INFLUENCE OF OPERATIONAL RATE AND CONDITIONS SEASONAL VARIATION ON AUTOMOBILE ENGINE OPERATING LIFE

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ABSTRACT

Results of a research aimed to determine the influence regularities of seasonal variation of cars' operational rate and conditions on engine operating life forming are presented. Research object is the process of car engine operating life forming according to seasonal variation of operational rate and conditions. As the result of the carried out research: the regularity of car engine operating life forming according to seasonal variation of operational rate and conditions is determined; an imitating model of car engine operating life forming is developed; a type of a mathematical model of the air temperature influence on car engines crankcase gases flow is defined; numerical values of mathematical model parameters are defined experimentally for engines of cars KamAZ-4310.

Keywords: car engine operating life, operating life rationing, technical state change regularities, climate conditions, engine.

1. INTRODUCTION

Automobile transport is an essential element of the transport system. Along with the obvious advantages over other types of transport, it has a number of disadvantages (Zakharov N.S., 2015), a high transportation cost in particular. Automobile engineering servicing and repair expenses constitute a significant proportion of the cost, up to 40% of which is spent on the engine (Zakharov N.S., 2016). One of the most important conditions of those expenses decrease is managing engine operating life, which is impossible without having objective standards. The current system of automobile engines' operating life rationing does not meet all demands. Engine operating life is influenced by a number of factors. The most significant ones are climate and road conditions, which vary seasonally. Engine operation at excessively high or low temperature decreases its dependability and intensifies its parts' deterioration (Grigor'ev M.A., 1981).

At a decreased thermal regime, deterioration of cylinder-piston group details intensifies because of their grease aggravation (because of insufficient supply of increased-viscosity oil; flushing it off by the fuel; the presence of water in oil), and electrochemical corrosion processes' occurrence caused by condensed aggressive products of fuel combustion in cylinder (Avdon'kin F.N., 1993). Besides, at the decreased thermal mode, the amount of low-temperature scurf (sludge) on details increases; the increase of oil viscosity leads to higher friction losses, and engine's effective indices go down. At excessively high temperatures, details' grease deteriorates because of oil's low velocity, additives' work and the burning of oil off the cylinder walls; the amount of high-temperature scurf on details increases, tendency to burrs, gas corrosion of individual parts, detonation and glow ignition increases.

That's why, for reliable operation of engines with the regular cooling, it is necessary to stabilize their thermal mode according to water and oil optimal temperatures, 80 ... 90 °C. Along with that, minimal variation of details' temperature must be provided. Unequal heating leads to thermal stress in details, which can result in warpage, excessive wear, cracks in blocks' heads, etc. (Akimov M. Ju., 1993)

At an uneven circulation of coolant in cylinders, increased corrosive wear of cylinders and piston rings is observed in the most cooled cylinders, and burrs of cylinder-piston group parts occur in the least cooled cylinders. If cars' operational rate isn't even during a year, then engine operating life depends on mileage proportions at different seasons. In the cold climate, the engine' operating life of a car operated only in winter is significantly shorter than the engine operating life of a car operated only in summer. The influence of cars operational conditions and rate combinations isn't considered at operating life rationing.

On the basis of the stated, as well as taking into consideration the fact that more than 70 % of Russia's territory is located in zones of cold and very cold climate, and cars' operational rate in these conditions changes significantly during a year, it is necessary to admit the topicality of the research aimed to determine the regularities of seasonal conditions influence on engine operating life forming. Individual cars' operational rate variation is caused by the fact that shift or daily runs are random variables. Their variation coefficient is 0, 2…0,5 (Bakurevich Ju. L., 1973). Besides, shift runs are distributed normally (Kuznecov E.S., 1990).

Cars' average year runs depend on their potential speed properties and factors influencing their realization level. These factors can be divided into two groups: operational conditions and factors determining cars' technical condition. Operational conditions include road, traffic and organizational-technological conditions (the method of loading and unloading works organization, cargo type, etc.) (Automobile engineering servicing, 1991, 1983).

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2. METHODS

On the basis of studying the researches carried out earlier, it was determined that the current system of automobile engine operating life rationing doesn't take into account operational rate and conditions' variation, which is the reason why in some cases the standards don't match the actual durability. Regularities of temperature influence on individual elements' deterioration rate and engine operating life expenditure rate on the whole were defined in the earlier researches.

