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THE RULES OF INFERENCE IN MACHINE STATE RECOGNITION

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Abstract

The results of investigations connected with the implementation of the procedures of monitoring the technical condition of machine engines and their investigation for the chosen arrangements of mechanical vehicles were introduced. The examples of the rule of inference of diagnostic were passed for the gathering of diagnostic parameters and the opinion of the state.

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

1. Introduction

The usage in exploitation process of machines technical state evaluation methods, being the basis of the automation of state recognition, requires the determination of diagnostic parameters set, diagnostic tests assignment and method optimization of diagnosis, genesis, forecasting. The realization of these tasks depends on many factors related to the level of machine complexity, the quality of exploitation process and the course of wear process. For this purpose it is necessary to identify the methods of machine state recognition, create procedures possible to use in the machine state recognition process, as well as determine the rules of concluding being an element of the on-board software of machine state recognition system [2, 3, 5, 6, 10, 11].

Machine state recognition is a process which ought to enable:

a) real-time estimation of the machine's technical state on the basis of diagnostic researches results, through the control of state and the location of damages in case of the machine's disability;
b) anticipation of the machine's state in the future on the basis of incomplete history of diagnostic researches results, which enables time estimation of the machine's flawless operation or the value of work done by the machine in the future;
c) anticipation of the machine's state in the past on the basis of incomplete history of diagnostic researches results, which enables the estimation of the machine's state or the value of work done by the machine in the past.

2. Problem characteristics

The problem of state evaluation, prognosis and genesis of the machine's state is equally important at the stage of construction preparation, production and exploitation, and the main problems appearing during the solution of the machines' state recognition task are [4, 6, 7, 8, 10]:

a) formalizing the aim of diagnosis, forecasting and genesis of the machine's state;
b) the description of the machine's state changes in the exploitation time;
c) building a diagnostic model – the relation between state characteristics and diagnostic parameters;
d) the solution of state diagnosis task;
e) the solution of state forecasting task;
f) the solution of state genesis task.

The machine's state $W(\Theta_n)$ at the moment in time Θ_n can be characterized with the use of the parameter values set $\{y_j(\Theta); j=1,...,m\}$. The machine at the moment Θ_b (machine's state diagnosis task) is in the state of aptitude S^0, when satisfied is the condition:

$$W(\Theta_n) = W^0 \Leftrightarrow \forall\ (j=1,...,m) \quad [\{y_{j,d}\} \leq \{y_j(\Theta_b)\} \leq \{y_{j,g}\}], \tag{1}$$

where: $\{y_{j,d}\}$, $\{y_{j,g}\}$ – sets of upper and bottom boundary values of diagnostic parameters.

Respectively, it is possible to formulate the condition of aptitude at the moment $\Theta_{n+\tau}$ (forecasting task) [9,10,14]:

$$W(\Theta_{n+\tau 1}) = W^0 \Leftrightarrow \forall\ (j=1,...,m) \quad [\{y_{j,d}\} \leq \{y_j(\Theta_{b+\tau 1})\} \leq \{y_{j,g}\}], \tag{2}$$

whilst the elements of the set $\{y_j(\Theta_{b+\tau 1})\}$ are unknown, hence the necessity of foreseeing them in the assumed time range τ_1. The element τ_1 means the time range for which the forecasting process is realized (the element τ_1 is also called advance or "prognosis time horizon"). In this aspect, the time evaluation of machine's passage from the aptitude state into the inaptitude state is determined by the results of diagnostic parameters prognoses $\{y_j(\Theta_{b+\tau 1})\}$ signalizing the exceeding of boundary values.

