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THE PROGNOSIS OF MACHINES CONDITION STATE

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Abstract

In this paper we introduce problem of estimating state prognosis algorithms which are the basis for determining conclusion rules for estimating the next machine operation term.

Keywords: *machine state prognosis, procedure algorithmization, conclusion rules*

1. Introduction

Using in the exploitation process methods of machine state prognosis as a basis for automatization of state recognition process, it requires the diagnostic parameters sets optimization and prognosis methods. The solution of these problems depends on many factors connected with the level of machine complexity, application of multi-symptom observations, and exploitation process quality. The prognosis of vehicles' states is a process which ought to enable the anticipation of machine's state in the future, basis on an incomplete history of diagnostic tests research results. It allows to estimate the time of a faultless machine usage or the value of work done by it in the future.

In the process of state prognosis, very important problem is to choice [1]:

a) a set of diagnostic parameters depending on the machine's work time, quality of time step and the size of an optimal diagnostic parameters set;
b) prognosis method depending on the prognosis horizon, the minimal number of elements of time row indispensable for running the prediction and the machine's operation time.

The question of testing the above problems in the process of machine state prognosis, as well as the legal acts concerning the users' safety and environmental protection, are an impulse for searching new diagnostic methods and determining new measures and tools describing their contemporary states in their exploitation process, which are further presented as appropriate procedures, algorithms and conclusion rules.

2. Optimization procedure of diagnostic parameters sets

Diagnostic parameters set is derived from the set of output parameters. Basis on researches results, aiming at confirming some of the proposals included in works concerning the reduction of diagnostic information in prognosis process, it is considered that the determination of diagnostic parameters set in the process of machine state prognosis ought to include:

a) the ability to reflect the machine state changes in exploitation time;
b) the quantity of information on the machine's state;
c) relevant changeability of diagnostic parameters values in the machine's exploitation time.

The above postulates can be presented as methods. They are [1,2]:

1. Correlation method of diagnostic parameters values with the machine's state. It consists in examining the correlations of diagnostic parameters values with the state of the machine $r_j = r(W, y_j)$ (or the time of machine's exploitation ($r_j = r((\Theta, y_j))$:

$$r_j = \frac{\sum_{k=1}^{K}(\Theta_k - \overline{\Theta})(y_{j,k} - \overline{y_j})}{\sqrt{\sum_{k=1}^{K}(\Theta_k - \overline{\overline{\Theta}})^2 \sum_{k=1}^{K}(y_{j,k} - \overline{y_j})^2}} \tag{1}$$

$$\overline{\Theta} = \frac{1}{K}\sum_{k=1}^{K}\Theta_k\ , \quad \overline{y_j} = \frac{1}{K}\sum_{k=1}^{K}y_{j,k}\ , \tag{2}$$

where $r_j = r(W, y_j)$, j = 1,..., m – coefficient of correlations between variables the W (state of the machine) and y_j; $r_{jn} = r(y_j, y_n)$; j, n = 1,..., m; $j \neq n$ – coefficient of correlations between the variables y_j and y_n.

In case of lack of data from the set W, they are replaced, assuming that the determination of state recognition procedures is realized within the range of normal wear, with the time of machine's exploitation. Then, $r_j = r(\Theta_k, y_j)$; j=1,..., m; k=1,...,K (r_j – coefficient of correlation between the variables $\Theta_k \in (\Theta_1, \Theta_b)$ (Θ_k – machine's exploitation time) and y_j).

2. Method of informational size of diagnostic parameter. The object of this method consists in the choice of the parameter which provides the largest quantity of information on the machine's state. A diagnostic parameter is the more important for the state change estimation, the more it is correlated with it and the less it is correlated with other diagnostic parameters. This relation is presented in the form of the size indicator of the diagnostic parameter h_j, which is a modification of the indicator relating to the set of variables explaining the econometric model [12]:

$$h_j = \frac{r_j^2}{1 + \sum_{j,n=1, j\neq n}^{m} \left| r_{j,n} \right|} \tag{3}$$

$$r_{j,n} = \frac{\sum_{k=1}^{K}(y_{j,k} - \overline{y_j})(y_{n,k} - \overline{y_n})}{\sqrt{\sum_{k=1}^{K}(y_{j,k} - \overline{y_j})^2 \sum_{k=1}^{K}(y_{n,k} - \overline{y_n})^2}} \tag{4}$$

$$\overline{y_j} = \frac{1}{K}\sum_{k=1}^{K}y_{j,k}\ ; \quad \overline{y_n} = \frac{1}{K}\sum_{k=1}^{K}y_{n,k} \tag{5}$$

In case of lack of data from the set W, they are replaced, assuming that the determination of state recognition procedures is realized within the range of normal wear, with the time of machine's exploitation.