In particular, it was determined that average year air temperature influence on car engines' operating life expenditure rate is represented by a quadratic model of the following type (Reznik L.G., 1989; Romalis G.M., 1979):

$$\bar{u} = u_0 + s\,[(\bar{t} - t_0)^2 + \sigma_t^2] \qquad (1)$$

where u_0 is optimal (minimal) operating life expenditure rate;

s is sensitivity parameter of engine according to operating life expenditure rate to the air temperature change;

$\bar{t}, \sigma_t$ are the average year value and standard deviation of the ambient temperature;

t_0 is air temperature optimal value according to minimal operating life expenditure rate.

This model lies in the base of the method of standards correction according to climate conditions (Polozhenie o tehnicheskom obsluzhivanii i remonte podvizhnogo sostava avtomobil'nogo transporta, 1987).

There are two limitations accepted for the model:

- 1 - air temperature is distributed normally;
- 2 - cars operational rate is constant.

In practice, these conditions are seldom observed, that's why the model doesn't always provide for adequate enough results. The more significant the variation of operational rate and conditions is during a year, the more the deviation of calculated values from the actual ones is. To eliminate that drawback, the regularity of car engine operating life forming according to seasonal variation of operational rate and conditions is determined. While that regularity determining, the operating life forming process was being considered according to the cars quality forming concept developed in Tyumen industrial university (TyuIU).

That approach allowed developing a mathematical model without the drawbacks stated earlier. Taking into account the complicatedness of the studied process, it can be assumed that an adequate description of the process can be fulfilled only with the use of an imitating model. For the model developing, the process was presented as a system which was structured and elements' interaction regularities were defined.

The most important regularities of that type are operational rate's and conditions' dependence on time and dependence of parameters change rate of engines' technical condition on air temperature. Mathematical models of these regularities were developed.

Experimental research was carried out to estimate the model's adequacy and parameters values. Cylinder-piston group contains the elements that limit engine operating life most significantly.

For their condition evaluation a number of indices are used ((Coombes P., 1988; Kraftfarzueg-Betrieb und Automarkt, 1988). Crankcase gases expenditure is the most informative parameter.

On the base of models of the stated regularities, engine operating life standards correction method was created, a software for its realization was developed, correction coefficients values were calculated (Zakharov N.S., 1999).

Thus, the carried out analysis allowed formulating the following research tasks:

to determine the regularity of car engine operating life forming according to seasonal variation of operational rate and conditions;

to develop an imitating model of car engine operating life forming;

to develop an imitating model of air temperature influence on car engines crankcase gases expenditure;

to define values of mathematical model parameters for engines of cars KamAZ-4310;

to develop a method of engine operating life standards correction according to seasonal variation of operational rate and conditions;

to estimate economical effectiveness of the research results use.

For modelling of engine operating life forming process according to seasonal variation of operational rate and conditions, it is almost impossible to use analytical model for the following reasons. Firstly, operating life depends on technical condition change rate during cars operation and is defined by a number of factors that are being randomly changed in time. Secondly, engines' durability depends on cars run proportions in different operational conditions, which means that operating life is defined not only by the general run, but also by the operational conditions (Figure-1).

Regarding the conditions of the West-Siberian region, combination of run and operational conditions is especially topical. If one car is being mostly operated in summer, and another - in winter, their operational conditions differ significantly, regardless the fact that they are being used in the same climate region. It is impossible to take into account random changes of operational rate and conditions in analytical model, which is why an imitating model should be used for modelling the studied process.

For modelling the regularity of actual engine operating life forming, the system "Time - actual process" is structured and on the base of local models of elements' interactions a model of the whole system is made up. Actual engine operating life forming concept is presented according to the concept of cars quality forming during operation (Figure-1). The speed of engine operating life

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expenditure process is characterized by expenditure rate y and cars operational rate. Air temperature changes during a year (Figure-2, regularity a) causing the change of y (Figure-2, regularity b). Operational rate also changes during a year (Figure-2, regularity c) (Zakharov N.S., 1998).

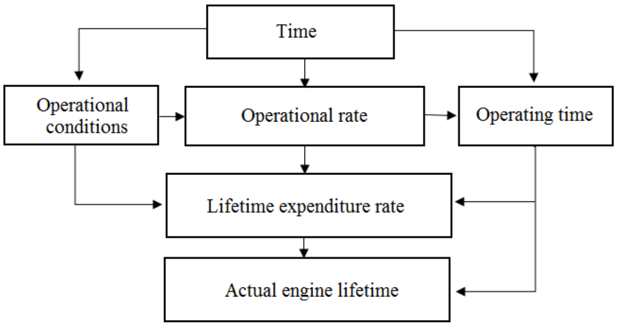

Figure-1. Structure of the studied system.

