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APPLICATION OF INFORMATION TECHNOLOGIES IN OPTIMIZATION OF THE MACHINE STATE EVALUATION PROCESS

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Abstract

The use of information technologies in machine diagnostics allows to optimize the process of the machine state evaluation. Information technologies are tools used to support the machine technical state. There is a need to do more research into these technologies and continue to develop them as they provide methods for the process optimization. Multiple criteria optimization methods often find application in selection of a set of diagnostic parameters to be further used for assessment of a machine state. This study deals with the properties and possibilities of OPTIMUS software used for the optimization process.

Keywords: *technical state of a machine , multiple criteria optimization, information technologies*

1. Process of the machine state evaluation

The methodology for the machine state evaluation process consists of a few stages involving the following diagnostic procedures (fig.1) [1]:

a) diagnostics – a process involving determination of the machine state in time Θ_b;
b) prognostics - a process involving predicting the machine future condition, enabling for example, to schedule the date of next servicing Θ_d .
c) genesis – a recovery process of a machine condition history in order to evaluate the machine past performance;

which in turn makes it possible to:

a) determine the machine actual technical condition on the basis of diagnostic tests results. It enables control of the machine condition and sites of damage when the machine is not usable.
b) predict the machine future state on the basis of an incomplete history of diagnostic tests results. It enables estimation of the machine correct operation time or work to be performed by the machine in the future.

The main tasks to be formulated in order to solve the problems connected with evaluation of the machine state include [2]:

- formulation of the goal of the machine state diagnosis, prognosis and genesis;
- change of the machine states during operation;
- description of the machine state by means of its characteristics and the dependence between the characteristics and diagnostic parameters.

- solution of the problem connected with the machine state diagnosing;
- solution of the problem connected with the machine state prognosis;
- solution of the problem connected with the machine state genesis.

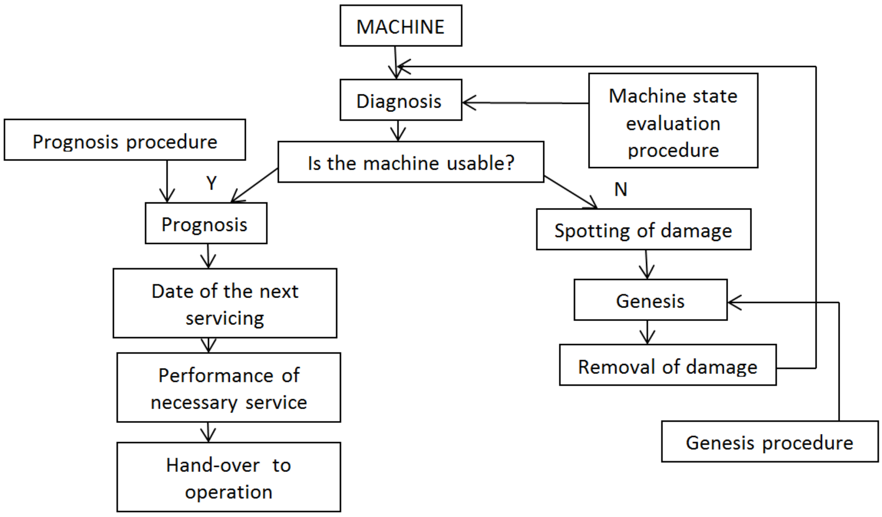

Fig.1. Scheme of the machine state evaluation in the system of maintenance [1]

Number of states which a machine can undergo results from its constructional –functional structure. Three states can be distinguished for a complete machine:

- ✓ usable machine;
- unusable machine;
- ✓ machine usable to perform tasks.

The state referred to as 'machine usable to perform tasks' refers to a situation when there are failures impairing its general technical condition though the required quality of its operation is maintained. In this case, according to the theory of technical diagnostics, though being unusable, the machine can successfully perform the assigned tasks. The machine technical condition should be considered together with the processes that are involved in its operation because the operation quality is a function of its technical condition. In practice, it is not necessary or possible to distinguish too many states a machine goes through as the probability of occurrence of simultaneous failure of more than one component is very low. Thus, with the assumption of a single failure occurrence, the number of states in which a machine is unusable equals the number of its K elements [2].