An advantage of the presented methods is a fact that both allow to choose single-element as well as multi-element sets of diagnostic parameters from the set of output parameters. A single-element set refers case, when the machine is decomposed into units, and it is necessary to choose one diagnostic parameter. A multi-element set is acquired when in presented procedures less strict limitation is used, which consists in classifying into the diagnostic parameters set these parameters whose indicator values are higher (lower) than, accepted respectively for the method, high (low) positive numbers.

The estimation methodology algorithm of the optimal machines diagnostic parameters set consists stages [2,3]:

1. Data acquisition:
   a) the set of diagnostic parameters values in the function of machine's exploitation time $\{y_j(\Theta_k)\}$, acquired in the time of passive-active experiment realization, where $\Theta_k \in (\Theta_1, \Theta_b)$;
   b) the set of diagnostic parameters values: $\{y_j(\Theta_1)\}$ – nominal values, $\{y_{jg}\}$ – boundary values, j=1,…, m;
   c) the set of machine's states $\{\Theta_k: \{s_i\}, k=1, \ldots, K; i=1,\ldots, I\}$ determined in the time of passive-active experiment realization, where $\Theta_k \in (\Theta_1, \Theta_b)$;;

2. The optimization of diagnostic parameters set values (only in case of large size of Y, e.g. m>10). Diagnostic parameters set is estimated with use of:
   a) correlation method of machine's state diagnostic parameters (exploitation time), $r_j = r(W, y_j)$, $(r_j = r((\Theta, y_j))$
   b) method of machine's state diagnostic parameters information quantity h_j.

In order to choose a diagnostic parameters set, weight values are used:

a) standardized calculation weights w_{1j}:

$$w_{1j} = \frac{1}{d_j}, \; d_j = \sqrt{(1-r_j^*)^2 + (1-h_j^*)^2} \tag{6}$$

$$r_j^* = \frac{r_j}{\max r_j}, \; h_j^* = \frac{h_j}{\max h_j} \; ; \tag{7}$$

b) as the criterion of diagnostic parameter (diagnostic parameters) selection, the maximization of the values of weights w_{1j} and the diagnostic parameters selection according to the above criterion were accepted.

c) in order to consider the user's preferences, it ought to be possible for him/her to insert the weights w_{2j} (standardized values) from the range (0,1) and choose parameters according to the above criterion.

3. The procedure of machine state prognosis

The machine's state prognosis process can by realized with different methods at the same time that determine the aim and form of the prognosis [4,5,6,7,8]. Applying the criteria concerning the requirements are connected with:

a) the form of prognosis (forecasted symptom value, machine operation date or another for machine state prognosis);
b) the influence of machine's exploitation changes and maintenance actions conditions over the machine's exploitation characteristics, which should be considered while choosing the prognosis method;
c) possible to use prognosis methods (e.g. extrapolation trend methods and adaptation methods) [4,9]

several solutions are possible.

One of them is usage the diagnostic parameter value change in function of machine exploitation. It uses the assumption that the phenomenon of the machine's technical state worsening is represented by the time row $y_\Theta = \langle y_1, y_2, ..., y_b \rangle$, i.e. the set of discrete observations $\{y_\Theta = \zeta(\Theta);\ \Theta = \Theta_1, \Theta_2, ..., \Theta_b\}$ of a certain non-stationary stochastic process $\zeta(\Theta)$. As the acceptable period of the machine's usage, accepted is the time of it's work in which the boundaries of mistake range for separate prognoses determined on the subset $\Omega^y \subset \Omega$ of available realizations of the observed parameters $\{y_j(\Theta)\}$and their prognoses $\{y_{j,p}\}$ according to the accepted predictor $P(y_\Theta,\tau)$ do not exceed the boundary values $\{y_{j,gr}\}$ [11].

The date of the next operation Θ_{b1} of the machine is therefore determined by the prognosis time horizon τ^* [2,11,12]:

a) for which there will be no excess of the diagnostic parameter boundary value y_{gr} by the boundary of the prognosis mistake range appointed by the radius r_σ;
b) for which there will be no excess of the diagnostic parameter boundary value y_{gr} by the forecasted value of the diagnostic parameter;
c) for which there will be no excess of the diagnostic parameter boundary value y_{gr} by the estimated value of the diagnostic parameter;
d) for which there will be no excess of the diagnostic parameter boundary value y^*_{gr} by the value of the diagnostic parameter at the time Θ_b.

