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IMPACT OF DIAGNOSTICS STATE MODEL TO THE RELIABILITY OF MOTOR VEHICLES

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ABSTRACT

This paper presents the model of diagnosis of the condition in order to maximise the reliability of motor vehicles and their availability to work. The studied model of the reliability condition diagnosis of motor vehicles included the most important parameters of the theoretical and experimental analyses. Analysis of its formation is based on the recordings of total failures of integral components which are in the function of the parameters observed in the condition diagnostics of motor vehicles components. The research included failures that occurred under the influence of increased operating temperatures and worn-out of bearings (stable, flying and sliding) on the crank and camshaft, all in order to provide better insight into the problem. By reliability analysis, we conclude that it is in parallel collusion with authoritative reliability of motor vehicle which is determined and depends on the observed increase in diagnostic parameters: temperature and worn-out of bearings.

Keywords: reliability, motor vehicles, temperature, worn-out, failures, clearance.

AIMS AND BACKGROUND

Frictional energy dissipation significantly contributes to parasitic mechanical losses, which account for 10–15% of the energy generated by an internal combustion engine[1]. Engine and drive train parts like piston rings, valve guides cam followers, fuel injector plungers, tappet shims, transmission gearing, and face seals are affected to some degree by friction[2]. Reduce of friction and wear out of machine

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construction can be achieved in many ways. One is, of course, the appropriate choice of construction. Then, selection of materials with small coefficient of friction and high resistance to wearing out[3,4]. The third and most important is the use of appropriate types of lubrication field for their lubrication. At the same time, with the examination of motor-oil condition in exploitation and moment of this necessary substitution, in the last couple of years ecological treatment of fuel and lubrication field obtain more and more importance. The presence of high-quality oil in normal exploitation can make longer average working life duration of motors for few thousands motto hours, but only with high-quality choice of motor-oil, by correct exploitation and timely substitution[5]. Timely substitution of oil in internal combustion engine is a very complex problem. It is an object of that substitution and definition of optimum borders of motor-oils parameters[6,7]. From the standpoint of the basic technological concept, the elimination of clients who note during technical inspection or during the use of the vehicle is done primarily by replacing the cancelled elements and aggregates (whenever possible or faster, simpler and cheaper). This reduces the retention time of vehicles maintenance and meets the ever-present demand for a high maintainability. Failure repairs, or faulty elements and aggregates are done outside of vehicles, if possible and economically feasible. It is used for this workshop at the facility or referred to a central repair, a separate organisational unit dedicated exclusively to this type of work. In technological terms, the central repair works on the principle of industrial repair, i.e. technology by which the element or repaired unit gets to good as new condition[8].

Raising reliability level of technical systems can be achieved through measures of technical maintenance, repair and overhaul[9,10]. On motor vehicles engines these measures are carried out on the crank bearings and camshafts[11]. Within this context of the reliability increase the influence of condition diagnosis model on reliability of motor vehicles, which describes different dependence parameters, and at the same time requires the introduction of complex mathematical equations to analyse the problem. Mathematical model, in the broadest sense, includes the ordinary, partial, differential equations and systems of equations, then tables, figures, recurrence relations, etc., which are analytical, numerical interpretation of the phenomena that occur in a given case, the effects of interest and describing function analysis of the labour component assemblies of motor vehicles[12]. Formed model is based on a methodology that relies on making a block diagram of a motor vehicle (bus) Volvo – D7C 275, with the aim of determining the security of the constituent components of the analysed components of motor vehicles. Methodology includes the construction monitoring systems and components are arranged in the determined order on circuits from the crankshaft via the connecting rod and camshaft (stable, flying and sliding bearings) on the crank and camshaft, taking their functionality and purpose. In this way, a reduction of the complex structure of the block diagram is done. Based on the given values of the observed reliability is determined the reliability model based on the model of the block diagram that includes measurement of reliability under working temperature and reliability arising under the influence of worn-out bearings[13]. Based on the established and given correlation, the analysis of the condition model diagnosis of motor vehicles through empirical research is conducted. Through an appropriate sensor system information on changes of relevant parameters and components work time was gained. These systems can successfully be used, because they are able to, based on the software package, very quickly examine, compare, check a large number of data and diagnose the condition of each component of the motor vehicles[14].

