GDAŃSK UNIVERSITY OF TECHNOLOGY

Journal of POLISH CIMAC

Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

VIRTUAL TECHNIQUES IN THE OPTIMIZATION OF THE RECOGNIZING THE STATE OF MACHINES

Joanna Wilczarska, Tomasz Kałaczyński, Marcin Łukasiewicz, Ewa Kuliś, Andrzej Sadowski

University of Technology and Sciences in Bydgoszcz
ul. Ks. Kordeckiego 20, 85-225 Bydgoszcz
tel.: +48 52 3408283, fax: +48 52 3408286
e-mail: asiulazol@utp.edu.pl

Abstract

The system of recognizing the state of machines should enable: control of the state, forecasting the state in case of the applicability of the machine, location of damage in case of the unfitness of the machine, genesis of state and describing the probable reason for the appearance of located damage. In the recognition process of the state of the machine a set of diagnostic parameters is being used. He is being favored from the set of output parameters. With the tool an optimization of the set of diagnostic parameters is of help in a process of selection of parameters.

At the work an effect of computer programs which enables the realization of the optimization methodology of the recognition process of the state of machines was described. The program consists of five modules: canvassing of data, optimization of diagnostic parameters, evaluation of the state, forecasting the state, genesis of state.

Keywords: *optimization, recognizing the state of machines, diagnostic parameter*

1. Introduction

The system of identifying the state should enable machines:

- control of the state;
- forecasting the state in case of the applicability of the machine what in practice is being imported for establishing a date of his next diagnosing;
- location of damage in case of the unfitness of the machine;
- genesis of state and describing the probable reason for the appearance of located damage.

Fundamental requirements which a system of identifying the state of the machine should fulfil it:

a) reliability
b) high speed operation;
c) standardization;
d) cost-effectiveness (low manufacture costs and exploitation).

The system of identifying the state of the machine moreover should be characterized:

- ✓ with simple, possibly optimum algorithm of functioning;
- ✓ with the versatility, i.e. possibilities of identifying the state of machines of different types;
- ✓ with possibilities of identifying the state of machines about small and large degree of the complexity;
- ✓ with automatic generating diagnoses;
- ✓ with the explicitness and the legibility of presenting diagnoses;

- ✓ with simplicity of supporting.

The system of identifying the state should provide machines so that the diagnostician interferes in his action but where:

a) changes of the object of identifying the state;
b) amendment to the algorithm of diagnosing, forecasting and genesis of state;
c) of removing detected automatically damage to the diagnostic device.

The system of identifying the state of the machine should accomplish the requirement concerning the quality of products according to applicable standards [2].

The system specification of identifying the state of the machine should grasp the following issues from the area of the design, the production and the exploitation of machines:

- functional properties;
- of design features
- conditions of using and supporting;
- potential service centers;
- economic calculation.

2. Optimization of the process of examining the state of machines

Set of diagnostic parameters, exploited in the recognition process of the state of machines, stands out from the set of output parameters. Determination of a set of diagnostic parameters in the genesis of engineering should take into account [1]:

a) ability to copy transitions of the machine during the exploitation;
b) quantity of the information about the state of the machine;
c) right changeability of the value of diagnostic parameters during the exploitation of a machine.

Diagnostic parameters $y_j \in Y$ are with changeable sizes during $Y=Y(\Theta)$, because depend on the course of extorting processes grow old and wear and tear..

The set of diagnostic parameters Y is standing out from the set of output parameters Y_{WY} which are describing the course of initial processes (working and associated processes), dependent on the technical condition of the object:

$$Y_{wy} = Y_{wy}(S, \Theta) \tag{1}$$

To the purpose of more thorough distinguishing $Y \subset Y_{wy}$ sets a criterion of the minimal mistake of the diagnosis is most often applicable. The parameters which are characterized by the minimal mistake of the diagnosis and a procedure of choice of diagnostic parameters are distinguished according to the minimal mistake of the diagnosis.