On the base of y change regularity according to time T, it is possible to predict values of technical condition parameters by the moment T_i, using the following formula:

$$Y = Y_0 + \int_{L(T_0)}^{L(T_i)} y(T) \cdot dT \ . \qquad (2)$$

Taking into account that y depends on air temperature and engine's run while these factors depend on time, it is necessary to determine the change regularities of air temperature and operational rate during a year and create appropriate mathematical models.

For describing operational rate's dependence on time, it is offered to use harmonic series (Zakharov N.S., 1999):

$$l_i = l_C + \sum_{k=1}^{g} l_k Cos(m(kT_i - T_k)) + l_P , \qquad (3)$$

where l_C is the constant component of operational rate (cycle average value); k is harmonic number; g is harmonics quantity; l_k is vibration half-amplitude of the k-th harmonic; m is interval between T_i and T_{i+1} (in degrees); T_k is initial vibration phase (in months); l_P is random component.

To estimate the inequality of cars operational rate according to seasons, a numerical characteristic must be chosen. Irregularity factor characterizes only the change amplitude and is not appropriate for solving the tasks of this work. That is why the following hypothesis was offered.

a) Operational rate inequality according to seasons can be characterized by the proportion of a car's run in winter period

$$\Delta_w = \frac{L_w}{L_y} , \qquad (4)$$

where L_w is car's run in winter period (October to March);

Ly is car's year run.

b) Value Δw changes considerably for different cars groups.

c) Value Δw influences significantly on cars engine operating life.

For modelling of air temperature change regularities according to time, the following model is offered:

$$t_i = t_C + \sum_{k=1}^{g} t_k Cos(m(kT_i - T_k)) + t_P \qquad (5)$$

Analysis of the carried out research showed that normal distribution is mostly used for air temperature random component description (GOST 16350-80, 1981), while it doesn't always adequately describe empirical distributions (Gnedenko B.V., 1965). A hypothesis on temperature distribution regularity accordance to TP-distribution is offered (Zakharov N.S., 1999):

$$f(x) = \begin{cases} \dfrac{k\bar{x} - x}{2k^2\sigma^2} \cdot e^{-\left(\frac{k\bar{x}-x}{2k\sigma}\right)^2}, x < k\bar{x} \\ 0, x \geq k\bar{x} \end{cases} . \qquad (6)$$

That distribution was used for car tires air pressure distribution approximation, that is why it was called TP-distribution (T - "Tires" and P - "Pressure").

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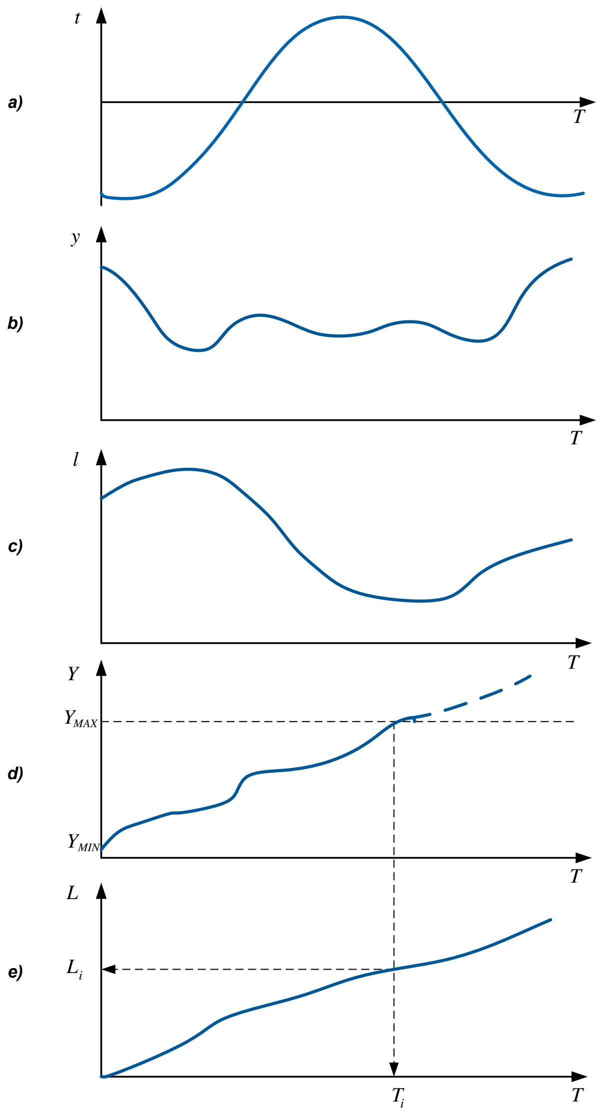

Figure-2. Regularities of automobile engine operating life forming.