EXPERIMENTAL

The subject of the research considered in this paper is a technical system of motor vehicles (buses) Volvo – D7C 275, in the company: JGSP – Novi Sad, Serbia. A total of 260 motor vehicles Volvo – D7C 275 underwent diagnostic testing. In these systems the reliability of their engines was tested, observed by monitoring the parameter of: temperature and worn-out/clearance bearings (stable – M_1 flying – M_2 and sliding – M_3), the crank and camshaft. Under the influence of technical diagnostics measures in certain periods of time routine maintenance measures, which are comprised of: replacement of damaged bearings, and the introduction of high-quality oil in the process of lubrication have been performed.

The quality of the selected engine oil affects the mentioned condition diagnostic model, in such a way that it prolongs often and unnecessary engine oil replacements. While the influence of the condition diagnostic model itself is shown in a timely replacement of engine oil. The optimum moment of engine oil replacement considerably influences the costs of motor vehicle maintenance. In order to have the lowest possible maintenance costs, it is necesary to use high quality engine oil, specified by an engine manufacturer, high quality fuel and in this regard the exchange of engine oil in optimum intervals depending on technical engine condition and motor vehicle components exploitation conditions. Increased oil consumption, which is higher than one defined by the producer (higher than 10% of oil quantity in a crankcase), represents the first indicator of operation and construction engine characteristics loss, because it is estimated that more than 95% of total oil loss takes place in bearings and crankshaft circuits.

Observed engine components conditions diagnostics during operation is of a big importance for motor oil condition assessment. This confirms the validity of the observed motor vehicles condition diagnostics developed model in precisely determined intervals during their operation, while there were no diagnostic components failures.

The problem of work research is demonstrated through the analysis of data on failures of motor vehicles and their use in diagnosis as well as the safe functioning of the constituent components of motor vehicles assemblies. Performed qualitative analysis of the problem was a precondition that had to be met in order to be able to create high-quality mathematical model. After which we set off the estimated verification of the presented model, which enables obtaining of quantitative solutions. To effectively solve the problem of motor vehicles condition diagnosis, in addition to knowledge of the desired goal or set of permissible operating conditions of the components and the choice of parameters, it was necessary to define a mathematical model to accurately describe all the significant features of the constituent components of motor vehicles assemblies.

The main goal of this research work was to determine the impact values of the condition parameters reliability based on the recorded parameters diagnosed integral components assemblies of motor vehicles, based on certain addictions, to enforce reduction of a diagnostics model.

The choice of a suitable model for condition diagnosis requires questioning what is expected from the model, because a potential effort involved here is, as a rule, a significant savings in time, labour and means engaged. After analysing the available information on the constituent components of motor vehicles assemblies condition, eventually we set off to define model, which makes a bridge between mathematical models and methods[15]. Diagnostics of motor vehicles Volvo – D7C 275 reliability, was determined using a mathematical model, which has the following characteristics[13]:

- the possibility that motor vehicles are observed as a whole or a set of assembly components, that will enable the extent defining and the concept of all variable parameters impact;
- evaluation of a number of possible variations comparison, thus facilitating the selection of the best or optimum value;
- discloses a connection between certain influential parameters that can be determined by empirical methods;
- indicates the information to be provided in order to conduct the necessary analysis;
- facilitates the prediction of future conditions with risk assessment or confidence limits.

On the basis of the final term transfer function of the analysed components $V_p(t)$ for the circuit components Volvo – D7C 275 on the shaft of the crankshaft and the replacement of component reliability values $K_0(t)$ for the time intervals 500 000 km $\leq \Delta_{si} \leq$ 1 200 000 km determined distance crossed in the period from 30.06.2009 until 31.12.2013 significant reliability values are obtained from which the reliability function curves of the observed assemblies components are controlled.

