, under loading modes respectively, h; $M^{ОБ}$, $M^{П}$, $M^{X}$, $M^{H}$ - average values of torque at run-in, start-up, idling and under load operation respectively, Nm; $n^{ОБ}$, $n^{П}$, $n^{X}$, $n^{H}$ - average values of rotational frequency at run-in, start-up, idling and under load respectively, min-1; Vl - average speed of the vehicle, km / h; Ll -vehicle mileage for one working cycle, km.

Let us assume that lifetime of the mobile interface is equal to:

$$L_{Ð} = L_{Ý} L_l, \qquad (9)$$

and the number of working cycles in operation will be:

$$L_{Ý} = \frac{\Delta_{ÏÐ} - \Delta_{\grave{I}} - \grave{A}^{\hat{I}Á}(1-E_g^{OÁ})\grave{I}^{OÁ} n^{OÁ} \grave{O}^{OÁ}}{\grave{A}^{Ï}(1-E_g^{Ï})\grave{I}^{Ï} n^{Ï} T^{Ï} + \grave{A}^{Õ}(1-E_g^{Õ})\grave{I}^{Õ} n^{Õ} T^{Õ} + \grave{A}^{Í}(1-E_g^{Í})\grave{I}^{Í} n^{Í} \frac{L_l}{V_l}}. \qquad (10)$$

Then the mathematical model of lifetime expenditure of mobile interface can be represented in the form:

$$L_p = L_l \frac{\Delta_{ПРЕД} - \Delta_M - A^{ОБ}(1-E_g^{ОБ})M^{ОБ} n^{ОБ} T^{ОБ} K_{\partial}^{ОБ}}{A^{П}(1-E_g^{П})M^{П} n^{П} T^{П} K_{\partial}^{П} + A^{X}(1-E_g^{X})M^{X} n^{X} T^{X} K_{\partial}^{X} + A^{H}(1-E_g^{H})M^{H} n^{H} \frac{L_l}{V_l} K_{\partial}^{H}}. \qquad (11)$$

The target function of increasing the automobile engines durability is:

$$L_{\eth} \rightarrow L_p(max) \qquad (12)$$

Under limitations:

$$E_{g.äîï} < E_g \leq 1; n_{õõ} \leq n \leq n_{íîì}; \hat{E}_{ä} \geq 1; L_{l\min} \leq L_l \leq L_{l\max}$$

$$V_{l\min} \leq V_l \leq V_{l\max}; T_{\min} \leq T \leq T_{\max}; A_{\min} \leq A \leq A_{\max}.$$

Results of the theoretical study show that value change of parameter Eg has the greatest impact on the value Lp when working under load. Thus, when value of Eg parameter is reduced by 0,02 relatively to the average value of 0,97, the lifetime is reduced by 1,5 times. However, with an increase in parameter by 0,02 relatively to the average value, the lifetime rises already 2,1 times. In general, to increase the lifetime, it is necessary to ensure a high level of values of the parameter Eg both at run-in and at the stages of operating modes. So, while simultaneously taking into account the maximum values of Eg at run-in (0.8), starting (0.9), idling (0.7) and under load (0.99), the increase in lifetime reaches 2.6 times.

## RESULTS AND DISCUSSION

Based on a common understanding of regularities of change in technical state of mobile interfaces in operation, the scientific concept of maintaining the automobile engines efficiency is proved, which differs in terms of limiting the wear intensity of mobile interfaces in repair and maintenance cycle based on the development of tribo diagnostics methods.

Conceptual provisions are formulated as follows:

- aim is to reduce cost of transportation process support by increasing the durability of automobile engines through maintaining their efficiency by means of tribo diagnostics methods;
- criterion is maintenance of automotive engine efficiency based on management of technical state change of limiting the lifetime mobile interfaces due to minimization of wear intensity and lubrication process control;
- limitation is the assumption that deterioration of the technical state occurs due to wear, the intensity of which depends on the parameters of the lubrication process;
- scope are stages of repair and operational cycle of engine: run-in, operation modes for the intended purpose, maintenance and repair;
- stages include development of theoretical and methodological provisions of the lubrication process control in mobile interfaces; development of the lubrication process control system in mobile interfaces: information, technical, intellectual component;
- technical solutions are software and hardware complex of tribo diagnostics [14]; application programs packages; methods and technology of management [15-18]
- organizational solutions are methods of maintaining efficiency at the stages of the repair and maintenance cycle of the engine [10], guidelines, personnel training.

## CONCLUSION

The concept of maintenance of automobile engines working capacity in operation due to restriction of wear intensity of mobile interfaces on the basis of development of mathematical, information, technical and organizational support of the lubricating process control system by application of tribo diagnostics methods is formulated. The presented results of scientific research can be used for development of new technical and organizational solutions to effectively maintain the automobile engine performance based on the development of lubrication management system using modern and prospective methods of tribo diagnostics.

### CONFLICT OF INTEREST

There is no conflict of interest.

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### FINANCIAL DISCLOSURE

None

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