In the levelling method of prognosis mistake value for the value Θ_{b1} are acceptable values of the time determined by the horizon value τ^*, appointed as the intersection point of the line of diagnostic parameter boundary value y_{gr} with the bottom (with the assumption that $y(\Theta_b) > y_{gr}$) or top (with the assumption that $y(\Theta_b) < y_{gr}$) boundary of the prognosis mistake range appointed by the radius r_σ for the trust level $1-\gamma=0,95$ or $1-\gamma=0,99$, which corresponds to the probability of the value $p=0,05$ or $p=0,01$ that in the range appointed by the horizon τ^* the diagnostic parameter will reach the boundary value y_{gr}.

Then, the following interpretations of the obtained terms are possible:

a) not exceeding by the controlled diagnostic parameter the boundary appointed by the radius $r_\sigma^{0.01}$ is interpreted as the alarm signal for thorough and more accurate diagnostic observation of the vehicle's unit or system;
b) exceeding by the controlled diagnostic parameter the boundary appointed by the radius $r_\sigma^{0.01}$ is interpreted as the lack of alarm signal for thorough and more accurate diagnostic observation of the vehicle's unit or system (alert threshold);
c) the moment of exceeding by the controlled diagnostic parameter the boundary appointed by the radius $r_\sigma^{0.05}$ is interpreted as the time Θ_{b1} – the operation date of the vehicle's unit or system (alert threshold).

In such situation, the time range (Θ_1, Θ_b) will be the estimation period of the prognosis mistake expected value e_p and the boundary radius of the prognosis mistake range r_σ, whilst the time period after Θ_b will be the period of the active prognosis, i.e. estimation of:

a) the prognosis value of diagnostic parameter after prognosis horizon time τ, $y_{jp}(\Theta_b+\tau)$;
b) the estimation of the value of boundary radius of the prognosis mistake range $r_\sigma(\Theta_b+\tau)$;
c) the estimation of the next diagnosis and operation time of the machine Θ_{b1}.

In the levelling method of diagnostic parameter boundary value the date of the next operation of device Θ_{b1} is determined by the horizon value τ^*, estimated as the intersection point of the diagnostic parameter trend line $y(\Theta)$ with:

a) the bottom (with the assumption that $y(\Theta_b)>y_{gr}$) border of the boundary value y_{gr}^*:

$$y_{gr}^* = \frac{1}{10}\left| \, y(\Theta_1) - y_{gr}\right| + y_{gr} \tag{8}$$

b) or the top (with the assumption that $y(\Theta_b) < y_{gr}$) order of the boundary value y_{gr}^*:

$$y_{gr}^* = y_{gr} - \frac{1}{10}\left| \, y(\Theta_1) - y_{gr}\right| \tag{9}$$

The values $S_p(\Theta_b+\tau)$ and Θ_{b1} are estimated with one of the prognosis methods, whilst the date of diagnosis and operation according to the relation:

$$\Theta_{b1} = \Theta_b + \frac{\tau\ (y^*_{gr} - y(\Theta_b))}{y(\Theta_b + t) - y(\Theta_b)} \tag{10}$$

In the method of determination of the diagnostic parameter value change, with the assumption of:

a) exponential decomposition of the diagnostic parameter at the time Θ_b;
b) probability of the machine's reliable work P_r: $1 < P_r < 0.8$
c) dynamics of the parameter S growth in the time (with $S(\Theta) < S_{gr}$):

$$S(\Theta) = \frac{S(\Theta_b)}{S_{gr} - S(\Theta_b)} \tag{11}$$

The value Θ_{b1} is estimated as:

$$\Theta_{b1} = \frac{(1-P_r)(S_{gr} - S(\Theta_b))}{S(\Theta_b)}\Theta_b \tag{12}$$