In order to successfully form a model of safe performance, it was necessary to specify all the listed parameters of theoretical and exploitation analysis, and then connect to the same mathematical form. This is achieved analytically and

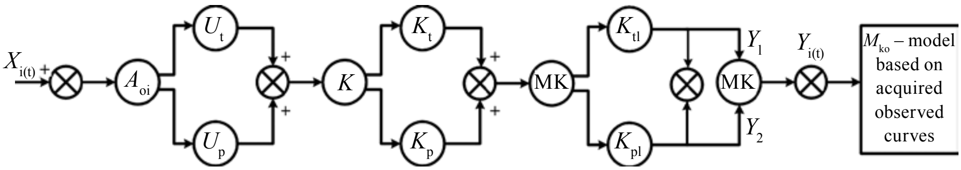

Fig. 1. Condition diagnostics model of constituent components motor vehicles assemblies Volvo – D7C 275 (where A_{oi} – total failures of constituent components due to the parameters analysed; U_t – cancellations due to increased operating temperatures; U_p – cancellations due to clearance bearings; K – reliability; K_t – the reliability of the constituent components based on the influence of operating temperature; K_p – the reliability of the constituent components based on the influence of clearance bearings; MK – reliability model; K_{tl} – reliability based on the operating temperature; K_{pl} – reliability based on the outworn of bearings and K_{TL} – correlation of operating temperatures and bearing outworn; M_{ko} – reliability model based on the block diagram of the measuring points temperature level and outworn of bearings)

expressed in the form of a transfer function of the optimum operation model $K_a(t)$ which will define the safety of the analysed components.

Researching the model, along with the resulting reliability transfer functions of components assemblies motor vehicles $V_p(t)$, made its final resolution. As shown in Fig.1, it is an open system of automatic control reliability. The block reliability diagram model of the analysed components of motor vehicles assemblies, is made of selected measuring points of temperature and worn-out of bearings[16]. All measurements during the work are carried out by means of a temperature sensor and a comparator for measuring the outworn.

Displayed model value in Fig. 1 can be applied to the corresponding components with a very large number of input parameters, while defining the optimum conditions and operating conditions of components of motor vehicles. Applying the model determines the relationship between the periodicity of checking the existing parameters of the components and the desired state of reliability of new components.

THE CHOICE OF MATHEMATICAL CONDITION DIAGNOSTICS MODEL WHICH INCREASES MOTOR VEHICLES RELIABILITY

Analysis conducting included fourth-degree polynomial with real coefficients (v_1, v_2, v_3, v_4), so it starts from the general form of the real polynomial of n degree, $c_1 \in N$, $i = 0, 1, 2, 3, 4, \ldots n$, and $n \in N$, and it is also known as a polynomial with real coefficients and applied in the analytical determination of polynomials of a higher degree[13], equation (1):

$$g(x) = v_1 x^n + v_{n-1} x^{n-1} + \ldots + v_1 x + v_0. \quad (1)$$

where v_{0-n} is the coefficient of real polynomials and x^n – change parameters in the components condition.

Given analysed value of the fourth degree polynomial of *n* degree, gives equation (2):

$$N(t) = v_4 Z^4 + v_3 Z^3 + v_2 Z^2 + v_1 Z + v_0. \tag{2}$$

where *N*(*t*) is the polynomial with real coefficients, which gives the reliability dependence of value function in the work of components, Z_i^n – value of clearance in the selected measuring point and v_i – real change coefficient of components conditions.