Similarly we can formulate the condition of aptitude at the moment $\Theta_{b-\tau 2}$ (machine's state genesis task):

$$W(\Theta_{n-\tau 2}) = W^0 \Leftrightarrow \forall\ (j=1,\ldots,m) \quad [\{y_{j,d}\} \leq \{y_j(\Theta_{b-\tau 2})\} \leq \{y_{j,g}\}], \tag{3}$$

Whilst some elements of the set $\{y_j(\Theta_{b-\tau 2})\}$ are unknown, hence the necessity of foreseeing them in the assumed time range τ_2. The element τ_2 means the time range for which the genesis process is realized (the element τ_2 is also called advance or "genesis time horizon"). In this aspect, the estimation of the machine's state or the value of work done by it in the past are determined by the results of diagnostic parameters values genesis $\{y_j(\Theta_{b-\tau 2})$.

The main problems appearing at the solution of such defined tasks are: the selection of "the best" diagnostic parameters describing the actual state and their change in exploitation time, diagnostic test determination, the determination of forecasted value of diagnostic parameter for prognosis horizon τ_1, $y_{jp}(\Theta_b+\tau_1)$ with the help of "the best" prognosis method, and the determination of the next diagnosis or operation Θ_d, the determination of genesis value of diagnostic parameter for genesis horizon τ_2, $y_{jp}(\Theta_b-\tau_2)$ with the help of "the best" Genesis method, and the estimation of the machine's state, work done by it in the past, and the determination of the cause of an existing damage.

The above used notion "the best" is connected with the acceptance of appropriate criteria and considering these problems in the categories of optimal solution search, whilst taking into consideration many estimation criteria, it is necessary to consider these problems in the categories of polioptimal solution [1, 10].

3. The algorithm of machine state recognition

The scheme of determining procedures for machine state recognition is shown in the Fig.1, whilst the algorithm of the use of the appointed optimal diagnostic parameters set, optimal diagnostic test, optimal genesis method and optimal method is shown in the Fig.2.

Summing up the considered in this chapter problems concerning theoretical bases of the state recognition process methodology, it is necessary to state that:

1. The process of machine state recognition includes the following kinds of diagnostic research: state evaluation, genesis and prognosis.