The essence of this method is to determine the diagnosis error of D, i.e. the area of "covering" the conditional probability density function parameter $y_j \in Y$ defined by Serdakow [2] relationship:

$$D = P\left(\frac{S_1}{y_j}\right) \cdot Q_1 + P\left(\frac{S_2}{y_j}\right) \cdot Q_2 , \tag{2}$$

whereas probability of the Q_1 type I error consisting in ranking the machine being in the state of the applicability $S_0 = S_1$ to the condition of the unfitness $S_1 = S_2$:

$$Q_1 = \int_{y_{gr}}^{+\infty} f\left(\frac{y_j}{S_1}\right) dy_j \tag{3}$$

and probability of the Q_2 type II error consisting in ranking the machine being in the state of the unfitness $S_1 = S_2$ to the state of the applicability $S_0 = S_1$:

$$Q_2 = \int_{-\infty}^{y_{gr}} f\left(\frac{y_j}{S_2}\right) dy_j \tag{4}$$

Next choice "best" $y^* \in Y$ parameter through the minimization of the diagnosis error:

$$y^* = \min_j\left(D_j\right) \tag{5}$$

Choice of diagnostic parameters according to the presented method is being brought about then to:

1. Of qualitative analysis of parameters, relying on [1]:
   a) for studying the gravity of changes of the value of diagnostic parameters at the change of the technical condition of the machine;
   b) for appointing and estimating limit values y_{gr} according to the criterion of the smallest Bayes risk at assuming the cost value of mistakes and the II kind;
2. Of quantitative analysis which relies on choice of parameters under the angle of criteria connected ability to copy transitions of the machine during the use, quantities of the information about the state of the machine and the changeability of the value of diagnostic parameters in the time of the exploitation of a machine.

Relevant algorithms considering these demands were moved below as methods.

- **Method of the maximum relative variation of the diagnostic parameter**

In this method this diagnostic parameter which has a considerable value of the indicator is going k_j. He is taking into account the average speed of the change of parameters in the time interval (Θ_1, Θ_b). He is being described according to the relation:

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

$$b_j = \frac{1}{K}\sum_{i=1}^{K} \frac{\left| y_j(\Theta_{i+1}) - y_j(\Theta_i) \right|}{(\Theta_{i+1} - \Theta_i)\left| y_j(\Theta_1) - y_{j,g} \right|}, \tag{6}$$

where: K - number of elements of the time series in the period (Θ_1, Θ_b).

- **Method of correlation of the value of diagnostic parameters with the state of the machine**

The method consists in examining correlation of the value of diagnostic parameters with the state of the machine $r_j = r(W, y_j)$ (if necessary with the exploitation time, $((r_j = r((\Theta, y_j))$:

$$r_j = \frac{\sum_{k=1}^{K}(\Theta_k - \overline{\Theta})(y_{j,k} - \overline{y_j})}{\sqrt{\sum_{k=1}^{K}(\Theta_k - \overline{\Theta})^2 \sum_{k=1}^{K}(y_{j,k} - \overline{y_j})^2}} \tag{7}$$

$$\overline{\Theta} = \frac{1}{K}\sum_{k=1}^{K}\Theta_k, \quad \overline{y_j} = \frac{1}{K}\sum_{k=1}^{K} y_{j,k}, \tag{8}$$

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

- **Method of the maximum information capacity of the diagnostic parameter**

Nature of the method consists in choice of the parameter delivering a lot to information about the state of the machine. The diagnostic parameter has an all the greater significance in determining the transition, they more strongly are feeling with him correlated and for them more poorly is correlated with other diagnostic parameters.

This relation is being presented in the form of the rate of the information capacity of the diagnostic hj parameter which is with alteration of the indicator referring to the harvest of exogenous variables econometric model:

$$h_{\mathrm{j}} = \frac{r_j^2}{1 + \sum_{j,n=1, j\neq n}^{m} \left| r_{j,n} \right|} \tag{9}$$

$$r_{\mathrm{j,n}} = \frac{\sum_{k=1}^{K} (y_{j,k} - \overline{y_j})(y_{n,k} - \overline{y_n})}{\sqrt{\sum_{k=1}^{K} (y_{j,k} - \overline{y_j})^2 \sum_{k=1}^{K} (y_{n,k} - \overline{y_n})^2}} \tag{10}$$

$$\overline{y_j} = \frac{1}{K} \sum_{k=1}^{K} y_{j,k} \;\; ; \quad \overline{y_n} = \frac{1}{K} \sum_{k=1}^{K} y_{n,k} \;\; , \tag{11}$$

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

In case of the no data from the set they are being replaced with the Sec., on the assumption that fixing procedures of recognizing of the state the machine is carried out in the period of the normal wear and tear, sometimes of the operation of a machine.