In the date estimation method Θ_{b1} the effort to simplify the procedures of date estimation Θ_{b1} led to creating the date estimation method Θ_{b1}, in which there is no need to estimate the prognosis value of the parameter y_p. In this method, like in the levelling method of the boundary value, a certain level of the boundary value y_{gr}^* is determined, different from the boundary value y_{gr}, e.g. according to the relation (8,9) and compared to it the diagnostic parameter value. Then, as the date of the next device operation Θ_{b1} it is suggested to accept the value of working time (course) of the machine, determined by the horizon value τ^*, estimated as the intersection point of the diagnostic parameter value $y(\Theta_b)$ with the value y_{gr}^*:

$$\Theta_{b1} = \Theta_b \tag{13}$$

The estimation of the date Θ_{b1} on the basis of the presented methods is determined by many problems, most important of which are:

a) the determination of the optimal diagnostic parameter set describing the change of the machine state in function of its "lifetime";
b) the determination of weight function for a multi-element optimal set of diagnostic parameters;
c) the determination of "the best" method for date estimation Θ_{b1}.

The solution of the above problems, as it show in [2,11,13] requires the use of appropriate multi-criteria optimization methods and prognosis methods enabling the estimation of the prognosis value of the diagnostic parameter $y_{j,p}$ and the necessity to know the boundary value of the diagnostic parameter y_{gr}.

Analyzing, basis on researches results, presented methods of diagnosis and operation term estimation, the most suitable methods are:

a) method of levelling the prognosis mistake;
b) method of levelling the diagnostic parameter boundary value.

The algorithm of machine state prognosis includes the following stages [2,14]:

1. The prognosis of the diagnostic parameter value y_j^*:
   a) with the Brown-Mayer adaptation method type 1 (B-M1) with the coefficient $\alpha = (0.5 - 0.8)$ and for the prognosis horizon $\tau = (1 - 3)\Delta\Theta$ determined for the time range (Θ_1, Θ_b),
   b) with the Holt adaptation method with the coefficient $\alpha_1 = (0.6 - 0.8)$ and $\alpha_2 = (0.4 - 0.8)$ for the prognosis horizon $\tau = (1 - 3)\Delta\Theta$ determined for the time range (Θ_1, Θ_b),
   c) with the use of analytical methods (linear, exponential for the prognosis horizon $\tau = (1 - 3)\Delta\Theta$ determined for the time range (Θ_1, Θ_b),
2. The estimation of the next operation and diagnosis date for the machine Θ_d:

a) Θ_{d1} with the prognosis mistake levelling method for the radius of the prognosis mistake r_p (for the importance level β=0,05) according to the relation:

for $y_j(\Theta_b) > y_{jg}$: $$\Theta_{jd1} = \Theta_{jb} + \frac{\tau\lfloor y_j(\Theta_b) - y_{jg} - r_\sigma \rfloor}{y_j(\Theta_b) - y_{j,p}(\Theta_b + \tau)} \qquad (13)$$

for $y_j(\Theta_b) < y_{jg}$: $$\Theta_{jd1} = \Theta_{jb} + \frac{\tau\lfloor y_{jg} - y_j(\Theta_b) - r_\sigma \rfloor}{y_{j,p}(\Theta_b + \tau) - y_j(\Theta_b)}\ , \qquad (14)$$

where r_σ - the radius of the prognosis mistake range (calculated a'posteriori appropriately for each method of the prognosis value determination $y_{j,p}(\Theta_b+\tau)$);

b) Θ_{d2} with the levelling method of the diagnostic parameter boundary value ($y_{jg1}= y_{jg}$; $y_{jg1}= y_{jg} +\gamma(y_{jn} - y_{jg})$ for $y_{jn} > y_{jg}$ and $y_{jg1}= y_{jg}$; $y_{jg1}= y_{jg} - \gamma (y_{jg} - y_{jn})$ for $y_{jg} > y_{jn}$), e.g. for γ =0,1:

for $y_j(\Theta_b) > y_{jg}$: $$\Theta_{jd2} = \Theta_{jb} + \frac{\tau\lfloor y_j(\Theta_b) - y_{jg1} \rfloor}{y_j(\Theta_b) - y_{j,p}(\Theta_b + \tau)} \qquad (15)$$

for $y_j(\Theta_b) < y_{jg}$: $$\Theta_{jd2} = \Theta_{jb} + \frac{\tau\lfloor y_{jg1} - y_j(\Theta_b) \rfloor}{y_{j,p}(\Theta_b + \tau) - y_j(\Theta_b)}\ ; \qquad (16)$$

c) the determination of the next operation and diagnosis date of the machine $\Theta_d^* = \min(\Theta_{d1}, \Theta_{d2})$.