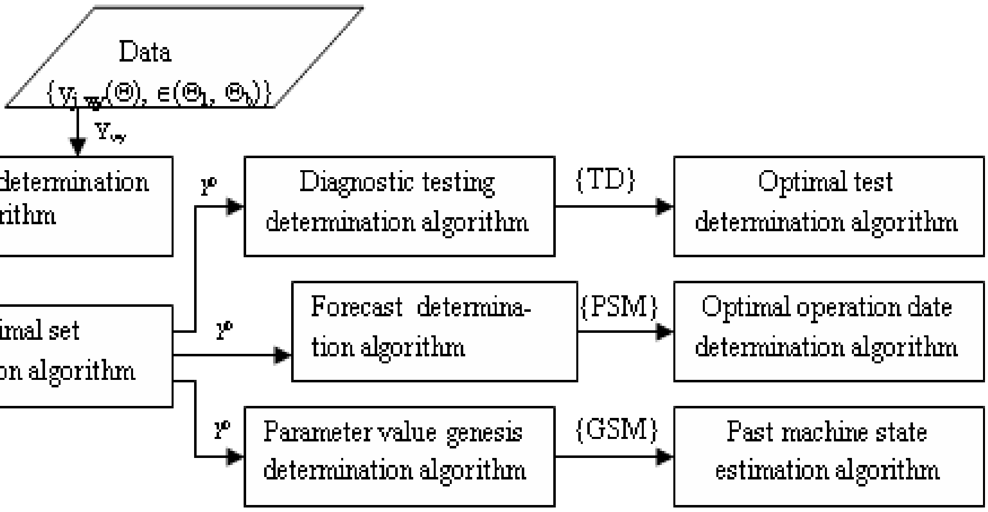

Fig. 1. Scheme of determining procedures for machine state recognition

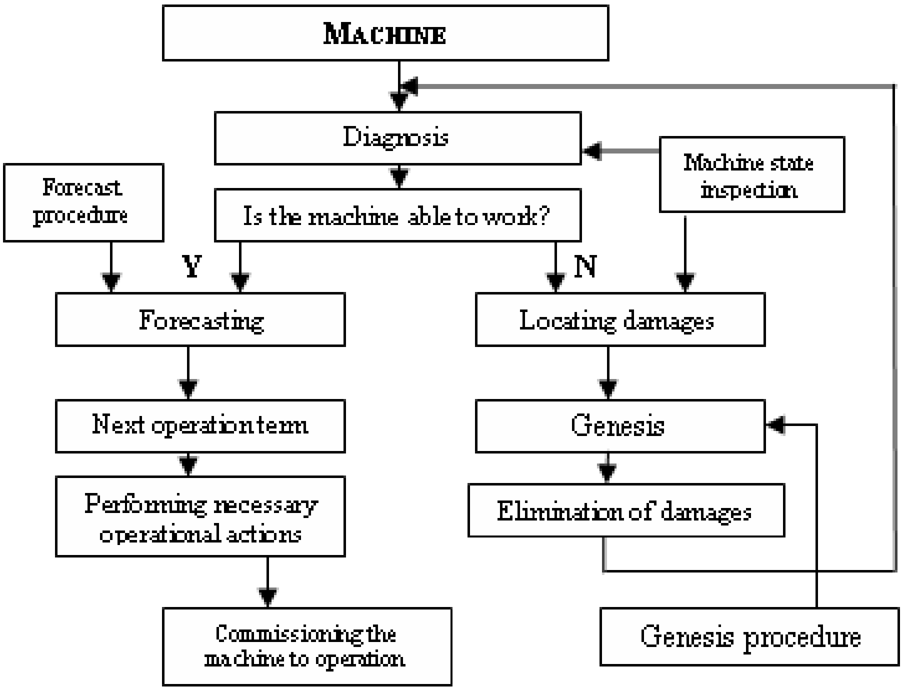

Fig.2. Scheme of machine state recognition realization

2. In the process of machine state recognition, an important element is the determination of the diagnostic parameters set:
   a) for the evaluation of the machine’s state considering the criterion of machine states differentiation;
   b) in the process of prognosis and genesis with the use of criteria of: correlation between the diagnostic parameter value and the state and machine’s exploitation time, and the information capacity of the diagnostic parameter.
3. In the procedure of machine state evaluation, analyzed was the possibility to use the following methods for examining the relations between diagnostic parameters and the machine’s states:
   a) mean test examination;
   b) examining the distance of trust ranges of the diagnostic parameter mean value;
   c) examining the changeability of the diagnostic parameter value.
4. The presented estimations allow to state that it is possibile to create appropriate algorithms of the machines’ technical state recognition, and appropriate concluding rules vital for creating the software of the on-board machine technical state recognition system.

4. On-board state recognition system

Created rules of diagnostic models identification, established procedures of acquisition and processing of information on state changes of examined models, their implementation in information technology, as well as proposed state recognition procedures (diagnosis, genesis, prognosis) are the basis of on-board diagnostic systems construction. In this chapter we presented the assumptions for the construction of the on-board machine state recognition system, the rules for its design, and the procedure of the diagnostic system construction [10, 11].

The idea of the on-board state recognition system ought to be included in the organizational range of the new machine’s design, including the problems determining:

a) functional features;
b) construction features;
c) exploitation and operation conditions;
d) operational resource base potential;
e) economic calculation.

Taking into consideration the above assumptions, the creation rules of the on-board machine state recognition system should include:

1. The project analysis – concerns the analysis of needs and possible problem solutions, the analysis of economic calculation concerning the construction of the system, as well as the analysis of functional, technical and economic requirements including the relation of manufacture and exploitation costs of the system to the acquired benefits in result of its use;
2. System design – concerns the determination of the architecture of microprocessor, modules, interfaces and other components, as well as software in the aspect of the system useful features fulfillment, including:
   a) logical project – concerns logical aspects of system, processes and information flow organization,
   b) functional project – concerns the function description of system elements and their co-operation,
   c) construction project – concerns the structure description of system elements (e.g. processor, memory, communication, input and output, clock, power supply);
3. The construction of system work simulator (computer) – its purpose is to ensure the initial evaluation of system work with simulated machine states;
4. System implementation – the aim is to create and build a physical model performing the assumed functions of the system;

5. System quality assurance – concerns testing the programs and exploitation research;
6. System documentation preparation – including the construction, requirements and limitations, functioning and operational procedures.