2. Multi-criteria optimization in assessment of the machine condition

In optimization of one criterion all the information necessary for finding a solution should be collected before calculations, whereas the decision process is often of iterative and multi-stage nature involving research affecting the solution. It often happens that during the research there emerges a need to apply a new criterion. Sometimes it is not possible to account for all the significant factors, or the optimization leads to a breach of constraints difficult to formalize or model, hence it appears that the formal apparatus for multiple criteria optimization which reflects complicated decision problems is more useful. Optimization of the machine state evaluation process should include the following stages:

a) determination of a set of permissible solutions X,
b) description of criteria based function F, whose elements are an exemplification of qualitative and structural requirements resulting from the properties of the process of machine maintenance and the operation (degree of assemblies fatigue wear, operational factors, structural-qualitative factors, character of external forcing, postulates connected with the formulated genesis goal);
c) solution of the problem of multiple criteria optimization and determination of the 'best' set of diagnostic parameters and the 'best' method of a machine condition evaluation;
d) assessment of the quality of an optimal solution through identification of sensitivities of the obtained procedures to some factors involved in the machine operation process (which have not been considered as elements of a criteria based function F).

The set of diagnostic parameters is to be specified from among the set of output parameters. On the basis of tests results and findings of research works whose aim was to confirm certain proposals concerning reduction of diagnostic information, it was found that to determine a set of diagnostic parameters for the machine state evaluation it is necessary to take into account [1]:

a) ability to represent the machine state changes during its operation;
b) some amount of information about the machine state;
c) appropriate variability of diagnostic parameters values during the machine operation and maintenance.

In most cases, identification of a set of diagnostic parameters from the set of output parameters $Y \subset Y_{wy}$ involves application of the minimum error criterion. Parameters which are characterized by a minimum diagnosis error are included here, as well as a procedure for selection of diagnostic parameters according to the minimum diagnosis error.

The essence of this method is to define the error of diagnosis D, that is, the 'coverage' area of function of parameter $y_j \in Y$ conditional probability density, defined by Serdakow [12.20] as dependence:

$$D = P\left(\frac{S_1}{y_j}\right) \cdot Q_1 + P\left(\frac{S_2}{y_j}\right) \cdot Q_2 , \tag{1}$$

whereas, the probability of type I error Q involving classification of a machine which is in usability state $S_0=S_1$ as being unusable $S_1= S_2$:

$$Q_1 = \int_{y_{gr}}^{+\infty} f\left(\frac{y_j}{S_1}\right) dy_j , \tag{2}$$

and error probability of type II error Q_2 involving classification of a machine being unusable S1= S2 as being in usability state $S^0=S_1$:

$$Q_2 = \int_{-\infty}^{y_{gr}} f\left(\frac{y_j}{S_2}\right) dy_j , \tag{3}$$

Next, there comes the choice of the best parameter $y^* \in Y$ through minimization of the diagnosis error.

$$y^* = \min_j \left(D_j\right) , \tag{4}$$

The choice of diagnostic parameters according to the presented method, is then reduced to:
1. Qualitative analysis of parameters involving [1,3]:
   a) investigation of significance of diagnostic parameters value changes for the machine technical state change,
   b) determination and estimation of boundary values y_{gr} according to Bayes minimum risk criterion with the assumption of type I and II errors value of costs:

2. Quantitative analysis which involves choosing parameters according to criteria that would be able to reflect the machine state changes during its operation and maintenance, provide adequate information on the machine state and variability of diagnostic parameters value changes during the machine operation. Appropriate methods accounting for these postulates are presented below:

Method of diagnostic parameter maximal relative change

This method involves a choice of a diagnostic parameter whose kj index is of the highest value. It accounts for the average speed of parameters change in time interval (Θ_1, Θ_b). It is defined according to dependence [2]:

$$k_j = \frac{b_j}{\sum_{j=1}^{m} b_j},$$

$$b_j = \frac{1}{K}\sum_{i=1}^{K} \frac{|\, y_j(\Theta_{i+1}) - y_j(\Theta_i)\,|}{(\Theta_{i+1} - \Theta_i)\,|\, y_j(\Theta_1) - y_{j,g}\,|}, \tag{5}$$

where:
K- population of elements in a time array in interval (Θ_1, Θ_b).