To determine their actual parameters, the system of equations in general form, which includes the value of points that determine this dependence will be set, the equation (3):

$$\begin{aligned} T_1 &= v_0 + v_1 Z_1 + v_2 Z_1^2 + v_3 Z_1^3 + v_4 Z_1^4; \\ T_2 &= v_0 + v_1 Z_2 + v_2 Z_2^2 + v_3 Z_2^3 + v_4 Z_2^4; \\ T_3 &= v_0 + v_1 Z_3 + v_2 Z_3^2 + v_3 Z_3^3 + v_4 Z_3^4; \\ T_4 &= v_0 + v_1 Z_4 + v_2 Z_4^2 + v_3 Z_4^3 + v_4 Z_4^4. \end{aligned} \tag{3}$$

Real coefficients of the polynomial are obtained by replacing the column of determinants with a column of reliability, equation (4):

$$v_4 = \frac{D_1}{D},\ v_3 = \frac{D_2}{D},\ v_2 = \frac{D_3}{D},\ v_1 = \frac{D_4}{D},\ v_0 = \frac{D_5}{D}. \tag{4}$$

In order to obtain accurate values of the coefficients of the polynomial $v_0, v_1^1, v_2^1, v_3^1, v_4^1$ compared to those obtained by analytical approach, programming of real coefficients of the polynomial obtained by using the mathematical program is done, the equation (5):

$$\begin{aligned} x &= \left[Z_1^1(t)_{Z_3}\ Z_1^2(t)_{Z_3}\ Z_1^3(t)_{Z_3}\ Z_1^4(t)_{Z_3} \right] \\ y &= \left[Z_1^1(t)_{Z_4}\ Z_1^2(t)_{Z_4}\ Z_1^3(t)_{Z_4}\ Z_1^4(t)_{Z_4} \right]. \end{aligned} \tag{5}$$

Determination of partial reliability blocks gives equations (6) and (7):

$$U(t) = M_1(t) M_2(t) M_3(t), \tag{6}$$

$$\begin{aligned} M_{M_1} &= \frac{M_1(t) M_2(t) M_3(t)}{f(t)_{M_1}} = \frac{Q_1(t) Q_2(t)}{f(t)_{M_1}}, \\ M_{M_2} &= \frac{M_1(t) M_2(t)}{f(t)_{M_2}} = \frac{Q_3(t)}{f(t)_{M_2}}, \\ M_{M_3} &= \frac{M_3(t)}{f(t)_{M_3}} = \frac{Q_4(t)}{f(t)_{M_3}}. \end{aligned} \tag{7}$$

where $Z_i(t)$ is the clearance of bearings in the measuring point, $f(t)_M$ – function of the clearance impact on the bearings surfaces, t_i – time of correct operation, β_i – correlation coefficient due to changes in the temperature of the bearings, $Q(t)$ – components in function of the clearance value by measuring points, T_i – change in temperature of the bearings at the measuring points and Y_{M_1} – reliability of bearings in a useful period of their work at the measuring points.

Based on the reliability block diagram of integral components of the technical system Volvo – D7C 275 and the distribution of work positions we get equation (8):

$$T_i(t) = M_{M_1} M_{M_2} M_{M_3} = \frac{Y_{M_1} Z_1(t)}{f(t)_{M_1}} \frac{Y_{M_2} Z_2(t)}{f(t)_{M_2}} \frac{Y_{M_3} Z_3(t)}{f(t)_{M_3}}$$
$$T_1(t) = \frac{Y_{M_1} Z_1(t)}{f(t)_{M_1}}, T_2(t) = \frac{Y_{M_2} Z_2(t)}{f(t)_{M_2}}, T_3(t) = \frac{Y_{M_3} Z_3(t)}{f(t)_{M_3}}. \quad (8)$$

Arranging the general security block of the motor vehicle integral components, depending on the outworn in the given measuring points M_1, M_2 and M_3 is expressed in equation (9):

$$T_\beta(t) = \frac{T_1(t)}{1 - T_1(t) T_2(t)}. \quad (9)$$

Mathematical rearranging and substituting the expression gives equation (10):

$$T_\beta(t) = \frac{\dfrac{Y_{M_1}(t) Z_1(t)}{f(t)_{M_1}}}{1 - \dfrac{Y_{M_2}(t) Z_2(t)}{f(t)_{M_1}} \dfrac{Y_M(t) Z_3(t)}{f(t)_{M_3}}}. \quad (10)$$