The object of the machine state recognition system working involves:

1. In the area of State Evaluation:
   b) concluding on the machine state based on the relations between the measured values of diagnostic parameters set and their nominal values on the basis of the created state control test;
   c) concluding on the machine state location based on the relations between the measured values of diagnostic parameters set and their nominal values on the basis of the created damage location test.

In the module State Evaluation we experience:

   a) diagnostic matrix creation on the basis of input data;
   b) the possibility to edit the diagnostic matrix;
   c) saving to a text file.

2. In the field State Genesis based on the concluding on a possible cause of the located disability state of the machine according to the algorithm:
   a) optimal diagnostic parameter (maximum weight value);
   b) optimal genesis method (minimum genesis mistake value);
   c) minimum value of the distance between the diagnostic parameter value with the range of genesis mistake and the boundary value of the diagnostic parameter d_{min};
   d) correlation of the minimum distance value d_{min} with the machine's disability states s_i, with the simultaneous testing of circumstances and exploitation conditions of their occurrence, as the potential cause of the located machine's disability state.

In the module State Genesis we experience:

   a) the determination of genesis value of diagnostic parameter and genesis mistake;
   b) the determination of the minimum distance between the genesis value of the parameter and its boundary value;
   c) testing the influence of exploitation factors (number of parameters, row size) over the state genesis;
   d) the visualization and record of approximation or interpolation function for chosen parameters of a chosen object in the form of a graph and a report (Fig. 3).