To develop a model of engine operating life forming according to seasonal variation of cars operational rate and conditions, it is necessary to consider the regularity of run increment and the change of basic operational factors indices in time. Engine operating life expenditure rate is a differential indicator, so, with change regularities of run and operational conditions in time taken into account, it can be generally stated:

$$y = f(L(T); X(T)). \quad (7)$$

To obtain a similar expression for operating life expenditure, which is an integral indicator, the method of variable changing while integrating is used:

$$Y = Y_0 + \int_{T_0}^{T_i} y(L(T); X(T)) \cdot dT \cdot \quad (8)$$

The change regularities of run and operational conditions in time are described by complicated three-component models which makes analytical calculating of the integral almost impossible. Consequently, to obtain a numerical solution, an imitating model should be used (Figure-3).

The experiment was carried out in three stages. At the first stage, statistical data on operational rate and actual air temperature were gathered. At the second stage, an experiment on estimation of the flow of crankcase gases at different air temperatures was carried out. At the third stage, an imitating experiment was carried out to determine the regularities of seasonal variation of operational rate and conditions influence on car engine operating life.

The methodology of experiment research contains:

experiment planning;
collecting data on actual rate of cars operation;
collecting data on actual air temperature;
experimental estimation of crankcase gases flow change at different air temperatures;
experiment results processing;
Imitation cycle parameters choosing;
an imitating experiment carried out in the software “RESURS”;
experiment results analysis.

In the process of experiments, the following tasks were solved:

empirical distribution laws of cars operational rate were defined;
hypothesis on distribution laws types of cars operational rate was checked;
hypothesis on the mathematical model type of seasonal changes of cars operational rate was checked and numerical values of its parameters were defined;
empirical distribution laws of air temperature were defined;
hypothesis on distribution laws types of air temperature was checked;
hypothesis on the mathematical model type of air temperature seasonal changes was checked and numerical values of its parameters were defined;
hypothesis on the mathematical model type of air temperature influence on crankcase gases flow change rate was checked and numerical values of its parameters were defined;
the adequacy of the imitating model was checked;
hypothesis on Δ_w influence significance on engine operating life was checked.

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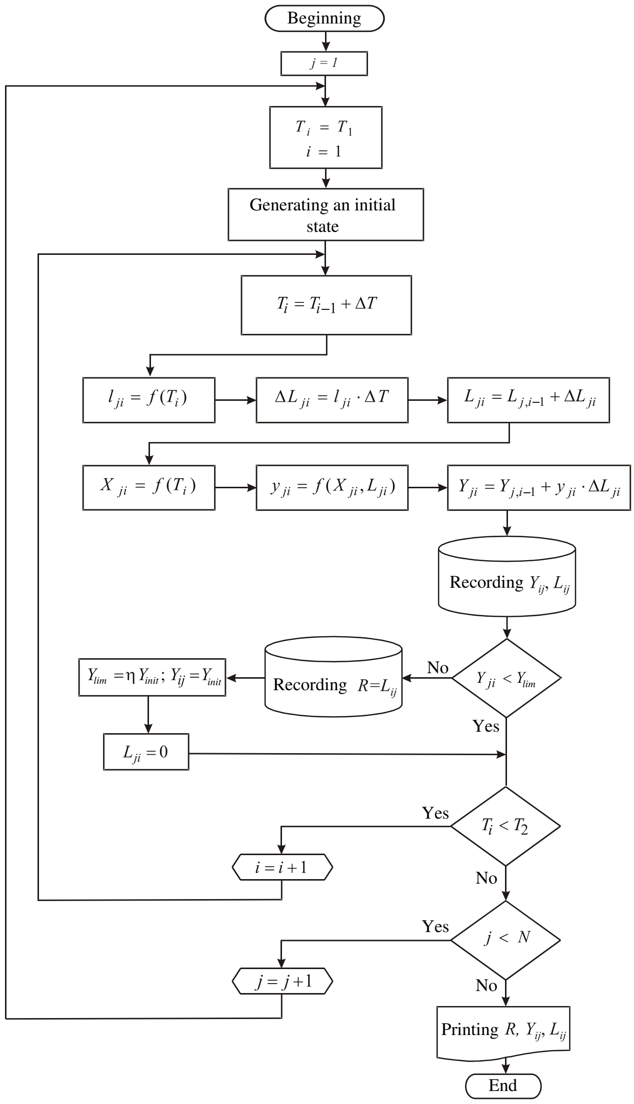

Figure-3. Imitating model algorithm of automobile engine operating life forming.