Method for correlation of diagnostic parameters values with the machine state

This method involves investigating correlation of diagnostic parameters values with the machine state $r_j = r(W, y_j)$ (possibly with operation time, $(r_j = r((\Theta, y_j))$ [2]:

$$r_j = \frac{\sum_{k=1}^{K} (\Theta_k - \overline{\Theta})(y_{j,k} - \overline{y_j})}{\sqrt{\sum_{k=1}^{K} (\Theta_k - \overline{\overline{\Theta}})^2 \sum_{k=1}^{K} (y_{j,k} - \overline{y_j})^2}}, \tag{6}$$

$$\overline{\Theta} = \frac{1}{K}\sum_{k=1}^{K} \Theta_k, \quad \overline{y_j} = \frac{1}{K}\sum_{k=1}^{K} y_{j,k}, \tag{7}$$

where:
$r_j = r(S, y_j)$; j = 1,..., m – correlation coefficient between variables S and y_j,
$r_{jn} = r(y_j, y_n)$; j,n = 1,..., m; j≠n – correlation coefficient between variables y_j and y_n.

In case there is no data from set S, it is being replaced with the machine operation time, with the assumption that determination of procedures for evaluation of the machine state is performed within the interval of normal wear.

Then, $r_j = r(\Theta, y_j)$; j=1,..., m; k=1,...,K (r_j – coefficient of correlation between variables $\Theta_k \in (\Theta_1, \Theta_b)$ (Θ_k – machine operation and maintenance i y_j)**.**

Method of diagnostic parameter maximum information capacity

The method involves choosing a parameter providing the largest amount of information about the machine state. A diagnostic parameter is the more valuable for evaluation of a machine state change the more correlated it is with the state and the weaker correlated it is with other diagnostic parameters.

This dependence is presented in the form of an index of diagnostic parameter hj information capacity which is a modification of an index referring to a set of variables accounting for econometric model [2]:

$$h_{\mathrm{j}} = \frac{r_j^2}{1 + \sum_{j,n=1, j\neq n}^{m} \left| r_{j,n} \right|}, \tag{8}$$

$$r_{\mathrm{j,n}} = \frac{\sum_{k=1}^{K} (y_{j,k} - \overline{y_j})(y_{n,k} - \overline{y_n})}{\sqrt{\sum_{k=1}^{K} (y_{j,k} - \overline{y_j})^2 \sum_{k=1}^{K} (y_{n,k} - \overline{y_n})^2}}, \tag{9}$$

$$\overline{y_j} = \frac{1}{K} \sum_{k=1}^{K} y_{j,k} \; ; \quad \overline{y_n} = \frac{1}{K} \sum_{k=1}^{K} y_{n,k}, \tag{10}$$

where:

$r_j = r(S, y_j)$; $j = 1,..., m$ – coefficient of correlation between variables S and y_j,

$r_{jn} = r(y_j, y_n)$; $j,n = 1,..., m$; $j \neq n$ – coefficient of correlation between variables y_j and y_n.

When there is no data from set S it is replaced with the machine operation and maintenance time, with the assumption that determination of the procedures for evaluation of a machine state is performed within the time of its normal wear.

An advantage of the above presented methods is the fact that they allow to choose one-element and multi-element sets of diagnostic parameters. A one-element set refers to the case when a machine is decomposed into subassemblies and it is necessary to choose one diagnostic parameter. A multi-element set can be obtained when the presented procedures provide less strict constraints involving acceptance of those parameters whose index values are higher (lower) than, the accepted for the method, high (low) positive numbers.

The above presented discussion, formulated in the form of an algorithm for determination of a set of diagnostic parameters includes the following stages [1]:

1. Data acquisition:
   a) set of diagnostic parameters values in the machine operation and maintenance time, $\{y_j(\Theta_k)\}$, obtained during performance of a passive-active experiment, where $\Theta_k \in (\Theta_1, \Theta_b)$;
   b) set of diagnostic parameters values : $\{y_j(\Theta_1)\}$ – nominal values, $\{y_{jg}\}$- boundary values, j=1, …, m;
   c) set of the machine states $\{\Theta_k$: $\{s_i\}$, k=1, …, K; i=1,…, I$\}$defined during passive-active experiment, where $\Theta_k \in (\Theta_1, \Theta_b)$;
   d) cost of diagnostic parameters $c(y_j) = const$.

2. Optimization of s set of diagnostic parameter values (only in case of high quantity of set Y, np. m > 10). The set of diagnostic parameters is determined by means of:

a) diagnostic parameters value correlation with the machine state (with operation and maintenance time , $r_j = r(S, y_j)$, ($r_j = r((\Theta, y_j)$));

b) method of amount of diagnostic parameters information about the machine state h_j.