Further rearranging to express the dependence:

$$T_\beta(t) = Z_1(t) Z_2(t) Z_3(t) \leq 1.00.$$

by shift, returning to the expression, equation (11):

$$\beta_1 = T_1(t) T_2(t); \beta_2 = T_2(t) T_3(t); U_i(t) = M_1(t) = M_2(t) = M_3(t);$$
$$T_i(t) = T_1(t) = T_2(t) = T_3(t). \quad (11)$$

The final equations of safety model of the motor vehicles component assemblies under the influence of temperature, clearance in the bearings and shafts, equation (12):

$$MV_{(t)} = \frac{T_i^2 Z_i^2 V_i^4(t) \left(\dfrac{1 + \nu_2(t)}{U_1(t)} \right)^2}{\left(\dfrac{\nu_1^2(t) V_2^2(t)}{\beta_1 + U_1(t)} \right)^2 \beta_2^2 U_i^4(t)} \quad (12)$$

by introduction of given shift we obtain equation (13):

$$v_0 = M_1 - Z_{M1}(t),\ v_1 = M_2 - Z_{M2}(t),\ v_2 = M_3 - Z_{M3}(t),\ v_3 = M_4 - Z_{M4}(t). \quad (13)$$

Introduction of the coefficient β_1 and β_2 gives the general form of the reliability model of the motor vehicles component assemblies according to the selected measuring points on the effect of temperature and bearings clearance[13], equation (14):

$$MV_i(t) = \frac{y(t)}{x(t)} MV_i(t) = \left[U_1\beta_1 v_0 + (v_1 + v_2 + v_3)^2 \frac{t_i^2 v_1}{1 + \frac{\beta_1 t_1}{U_1}} + \beta_2 v_4 U_2 \right] U_1 \beta_1 t^2 \beta_2. \quad (14)$$

The presented components condition diagnostics model includes such a parameters choice that can resolve the question of diagnostic control periodicity and the issue of failure occurrence time. In this regard, the corresponding analysis of ways and consequences of failure, in order to ensure the normal process of exploitation of motor vehicle Volvo – D7C 275.

SURVEY RESULTS

A special table for each motor vehicles diagnostic component was presented and it contains: a controlled technical parameters, determined variants of components conditions maintaining, Tables 1 and 2. The obtained values of the proper and safe operation of the analysed components of motor vehicles on t_p = 700 000÷1 200 000 km, when the operating temperature range is 94÷98°C are shown in Table 1, that is in the range of bearings outworn z = 0.05÷0.10 mm, are shown in Table 2.

Failures during monitoring of the slide bearing the M_3 camshaft in a determined period of time and determined distance of motor vehicle Volvo – D7C 275, are shown in Table 3. Based on the parameters presented in Table 3, reliability

Table 1. Temperature values at analysed integral component assemblies of motor vehicles Volvo – D7C 275, based on the exploitation data to which are applied parameters of condition diagnosis

Ordinal	Distance travelled (km)	Oil consumption (l)	Temperature at the measuring points (°C)		
			M_1 – stable bearings	M_2 – flying bearings	M_3 – slide bearings
1	$8\times10^5 \le S_i \le 8.5\times10^5$	0.5÷2.5	95.5	95	94
2	$8.5\times10^5 \le S_i \le 9\times10^5$	0.5÷2.5	96	95.5	94.5
3	$9.5\times10^5 \le S_i \le 10^6$	0.5÷2.5	96	96	95
4	$10^6 \le S_i \le 1.1\times10^6$	0.5÷2.5	96.5	96	95
5	$1.1\times10^6 \le S_i \le 1.2\times10^6$	0.5÷2.5	97	96.5	95.5

Table 2. Clearance values at the measuring points of analysed constituent components of motor vehicle assemblies Volvo – D7C 275, based on the exploitation data to which are applied parameters of condition diagnosis