3. RESULTS

Data on actual operational rate were collected in 14 automobile transport enterprises. On the whole, 74 statistical samples were collected. Normal law isn't appropriate for those distributions as it has no asymmetry, nor excess. One of the normal distribution modifications is Charlier's distribution (Gram-Charlier's, Laplace-Charlier's) which is obtained by alignment of distributions close to normal but with asymmetry and excess which differ from zero. For distributions alignment, standardized normal distribution density and its derivatives are used. In practice, derivatives of the third and fourth order are usually used, which are asymmetry and excess. Charlier's distribution has a limitation since negative excess (E<0) can result in negative density. Besides, in tasks in which the distribution behavior at its ends is considered, approximation of the finite series can be very unsatisfactory. Thus, normal and Charliers's distributions are not appropriate for the stated goals.

It was determined, that the best approximation of empirical distribution in most cases is obtained by Weibull's law (Figure-4) with 0, 47…0, 78 variation coefficient.

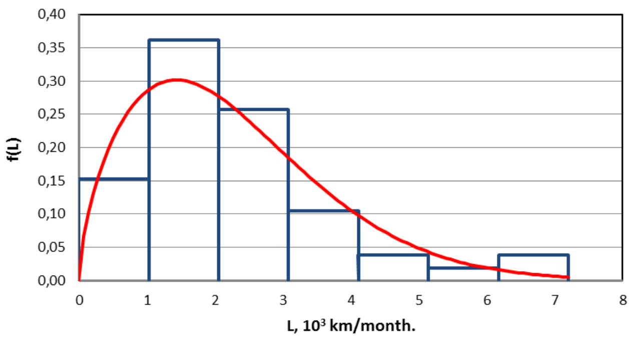

Figure-4. Automobiles operational rate distribution (Weibull's distribution).

Processing of the data on cars average monthly runs changes showed that this regularity is adequately described by a harmonic series with the number of harmonics from 2 to 4 (Figure-5).

$$l = 2{,}49 + 1{,}54 \cdot Cos\,(30 \cdot (T - 2{,}07)) + 0{,}62 \cdot Cos\,(30 \cdot (2T - 11{,}18)) + 0{,}29 \cdot Cos\,(30 \cdot (3T - 5{,}37))\text{ , km/month.,} \tag{9}$$

where T - time in months.

Cars run proportion in winter period changes from 0, 21 to 0, 88. In the North of Tyumen region that interval is significantly narrower: from 0, 43 to 0, 88.

To solve the tasks 4…6, data on actual air temperature in Tyumen, Nizhnevartovsk, Nefteyugansk, Surgut and Uray during several years were collected. Results processing showed that TP-law provides for the best approximation of empirical distributions in all cases (Figure-6). Particularly for Tyumen, the following law was obtained:

$$f(t) = \begin{cases} \dfrac{29{,}2 - t}{499} \cdot e^{-\left(\frac{29{,}2-t}{31{,}6}\right)^2}, x < 29 \\ 0, x \geq 29 \end{cases}. \tag{10}$$

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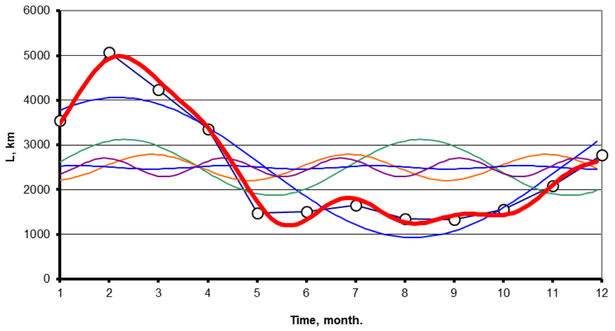

Figure-5. Typical regularity of operational rate change during a year.

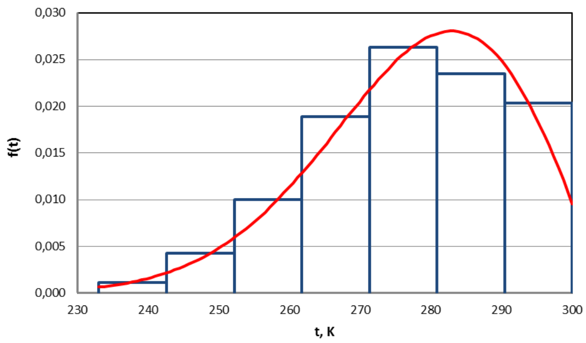

Figure-6. Air temperature distribution in Tyumen (TP-distribution).

Data on air temperature distribution in representative points of climate regions were got in GOST 16350-80 "The USSR Climate". That data processing showed that TP-law is adequate to the initial data in all cases. In 9 cases accordance probability is higher than 0, 95, in 7 cases it is higher than 0, 90 and in 5 cases it is higher than 0, 70.