In order to choose a set of diagnostic parameters the value of weights is used [3]:

a) standardized calculation weights w_{1j} [2]:

$$w_{1j} = \frac{w_j}{\sum_{j=1}^{m} w_j}, \tag{11}$$

$$w_j = \frac{1}{d_j}, \; d_j = \sqrt{(1-r_j^*)^2 + (1-h_j^*)^2}, \tag{12}$$

$$r_j^* = \frac{r_j}{\max r_j}, \; h_j^* = \frac{h_j}{\max h_j}, \tag{13}$$

max(w_{1j}) was accepted as a criterion for selection of a diagnostic parameter (diagnostic parameters) and the choice of diagnostic parameters was performed according to this criterion.

3.Description and optimization possibilities of OPTIMUS

OPTIMUS is a one-environment tool which is used to perform an automatic visualization of the problem and provides the possibility of critical approach to the project dynamics. OPTIMUS Noesus Solutions software can find an optimal point in the space of the created simulation design with the use of a combination of gradient methods, through a fast analysis – or genetic algorithms. In this way it is possible to automatize and control the whole process, eliminating errors which are inseparably connected with the design process.

OPTIMUS refers to different optimization methods, both the old and the newest ones. Then, it is possible to work faster and more efficiently without the necessity of restarting work with new tools and data. Software provides simple solutions to complex problems. Optimus differs from the available optimization tools as it is open to collaboration with any product of CAE software [4].

Operation of OPIMUS optimization program involves simulation with the use of data which put into the operating space in the form of an input file and obtaining output results through an analysis of codes by means of data analysis. The software enables observation and modification of each element starting with input data, throughout each indirect code, analyses, conditions up to the output data, that is, the intended final effect. It is possible when a user indicates a random graphic point in an interactive graphic grid of OPTIMUS operating space.

When the boundaries of parametric changes are defined, Optimus automatically generates, analyzes examines and follows alternative solutions – it starts a series of ‘experiments’ in a ‘virtual test laboratory’ through a systematic assessment of answers for each virtual object.

Distinctive features of OPTIMUS software [4]:

- possibility of using CAE codes of all engineering disciplines,
- creation of ‘virtual experiments’ on the basis of DOE techniques,
- methods: Taguchiego aries, Placketta - Burmana, Box- Behnkena, Taylora multinominal,
- vast Modeling of the response surface,
- powerful post-processing through modeling of the response surface,
- stochastic interpolations (kriging, RBF),
- optimization of numerical procedures,

- self-adaptive and differentia evolution of genetic algorithms,
- dynamic presentation of the design space,
- assessment of reliability and optimization,
- possiblity of using parallel computer networks.

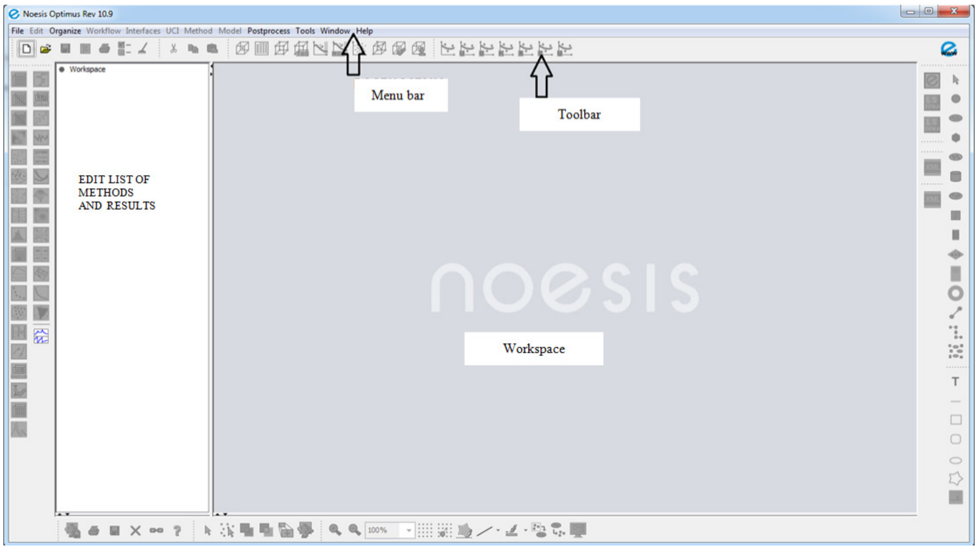

Fig.2. starting window of Optimus software [own research]

The software provides the possibility of creating simulation designs. While doing this it is necessary to indicate information that will flow between different processed objects. The elements to be accepted include:

- three project inputs,
- two simulation programs,
- one input file,
- two output files,
- four project outputs,
- three output vectors.