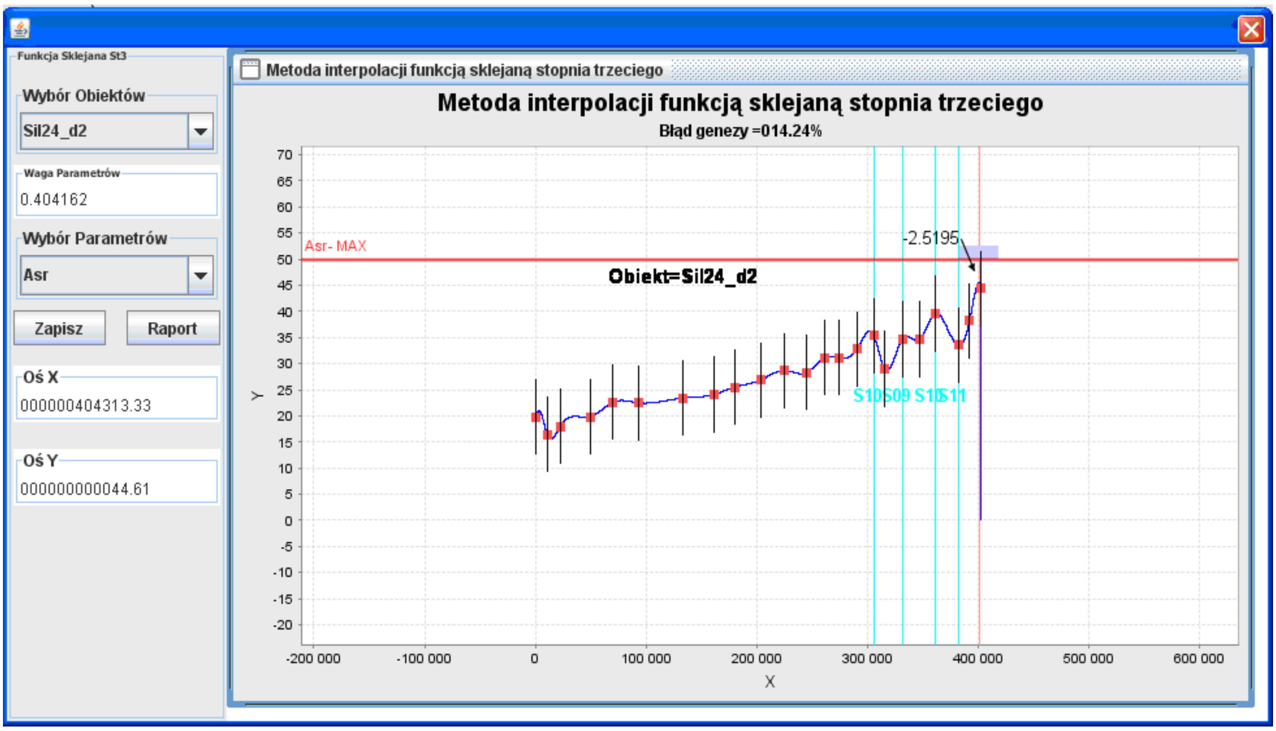

Fig. 3. Interpolation method with the third-degree compound function from the State Genesis module (estimating the genesis value of the parameter NO_2 (weight w_1=0,9229) for the interpolation with the combined function, type 3)

3. In the area State Prognosis on the estimation of the date of the next machine operation Θ_d (accepting the minimum date value Θ_{d1} , Θ_{d2}) on the basis of the analysis of values of dates generated by two prognosis methods for the next operation date Θ_{d1} and Θ_{d2} according to the algorithm:
   a) optimal diagnostic parameter (maximum weight value);
   b) optimal prognosis method (minimum prognosis mistake value);
   c) minimum value of the next operation date Θ_d.

In the module State Prognosis we experience:

a) the determination of the prognosis value of the diagnostic parameter and prognosis mistake,
b) the determination of the diagnosis and operation date of the machine;
c) testing the influence of exploitation factors (number of parameters, time row size, prognosis horizon value) over the state prognosis;
d) the visualization and record of analyzed prognosis models for chosen parameters of the chosen object (Fig. 4).

For the realization of the above system functions it is necessary to use the object programming procedures. Then the basic module of the machine state recognition system is the knowledge base <OBJECT, ATTRIBUTE (state characteristic) – VALUE>. The object defined in the state recognition system are the systems and units of the machine.

The information on the machine state have hierarchical structure, where general information take the highest level, e.g. for the State Evaluation (machine state control), and lower levels are predestined for more detailed information (system damage location).