4. Examining procedures of machine state prognosis

Examining procedures includes:

a) examining the set of diagnostic parameters in the aspect of estimating an optimal set of diagnostic parameters for prognosing diagnostic parameters values according to the algorithm (point 2);

b) estimating prognosis methods of diagnostic parameters values and methods of estimating the next examination term of a machine according to the algorithm (point 3);

a) examining the prognosis value of diagnostic parameters with the prognosis mistake, and the manner of estimating the next examination and operation term of a machine depending on the following parameters:
   - prognosis value of diagnostic parameters values,
   - the size of the diagnostic parameters set,
   - prognosis horizon.

In order to obtain measurement data for procedure researches, the set of diagnostic parameters Y_1 was used from stationary researches of the combustion engine UTD-20 [1,11,14] in the form of time rows whose elements are the values of diagnostic parameters: P_{sil} – engine power [kW], p_{spr} – compression pressure [MPa], p_{wtr} – fuel injection pressure [MPa], p_{ol} – engine oil pressure [MPa].

Examining procedure of estimating an optimal diagnostic parameters set for the prognosis of diagnostic parameters values consisted in:

1. Estimating an optimal set of diagnostic parameters according to the algorithm (point 2). For the set of output parameters $Y_{1,}$ the set of diagnostic parameters with appropriate weight values was obtained.

Result analysis for the engine UTD-20 showed that:

a) the highest weight values w_{j1} are possessed by the diagnostic parameters p_{wtr} and p_{ol}, and the lowest weight values w_{j1} by the diagnostic parameter P_{sil};

b) the accepted optimization criteria unambiguously identify sets of parameter values with largest quantity of information on technical state changeable in time of exploitation of the engine UTD-20, which confirms the propriety of formulating optimization procedures of diagnostic parameters set.

2. Examining the optimal set of diagnostic parameters in the aspect of the influence of time row size (research results are gathered in the appendix B) through estimating weight values w_{j1} for the set Y_1 and the set Y_2 in elation to the length of time row. For this purpose, time rows for set sizes: k=10, k=20, k=40, k=50 were considered;

Result analysis in it field indicated that:

a) there are value changes of the weight w_{j1} in the function of time rows lengths;
b) for the combustion engine UTD-20 the order of parameters p_{wtr}, p_{ol}, p_{spr}, P_{sil} is not sustained, which indicates that the accepted criteria for parameter sets of real objects unambiguously identify sets of parameter values changeable in time of machine and having the highest quantity of information on the machines' technical state.

Summing up the performed researches for the optimization procedure of the diagnostic parameters set, it is concluded that:

a) examining diagnostic parameters sets in the aspect of the influence of time row size for the set Y_1 showed a considerable influence of time row length on estimating weight values w_{j1} for the group Engine UTD-20.
b) in examining the methodology of machine state recognition, it is suggested to accept diagnostic parameters of the highest weight values, e.g. for the combustion engine UTD-20: $w_{j1} \geq (0{,}02 – 0{,}05)$, in order to obtain a set of at least 3 elements.

Examining the procedures of machine state prognosis in the aspect of determining a prognosis method according to the prognosis mistake function, examining the influence of prognosis horizon value on the prognosis mistake, and examining the influence of diagnostic parameters set size on the prognosis mistake, were realized on the basis of:

1. Determining the set of prognosis methods of diagnostic parameters values, and estimation method of the next examination and operation date of the machine according to the algorithm (point 3). For the set of diagnostic parameters $Y_2=\{p_{wtr}, p_{ol}\}$ (of the highest weight values), the visualization of their prognoses value was obtained (linear model, exponential model, Brown-Mayer model, Holt's model), and two methods of determining the dates of next machine examination (Θ_{d1},Θ_{d2}) for three values of the prognosis horizon ($\tau=\Delta\Theta$, $\tau=2\Delta\Theta$, $\tau=3\Delta\Theta$).

The analysis of research results for the combustion engine UTD-20 showed that:

a) different best (according to the minimum value of prognosis mistake) prognosis methods of diagnostic parameters values are accepted:

- for p_{wtr} – Holt method (α=0,1; β=0,1), prognosis mistake = 3,02%;
- for p_{ol} – Holt method (α=0,1; β=0,1), prognosis mistake = 3,39%;

b) different values of the next machine examination are obtained in relation to the prognosis horizon and the size of the diagnostic parameters set:

- for p_{wtr} – Holt method (α=0,1; β=0,1), examination dates: $\Theta_d(\tau=\Delta\Theta)$=8775,62; $\Theta_d(\tau=2\Delta\Theta)$=86993,23; $\Theta_d(\tau=3\Delta\Theta)$=8610,85;
- for p_{wtr} – Holt method (α=0,1; β=0,1) and p_{ol} – Holt method (α=0,1; β=0,1) weighed examination dates $\Theta_{dw}(\tau=\Delta\Theta)$=8740,03, $\Theta_{dw}(\tau=2\Delta\Theta)$=8622,07; $\Theta_{dw}(\tau=3\Delta\Theta)$= 8504,11.