More significant stages in OPTIMUS software include:

- creation of connections between appropriate groups (elements):
- determination of characteristics of an input file for simulation design
- introduction of appropriate commands necessary to perform a simulation,
- determination of a design constraints
- performance o calculations using methods available in the program (fig.5),
- visualization of results through creation of charts (fig.6).
- visualization of results by creation of diagrams (fig.6).

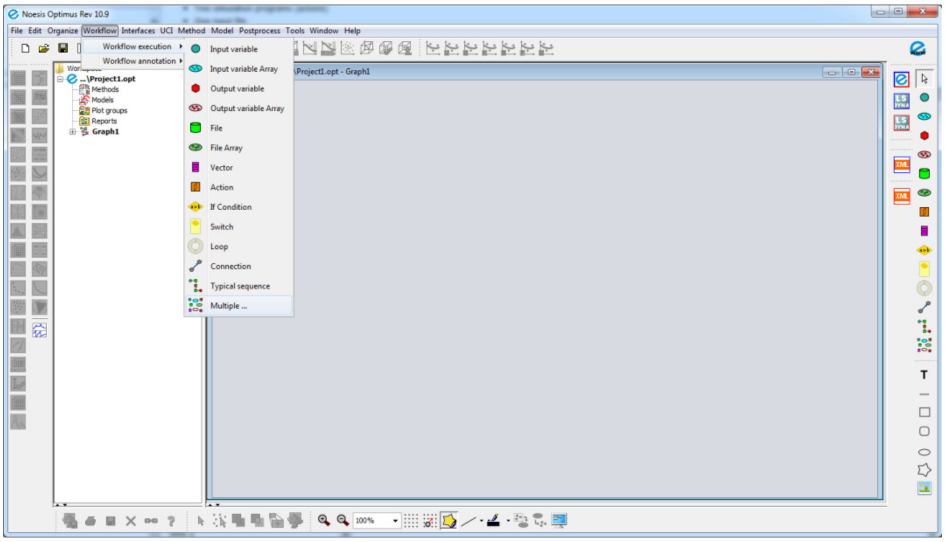

Fig.3. Specification of first parameters [own source]

Input data introduced to the program can be appropriately grouped.

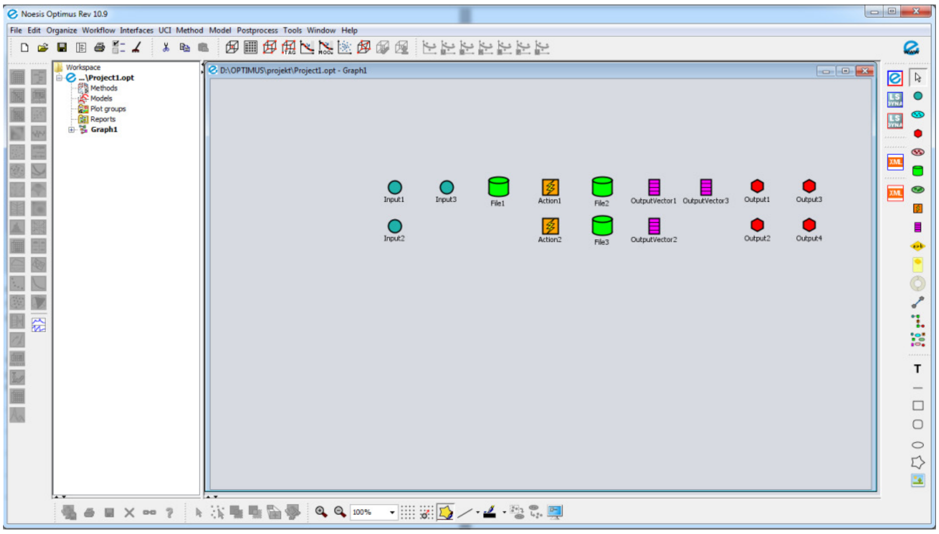

Fig.4. Grouping of input data [own source]