To the purpose of choice of the set of diagnostic parameters values of scales are being exploited [5]:

a) standardized computational scales w_{1j}:

$$w_{1\mathrm{j}} = \frac{w_j}{\sum_{j=1}^{m} w_j} \tag{12}$$

$$w_{\mathrm{j}} = \frac{1}{d_j}, \; d_{\mathrm{j}} = \sqrt{(1 - r_j^*)^2 + (1 - h_j^*)^2} \tag{13}$$

$$r_j^* = \frac{r_j}{\max r_j}, \; h_j^* = \frac{h_j}{\max h_j} \;\; , \tag{14}$$

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

4. Computer program to optimize the process of exploitation of the machines

The program called "Optimization" methodology enables the optimization of the process of recognition of the machines. The scope of capabilities includes the process of testing procedures for recognition of machine condition [4]:

a) examining the set of diagnostic parameters in the aspect of appointing an optimal set of diagnostic parameters for the evaluation of the state of the machine in the moment of the examination, of forecasting and genesis values of diagnostic parameters and on their base forecasting and genesis of state of the machine;
b) examining the quality of the evaluation of the technical condition of the machine in the aspect:
   - f appointing the motherland of the relation: technical condition - exploitation time - value of the diagnostic parameter,
   - of appointing the diagnostic test of the control of the state and the location of damage to the machine;
c) examining the quality of forecasting in the aspect:
   - of fixing the forecasting method of the value of the diagnostic parameter according to the function of the forecast error,
   - of determining the method of setting the next date of supporting according to the function of forecast error,
   - examination of the impact of the value of the horizon of the forecast for the forecast error,
   - examination of the impact of the number of the set of diagnostic parameters for the forecast error;
d) examining the quality genesis in the aspect:
   - of fixing the method genesis values of the diagnostic parameter according to the function of the genesis error,
   - examination of the impact of the number of the set of diagnostic parameters for the genesis error.

The program consists of five modules (fig. 1):

1. **Of canvassing** (leading, edition, data record, import from the csv file). The module of the canvassing consists of five bookmarks (fig. 2):
   a) group of machines,
   b) list of states,
   c) list of parameters,
   d) list of objects,
   e) list of measurements.