The check of hypothesis on mathematical model type of the average monthly air temperature change showed that in all cases polyharmonic model with 1 to 3 harmonics is adequate. For example, for Nizhnevartovsk that model looks like (Figure-7):

$$t = 18{,}9 \cdot Cos(30 \cdot (T - 7{,}09)) + 0{,}63 \cdot Cos(30 \cdot (2T - 9{,}38)) - 4{,}1\ ^{\circ}\mathrm{C}. \quad (11)$$

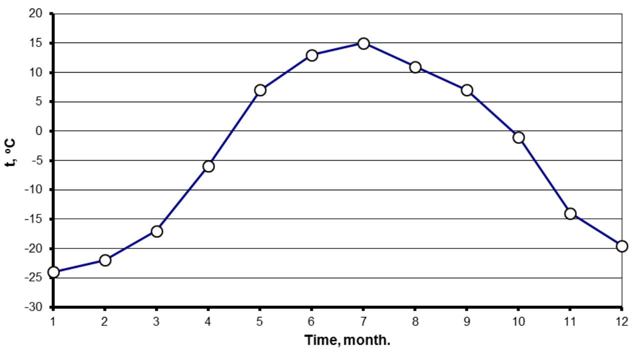

Figure-7. Change regularity of average monthly temperatures during a year (cold climate region).

For engines technical state change estimation, the parameter "Crankcase gases flow" was used. It was measured with gas flow indicator KI-13671-GOSNITI. The indictor is used for engines cylinder-piston group condition control of amount change of gases getting into the crankcase (Figure-8).

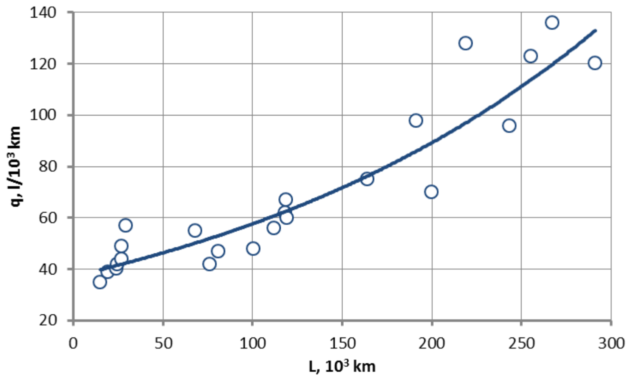

Figure-8. Run influence on crankcase gases flow of cars KamAZ-4310.

Experimental data processing showed that they are adequately described by exponential model with 0, 99 probability. Correlation ratio is 0, 93. Its significance level is 0, 99.

On the base of these results, differential indicator values of technical state change process - crankcase gases flow change rate - were obtained for different runs (Figure-9).

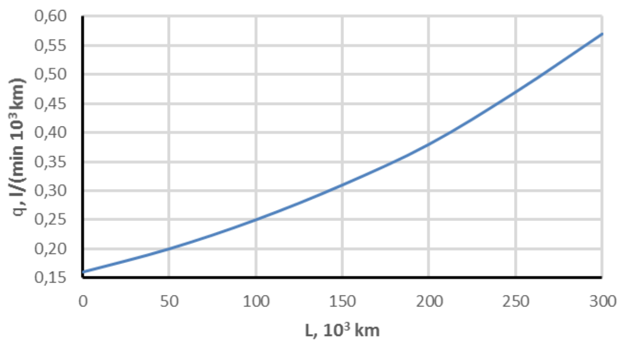

Figure-9. Run's influence on crankcase gases flow change rate by cars KamAZ-4310.

The regularity of run's influence on crankcase gases flow change rate according to run is described by the following model:

$$q = 0{,}16 \cdot e^{0{,}0042L}\text{, l/(min·th. km)} \quad (12)$$

To determine the influence of operational conditions (air temperature) on engine technical state change rate, the flow of crankcase gases was measured at different air temperatures. Technical state change rate was determined as the difference between two sequential measurements divided by car run in the interval between

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them. Experiment results were grouped by air temperature intervals and average values in each interval were calculated (Figure-10).

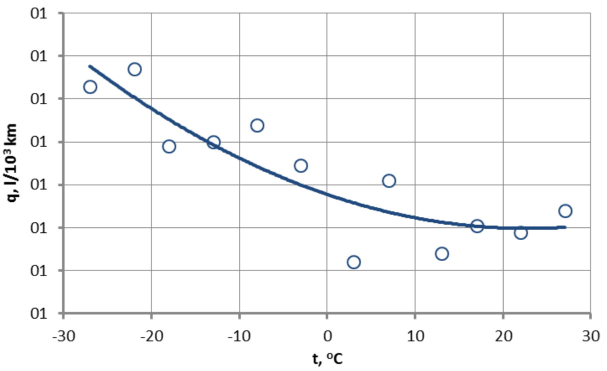

Figure-10. Regularity of crankcase gases flow change rate by engines of cars KamAZ-4310 according to air temperature.