Ordinal	Distance travelled (km)	Oil consumption (l)	Clearance (mm) at the measuring points with the new applied material for bearings		
			M_1 – stable bearings	M_2 – flying bearings	M_3 – slide bearings
1	$8\times10^5 \leq S_i \leq 8.5\times10^5$	0.5÷2.5	0.07	0.06	0.06
2	$8.5\times10^5 \leq S_i \leq 9\times10^5$	0.5÷2.5	0.07	0.07	0.06
3	$9.5\times10^5 \leq S_i \leq 10^6$	0.5÷2.5	0.08	0.08	0.07
4	$10^6 \leq S_i \leq 1.1\times10^6$	0.5÷2.5	0.09	0.09	0.08
5	$1.1\times10^6 \leq S_i \leq 1.2\times10^6$	0.5÷2.5	0.10	0.09	0.09

Table 3. Failures during monitoring of the slide bearing M_3 in a determined period and a determined distance for motor vehicle Volvo – D7C 275

Date of failure occurrence test	Distance (km)	Failures that occur without the use of control components condition	Failures that occur with the implementation of control components condition
30.06.2009	700 000	6	–
31.12.2009	750 000	7	–
06.06.2010	800 000	8	–
31.12.2010	850 000	9	–
30.06.2011	900 000	9	–
31.12.2011	950 000	–	3
30.06.2012	1 000 000	–	3
31.12.2012	1 050 000	–	4
30.06.2013	1 100 000	–	4
30.09.2013	1 200 000	–	5
31.12.2013	1 300 000	–	5

dependence diagram (as shown in Fig. 2) on the value of the number of cancellation due to worn-out of the bearings, in the areas of safe and proper operation is constructed, with and without using diagnostic parameters of motor vehicle conditions in a function of exploitation time (t). Based on it authoritative clearance values are determined (the value of bearings worn-out is reducing with the use of the model from 32.7 to 15.8%). Figure 2 shows the dependence diagram of the number of failures due to worn-out of bearings at the measuring point M_3 camshaft during the period of work and determined distance travelled of vehicles Volvo – D7C 275. In Fig.2, n_i is the number of tested buses, and $(z)_p$ – number of failures in the clearance.

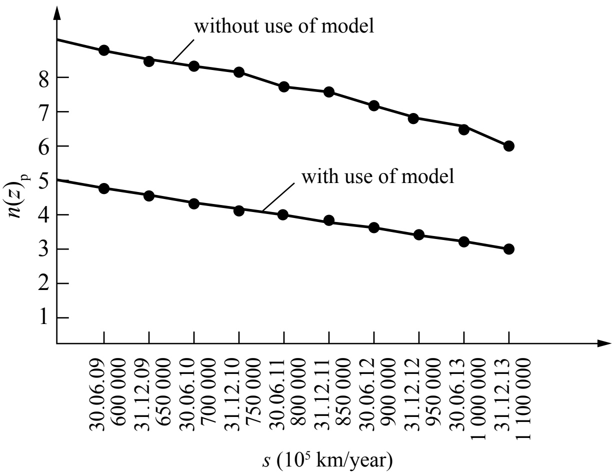

Fig. 2. Dependence diagram of the number of failures due to worn-out of bearings M_3 during the period of work and determined distance for motor vehicle Volvo – D7C 275

ANALYSIS OF RESULTS

Reliability research of motor vehicles Volvo – D7C 275, brought conclusion that it is in interdependent conjunction with the applicable reliability which is determined and depends on increasing levels of operating temperatures and worn-out of bearings. Based on the given values of analysed reliability, the reliability model is defined based on the block diagram model which includes the reliability measurement under working temperature and reliability, the influence of worn-out of the bearings. Interconnecting all the above mentioned values, parameters correlations of motor vehicles condition diagnostics methods are formed, such as the correlation of operating temperatures and worn-out of bearings (K_{TL}). Diagram for determining the correlation of temperature and worn-out of bearings at the measuring points (stable, flying and sliding bearings) on cranks and camshafts in a determined period of time and distance for motor vehicles, is shown in Fig. 3.