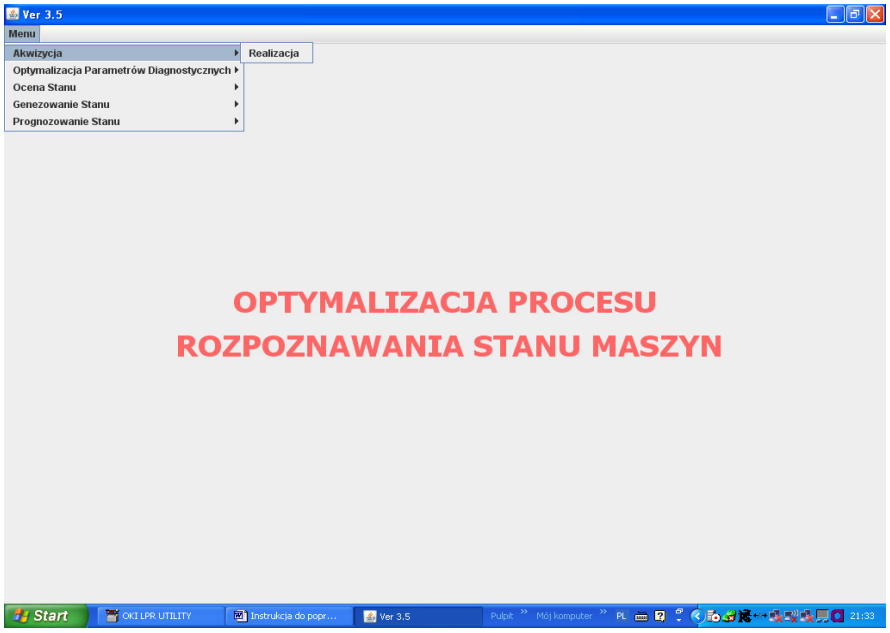
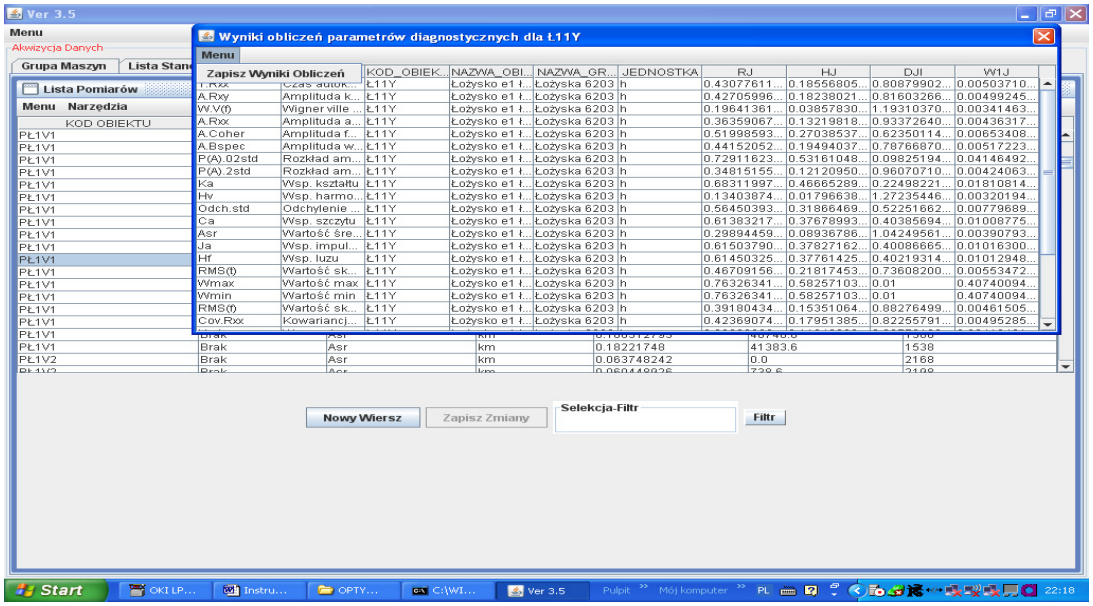


Fig. 1. View of the elaborated menu of the main programme [4]

2. In the module the **Optimization of Diagnostic Parameters** is taking place calculating the value of the criterial function and of scales of diagnostic parameters on the base given entrance for the chosen object with the possibility of the record to a text file (fig. 2).



Rys.2. Module the Optimization of Diagnostic Parameters [4]

3. In the module the **Evaluation of the State** is taking place (fig. 3):
   a) creating the diagnostic motherland based on the input;
   b) possibility of the edition of the diagnostic motherland;
   c) record to a text file.