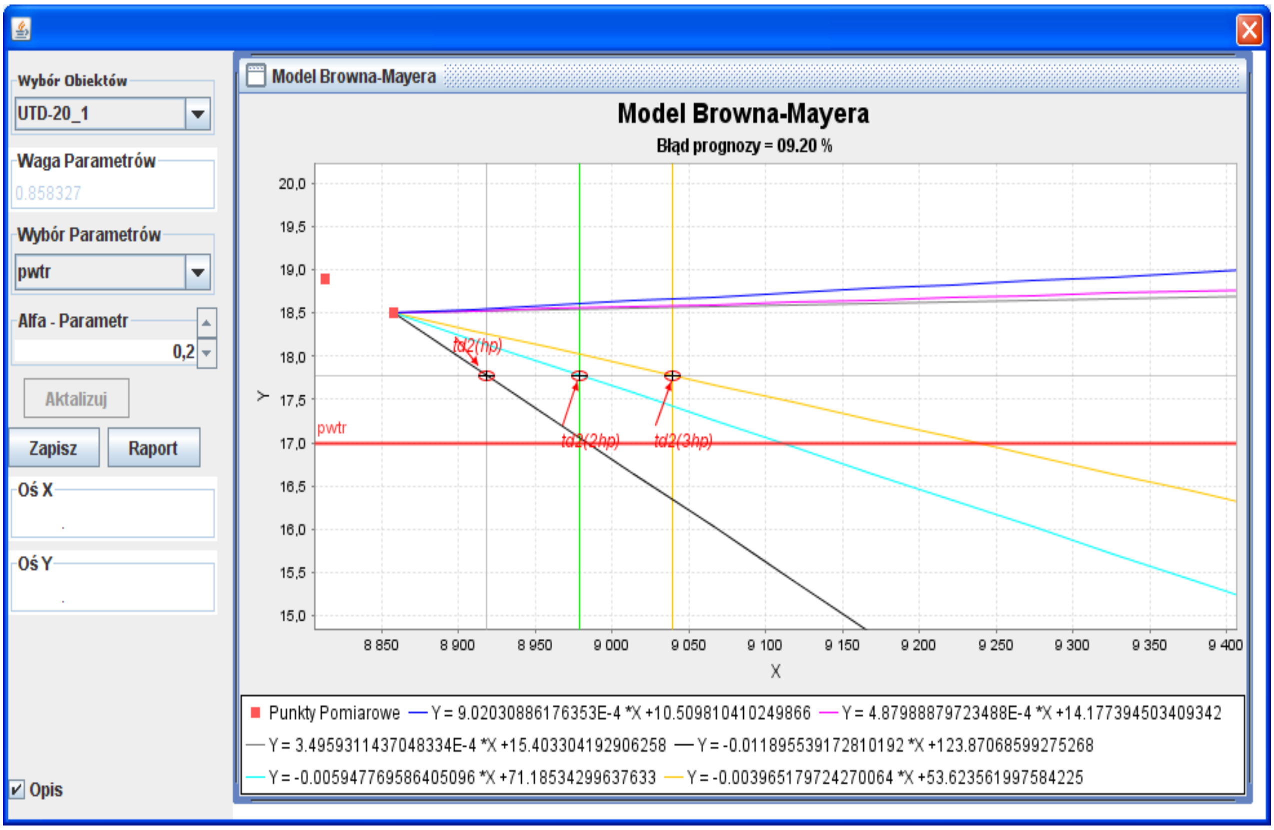

Fig. 4. Brown-Mayer model from the State Forecast module (Estimating the prognoses value of the parameter p_{wtr} (weight w_1=0,858) and date $\Theta_d(\tau=\Delta\Theta,\ \tau=2\Delta\Theta,\ \tau=3\Delta\Theta)$ for Brown–Mayer model, type 1 (α=0,2))

An ideal state recognition system is an on-board diagnostic system performing state control, damage location, state genesis and state prognosis functions. In this case the cost of the machine rises, however the machine's exploitation effectiveness grows as all the state recognition functions are performed. Such solution of the state recognition system can be appropriate for critical machines or other special machines.

A less costly solution is an on-board state recognition system which performs only state control functions. In this case the external state recognition system can forecast the state or locate the damages of the object and perform the genesis of the disability state. It can be a universal system used for diagnostic researches of different machines.

5. Dedicated conclusion rules

The analysis of research results (for example) 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).

6. Conclusion

From the analysis of action requirements, and the configuration of the on-board machine state recognition system, it results that the architecture of the system should assure:

a) the system configuration in the range of beforehand determined needs, including inserting the appropriate number of diagnostic parameters, their boundary values, and nominal values of diagnostic parameters, machine state, machine operational time;
b) measuring and recording diagnostic signals measured values according to determined conditions (the beginning and end of the measurement, which values, and when they are recorded);
c) diagnostic concluding on the basis of relation analysis between the standard values and the measured values on the basis of diagnostic conclusion rules analysis;
d) machine state visualization, including exploitation decisions generation (able, unable, damage location, other).

From the above it results that it becomes necessary to create a data base in which, apart from boundary and nominal values sets, and the set of diagnostic parameters values recorded during exploitation, there are diagnostic conclusion rules.

The presented conclusion rules can be the base for programming the machine state recognition system in an online mode (for an on-board system) and offline mode (for a stationary system).

The presented algorithm of conclusion rules generation unambiguously identifies the machine's set, system or the machine, in the aspect of their state recognition, which should enable the creation of a dedicated software (for machines' sets and systems) of the state recognition system.

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