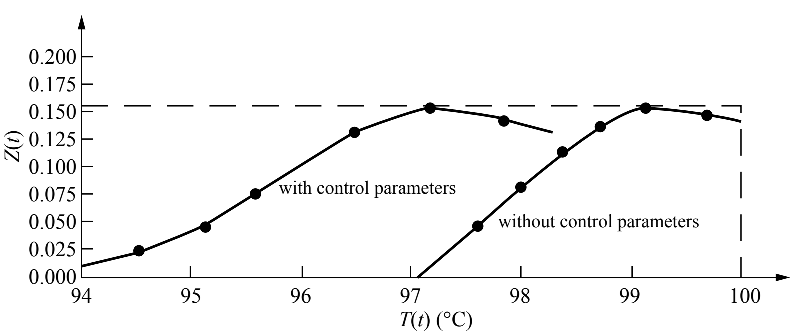

Fig. 3. Diagram for determining the correlation of worn-out of bearings and temperature with and without the control parameters of motor vehicle Volvo – D7C 275

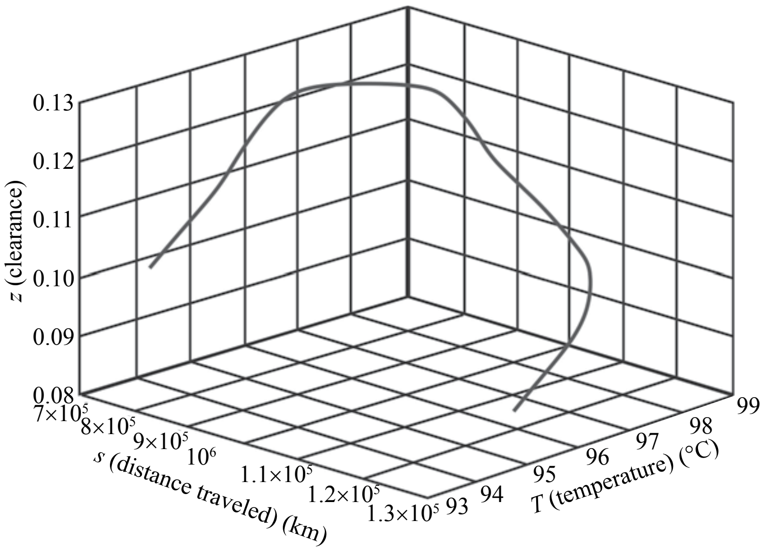

Fig. 4. Diagram for determining the correlation of temperature, clearance and determined distance with motor vehicle condition control parameters Volvo – D7C 275

Figure 3 shows the dependence diagram on the correlation of worn-out of bearings and temperature with and without the condition control parameters of motor vehicles Volvo – D7C 275. Figure 4 shows the dependence diagram, of the correlation of parameters: temperature, clearance and distance with the application of motor vehicles condition diagnosis.

CONCLUSIONS

The considered model is a dynamic, integrated and mathematical procedure which allowed optimum dynamic management of components condition change processes and maintenance of motor vehicles. It is based on the analysis of motor vehicles condition diagnostics parameters and forms certain conditions of component assemblies. The main purpose of the model is to, based on and with help of organized monitoring of condition parameters, determine the state of the motor vehicles constituent components and on the basis of obtained values the periodicity of the components conditions parameters check as well as the time point of the preventive motor vehicles assemblies maintenance. In the predicted period of investigation (stable, flying and sliding bearings) on the crank and camshaft of motor vehicles Volvo – D7C 275, the distance travelled to 1 200 000 km leads to intensive growth of failure occurrence under the influence of worn-out of the bearings, i.e. without the use of condition parameters. For this period, we can say that this is the time of their unstable work, which percentage is 32.7%. Introduction of the model parameters with the application of condition diagnostic, leads to a decrease of failure, i.e. decrease of the value of authoritative clearance, 15.8%. It can be concluded that this model can be applied to both simpler and more complex circuits, regardless of dimensions of motor vehicles components.

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