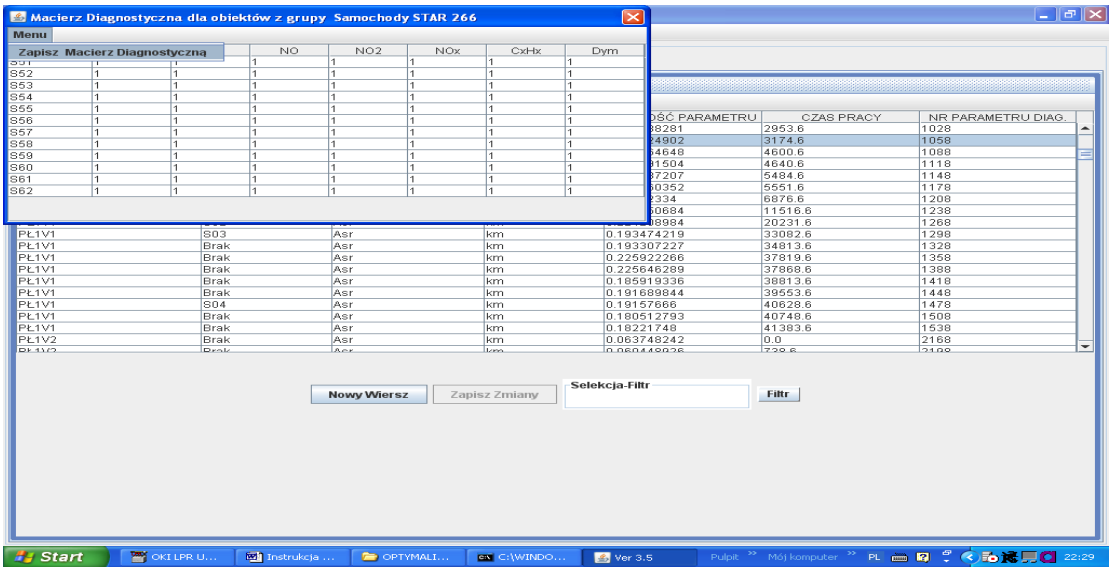


Fig. 3. Diagnostic motherland created in the module Evaluation of the State for the chosen group of machines [4]

4. In the module **Forecasting the State** is taking place (fig. 4):
   a) appointing the forecast value of the diagnostic parameter and the error of the forecast,
   b) of setting the date of diagnosing and operating a machine,
   c) examination of the impact of exploitation factors (number of parameters, number of the time series, value of the horizon of the forecast) to the forecast of the state,
   d) the visualization and the notation of analyzed models of forecasting the object for select parameters chosen in the form of the picture and the report.

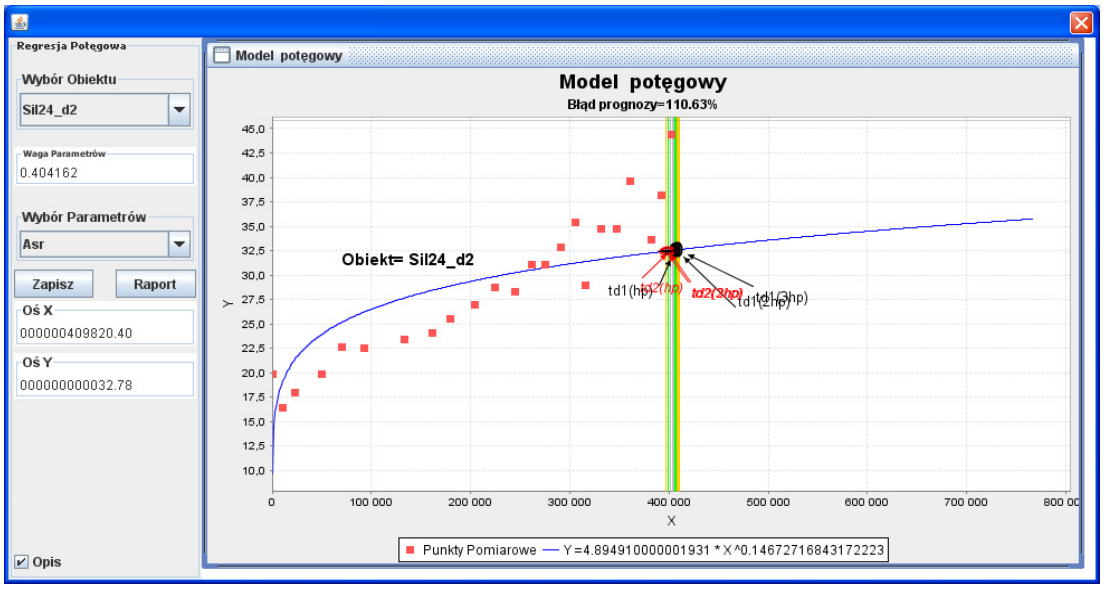


Fig. 4. Function of the exponential regression from the module Forecasting the State [4]