The obtained results are adequately described by quadratic model with 0, 95 probability

$$q = 0{,}69 + 0{,}00014 \cdot (t - 23{,}9)^2 \text{, l/(min·th.km)} \qquad (13)$$

Correlation ratio is 0, 87. Its significance level is 0, 99.

The imitating model experiment was carried out to check its adequacy as well as the hypothesis on the significance of Δ_w influence on engine operating life. To check the model adequacy, samples of run to engines overhaul were generated for various operational conditions. The obtained data were compared to the actual durability in those conditions. Analysis of the imitating experiment results showed that the difference between calculated and actual average engine operating life does not exceed 10 % and is 7,3 % on average, which proves enough adequacy of the model (Figure-11).

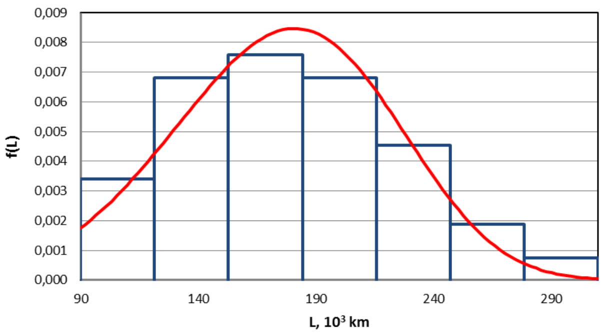

Figure-11. Modeling results. distribution of engine run realization to the limit state.

To assess the degree of influence of a car run proportion in the winter period on engine operating life, an imitating experiments were carried out for 34 different regularities of operational rate change in time characterized by various values of Δ_w (in the limit of 0,0 to 1,0) (Figure-12).

The regularity is adequately described by a linear model:

$$L = 192{,}3 - 53{,}9 \cdot \Delta w \text{, th. km.} \qquad (14)$$

The adequacy level exceeds 0, 99. Correlation ratio is 0, 97 at 0, 99 significance level.

Thus, the imitating experiment proved the hypothesis on the significance of Δ_w influence on engine operating life.

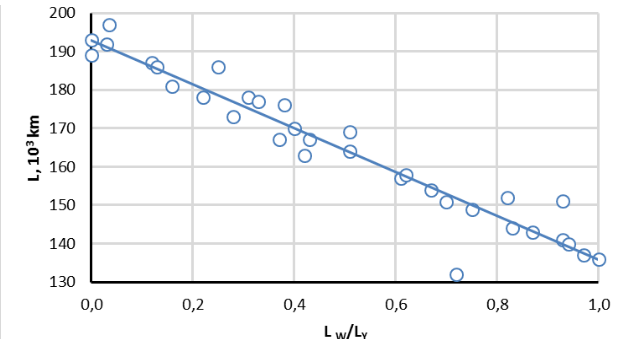

Figure-12. A car run proportion influence in the winter period on engine operating life.

On the base of the obtained results, automobile engine operating life standards can be corrected according to seasonal variation of operational rate and conditions. There are two ways of using the obtained results.

Option 1. Using the software package "RESURS" to calculate engine operating life in definite conditions on the base of certain initial data.

Option 2. Using tables of correcting coefficients created with the use of the software package "RESURS".

The imitating model of engine operating life forming developed in the second chapter is realized as a software package "RESURS" in the language "Microsoft Visual Basic 6.0".

The program allows generating arrays of engine's run to the limit state in various conditions (Figure-11) and time series of technical state parameters (Figures 13, 14).

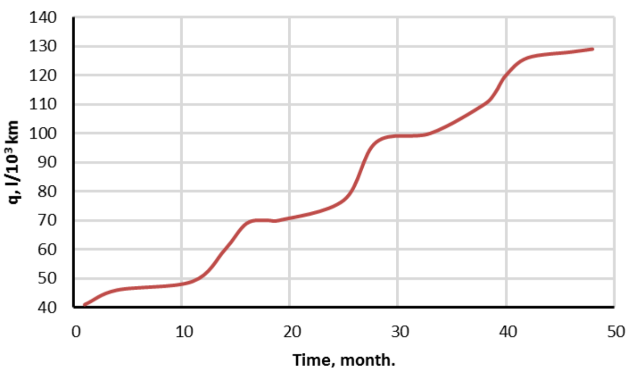

Figure-13. Modelling results engine crankcase gases flow change during the period of operating life realization.