Summing up the performed researches for the state prognosis method, it is stated that:

a) considering low values of the curvilinear correlation coefficient (< 0,8) and high values of prognosis mistakes, and negative values of the next operation dates of the examined objects in analytical models (power model, exponential model and exponential model) for potential applications, it is necessary to use the Brown–Mayer model and Holt model;
b) the accepted optimization criteria and the presented algorithm unambiguously identify the prognosis method and the method of estimating the next examination date, which confirms

the propriety of the formulated procedure, and will be the basis for examining the methodology of machine state recognition in the field of state prognosis for other objects.

The analysis of research results of machine state prognosis methodology allows to formulate dedicated conclusion rules of type “IF – THEN” or “IF – THEN – ELSE” in the area of:

a) diagnostic parameters optimization;
b) state prognosis.

In case of the combustion engine UTD-20, the generated rules have form:

a) for diagnostic parameters set Y^o:
   - if $w_{1j} \geq 0{,}05$ then $y_j \in Y^o$,
   - or if $w_{1j} = w_{1jmax}$ then $y_j \in Y^o$;
b) for state prognosis:
   - if $w_{1j} = w_{1jmax}$ and if $w_{1j} \geq 0{,}9$ then $y_j \in Y^o$ and the set Y^o is a single-element set, $Y^o = Y^{o1}$,
   - if $w_{1j} = w_{1jmax}$ and if $w_{1j} < 0{,}9$ then $y_j \in Y^o$ and the set Y^o is not a single-element set, $Y^o = Y^{oo}$,
   - if the prognosis mistake of Holt method (with appropriate values of the parameters α, β) for the set Y^{o1} < prognosis mistake of the Brown–Mayer method (with an appropriate value of the parameter α) for the set Y^{o1}, then the method of value prognosis of the set Y^{o1} is the Holt method (with appropriate values of the parameters α, β), otherwise the prognosis method of the value Y^{o1} is the Brown–Mayer method (with an appropriate value of the parameter α),
   - if the value of the next examination date of the engine UTD-20 Θ_{d1} (Y^{o1}) $\leq$ value of the next examination date of the engine Θ_{d2} (Y^{o1}), then the method to estimate the next examination date of the engine is the method of levelling the prognosis mistake value, otherwise it is the prognosis method of diagnostic parameter boundary value,
   - if the prognosis mistakes for methods: Holt (with appropriate values of the parameters α, β) or Brown–Mayer (with an appropriate value of the parameter α) for diagnostic parameters of the set Y^{oo} take minimum values, then prognosis methods of values of appropriate diagnostic parameters of the set Y^{oo} are the above methods,
   - if the value of the next examination date of the engine UTD-20 Θ_{d1} (Y^{oo}) $\leq$ value of the next examination date of the engine Θ_{d2} (Y^{oo}) then the method to estimate the next examination date of the engine (for the considered diagnostic parameter) is the method of levelling the prognosis mistake value, otherwise it is the prognosis method of diagnostic parameter boundary value,
   - if the value of the next examination date of the engine UTD-20 Θ_d is determined for Y^{oo}, then this values is the weighed value of the value Θ_{dw}.

The presented conclusion rules in range of machine state prognosis, after performing appropriate verification researches, could be the basis for dedicated software of a machine state recognition system in an on–line mode (for an on-board system) and off–line (for a stationary system).

5. Conclusion

The carried out presentation of machine state prognosis procedures allows to formulate the following conclusions:

1. Presented procedures allow to determine optimal, as far as the accepted criterion is concerned:
   a) diagnostic parameters set;
   b) diagnostic parameters values prognosis and machine operation date estimation.

2. In order to determine the set of diagnostic parameters and state prognosis, the above presented procedures can be the basis for estimating conclusion rules in the range of:
   a) determining an optimal set of diagnostic parameters;
   b) estimating the values of diagnostic parameters in the future, and estimating the date of the next machine operation.

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