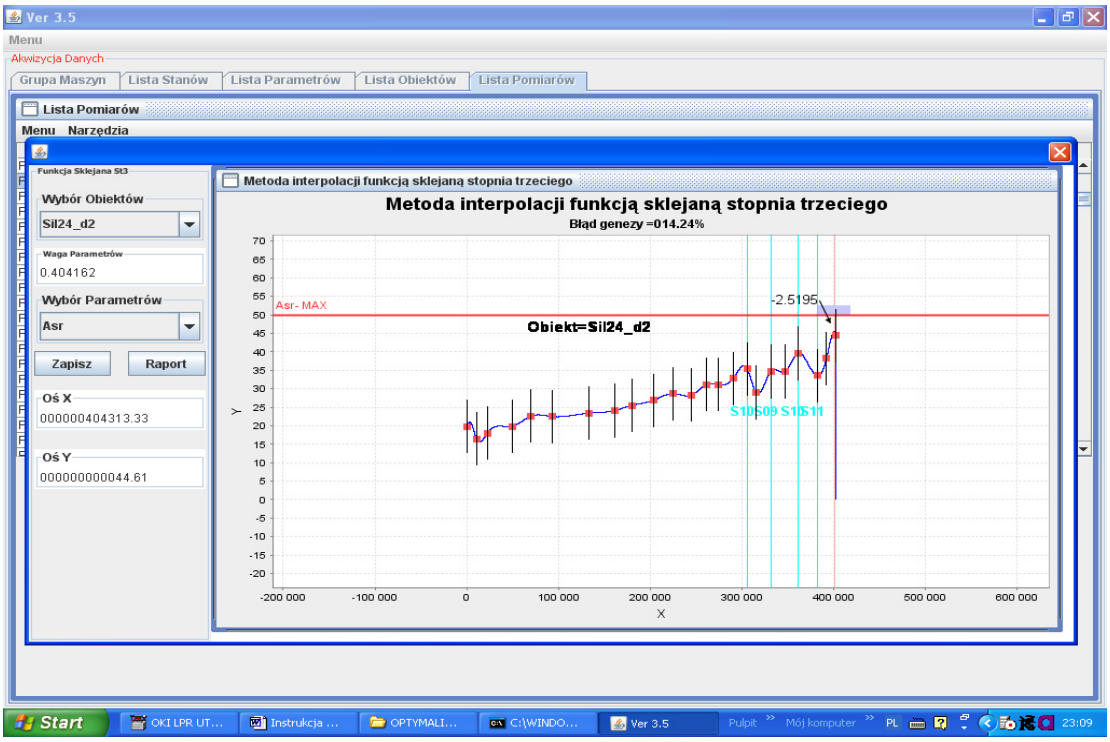


Fig. 5. Method of the interpolation with function glued together of the third step of the module Genesis of the State [4]

5. In the module **Genesis of the State** he is taking place (fig. 5):
   a) appointing the genesis value of the diagnostic parameter and the error of the genesis;
   b) appointing the minimum distance of the genesis value of diagnostic parameter from his threshold;
   c) examination of the impact of exploitation factors (number of parameters, number of the time series) to the genesis of the state;
   d) the visualization and the notation of the function of the approximation or the interpolation of the object for select parameters chosen in the form of the picture and the report.

Conclusions

The recognition process of the state enables machines:

- determining the technical condition of the machine in the current time on the basis of the results of diagnostic investigations. It enables the control of the state and the location of damage in case of the condition of the unfitness of the machine.
- predicting the state of the machine in the future based on the incomplete history of results of diagnostic research. It enables the work to judge the time of reliable using the machine or the value carried out by her in the future.
- determining the state of the machine in the past tense based on the incomplete history of results of diagnostic research what estimating the state of the machine in the past enables.

In the destination of appointing the set of diagnostic parameters, used in the optimization process of the recognition process of the state, a method is proposed correlation of the value of the diagnostic parameter with the state and the exploitation time of a machine and the method of the information capacity of the parameter diagnostic.

Computer programs drawn up aren't a commercial product on account of the specificity and functional redundancy concerning aspects of forecasting, genesis whether of inspections of mathematical models. He can however constitute a point of departure for the creation of the commercial product.

Literature

[1] Będkowski L., *Elementy diagnostyki technicznej*, WAT, Warszawa 1991.

[2] Hohmann L., *Journey of the Software Professional: A Sociology of Software Development. Englewood Cliffs*. NJ: Prentice Hall. 2000.

[3] Tylicki H., Różycki J., Żółtowska J., *Badanie jakości zbioru sygnałów diagnostycznych*. *Diagnostyka*, Olsztyn 2004, str.57-62, vol.32.

[4] Wilczarska J., *Genezowanie stanu maszyn w procesie eksploatacji*. Rozprawa doktorska. Bydgoszcz 2008.

[5] Żółtowski B., Cempel C., *Inżynieria diagnostyki maszyn*. Polskie Towarzystwo Diagnostyki Technicznej, Instytut Technologii Eksploatacji, Warszawa 2004.