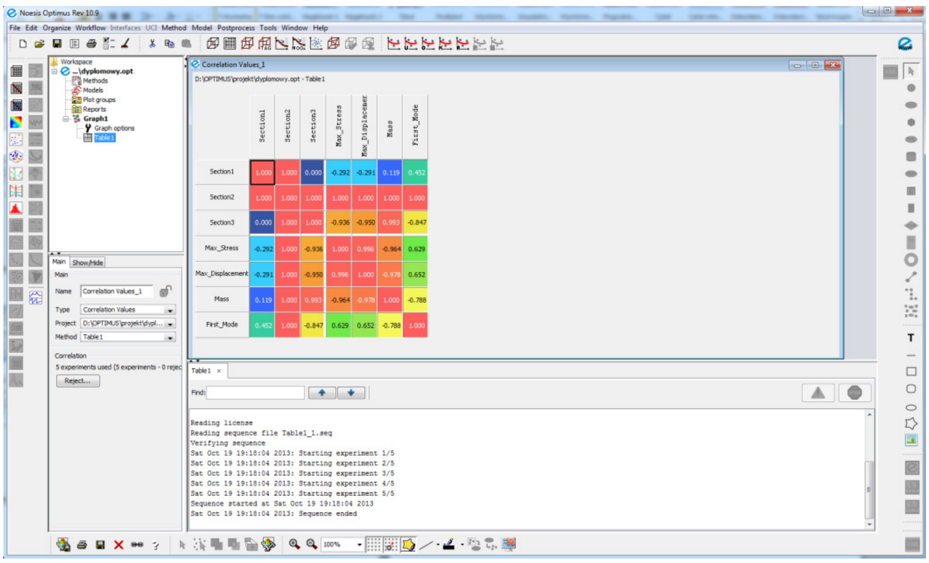

Fig.5. Graphic presentation of correlation method] own source

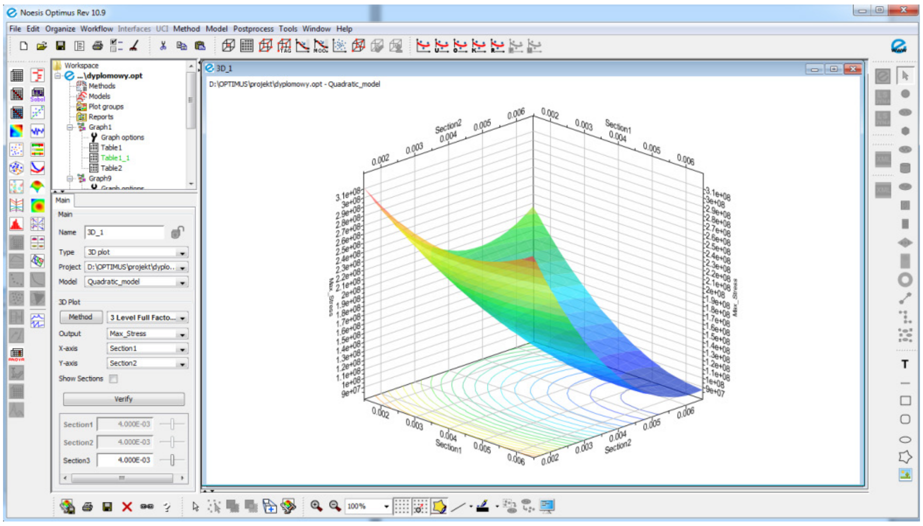

Fig.6. 3D chart of data [own source]

Advantages of OPTIMUS software application:

- possibility to perform simulation in a unique interface,
- use of many simulation tools in one environment,
- fast configuration of a model in a working space,
- direct interface to a world class software CAD/CAE,
- analysis and database parametrization stencils,
- possibility to perform simultaneous parallel calculations on an infinite number of processors,
- performance of a series of simulations inside a non-homogenous simulation environment,
- reduction of calculation time in order to obtain maximal efficiency
- automatic simulation using many processors without intervention of a user.

4. Conclusions

A system for evaluation of a machine state should meet requirements such as:

a) functions to be performed (determination of the next date of servicing), providing genesis of diagnostic parameters values (determination of the cause of a machine inability to perform its functions in the time of its operation)

b) properties: structural, functional, reliability and safety, economic and others.)

Multiple criteria optimization is the most genuine and natural concept of decision making, hence it seems to be necessary to use its tools including information technologies.

Optimization software OPTIMUS allows to perform different types of optimizations in a very short time. This program is the next step forward in the field of the most complex tools to be used for the process integration and optimization of design, with operation dedicated for applications in Qualitative Techniques.

The main advantages of the software:

- systematic approach to optimization of the design process and simulation definition as well as work flow automation,
- formalization of the design assessment process,
- improvement of a product efficiency through automation of assessment of alternative solutions of the design,
- increasing work efficiency,

- response to the real engineering challenge, which design is the best to meet the specified goals.

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