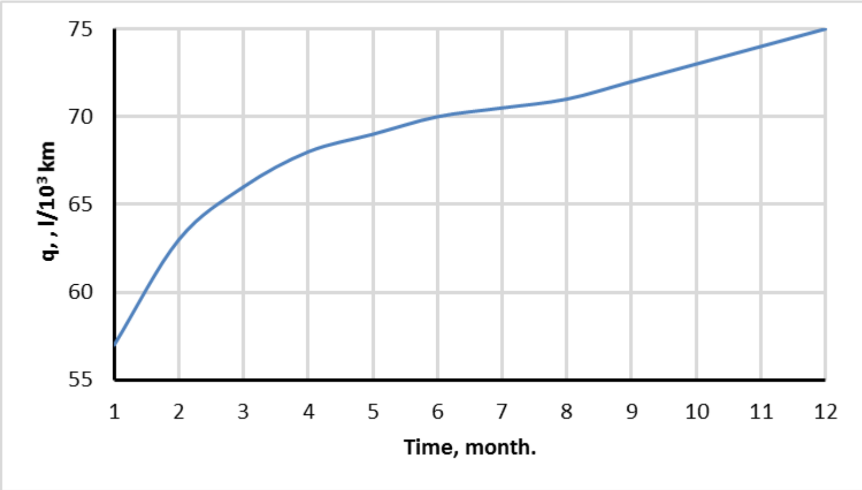

Figure-14. Modeling results Crankcase gases flow change during a year.

At the second option, operating life standard is calculated according to a method stated in the regulation on engineering servicing and repair of rolling stock of automobile transport. The K_3 coefficient is used (Table-1). The stated values consider not only the climate region, but also a seasonal variation of climate conditions in the region and a car run proportion in the winter period.

Table-1. Numerical values of K_3 coefficient for engine operating life standards correction according to climate region and car run proportion in the winter period.

Run proportion in winter period	Correcting coefficient values for climate regions			
	temperate	moderately cold	cold	very cold
0,0	1,14	1,07	0,99	0,85
0,1	1,12	1,04	0,97	0,84
0,2	1,09	1,01	0,95	0,84
0,3	1,05	0,98	0,91	0,83
0,4	1,02	0,95	0,89	0,82
0,5	1,00	0,92	0,87	0,81
0,6	0,97	0,88	0,83	0,76
0,7	0,94	0,86	0,79	0,72
0,8	0,92	0,83	0,76	0,69
0,9	0,88	0,80	0,72	0,66
1,0	0,85	0,76	0,68	0,60

4. CONCLUSIONS

On the base of the carried out research, an important scientific and practical task on determining the regulations of seasonal conditions influence on car engine operating life forming is solved. Methods of operating life standards correction were developed. The regularity of car engine operating life forming is determined. The studied system "Time - engine operating life" is structured; the most significant regularities of its elements' interaction are defined. They are the regularities of operational rate and conditions change according to time; the regularities of technical state parameters change rate according to run and operational conditions.

Mathematical models of interaction regularities of the studied system elements are developed. The average monthly air temperature change is adequately described by a polyharmonic model with 1 … 3 harmonics. TP-law provides for the best approximation of the random component of temperature. Average monthly cars run change is adequately described by a polyharmonic model with 2 … 4 harmonics. Weibull's law provides for the best approximation of the random component of operational rate.

The regularity of engines crankcase gases flow change according to run is determined. It is proved that run influence on crankcase gases flow change rate is adequately described by exponential model while its distribution in the context of equal runs is described by normal law. The regularity of the air temperature influence on crankcase gases flow change rate is determined. Quadratic model is offered for its description. Hypothesis on mathematical models types are checked experimentally. Their parameters numerical values are defined for engines of cars KamAZ-4310.

A software was developed for an imitating model realization. On the base of an imitating experiment, it is proved that operating life forming is influenced significantly not only by average year air temperature, but also by its variation level during a year and cars run proportion in the winter period. A method of engine operating life standards correction according to seasonal variation of operational rate and conditions is developed.

There are two options of using it: modelling engine operating life with the use of the developed software and correcting with the use of tables. The use of the research results allows defining fair standards of cars engine operating life according to seasonal variation of operational rate and conditions. That creates prerequisites for an effective management of engine operating life and their operation expenses. Accurate standards defining allows a better planning of repair works demand, determining the need for materials, labor resources and production facilities.

In the case if a standard determined by the offered method is less than the existing before, the need for resources will increase but downtime of vehicles in the repair will decrease; technical readiness, operational time and company income will increase.

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