Journal of POLISH CIMAC

Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

PROCEDURE OF CONSTRUCTING AND EVALUATING LINEAR DIAGNOSTIC MODELS OF COMPLEX OBJECTS

Bogdan ŻÓŁTOWSKI

Uniwersytet Technologiczno – Przyrodniczy
ul. S.Kaliskiego 7, 85-763 Bydgoszcz
e-mail: bogzol@utp.edu.pl

Abstract

In this work presented are chosen problems of machines' technical state diagnosis with the use of identification and technical diagnostics methods. Relations between methods of dynamic state evaluation and methods of technical state evaluation were indicated. Example modal analysis results illustrate the complexity of projecting dynamic state researches into diagnostic researches of machine state evaluation.

Key words: *technical diagnostics, identification, modeling, modal analysis.*

1. INTRODUCTION

Destruction processes of technical systems force the need to supervise changes of their technical state. It is possible with the use of technical diagnostics methods.

Methods and means of modern technical diagnostics are a tool of machine state diagnosis, which is the basis of decisions made at each stage of their existence.

Many previous works of the author [1,2,3,4,5] clearly indicate connections between machine dynamics and technical diagnostics, especially vibration diagnostics. The bases of identification, modeling and concluding fully convince towards the dominating role of vibrations in machine state identification [6,7,8,9].

Properly planned and realized experiment is the base to obtain diagnostically sensitive signals which processed will determine state diagnosis procedures. The processing includes: creation of numerous signal measures in time domain, frequencies and amplitudes, selection and reduction of the number of signal measures, creation and analysis of effectiveness of cause-and-effect models, as well as evaluation of the righteousness of made diagnostic decisions.

The realization of these tasks is possible only through broad support from information technology, which in this work is presented in the form of SIBI programs.

Practical applications of the presented ideas has been verified in researches on complex objects exploited in difficult climate conditions.

2. DYNAMICS AND DIAGNOSTICS

Into quality measures of machine's technical state, i.e. its dynamics, included is the level of vibration amplitudes, as well of the machines as the lot, and also of relative vibrations of separate elements and parts. Overall vibrations of the machine can be perceived as an external symptom while they are responsible for the level of interferences emitted into the environment. Relative vibrations of separate elements, however, influence mainly the state of internal forces in the machine, i.e. at its level of dynamic stress amplitudes.

Identification can concern both the construction of models and the reconstruction of the examined model state, which leads straight to the problem of technical diagnostics.

The process of diagnostic identification includes:
* modeling (symptom or structural),
* identification experiment (simulation and/or real),
* estimation of diagnostic parameters (state features or symptoms),
* diagnostic concluding.

The specificity of diagnostic identification tasks is different from general identification in the way that it includes a number of additional elements enhancing this process. These are:
- constructing models of diagnostic signals generation,
- choosing features of object structure state and diagnostic symptoms,
- modeling cause-and-effect relations,
- evaluating the accuracy of choosing variables for the model,
- determining boundary values of the symptoms,
- classifying the states and determining diagnosis periodicity.

Methods of identification can be divided concerning: the kind of identified model, the kind of experiment, identification criterion applied, as well as estimation procedure applied. In general these are: methods of analysis, time, frequency, correlation, regression, factor analysis, as well as iteration methods described in works of many authors [2,4,6,5,8].

For simple objects, a good tool to evaluate their changeable dynamic state are methods of simple identification which use amplitude-frequency spectrum. Searching rezonans frequency and amplitude value in this frequency with the use of tests (impulse, harmonic and random) are relatively well masterem in research techniques of our enterprises [2,5].

Another way of describing and analyzing the dynamic state of machines is a modal analysis used as a theoretical, experimental and exploitation method. It uses frequencies of own vibrations, values of suppression and forms of vibrations to describe the changing machine state, and it is used to improve the finished elements method. The presented procedures are based on the knowledge of the system model, and the conclusions drawn from the actions on the models depend on their quality. Depending on the aim of the performed dynamic analysis of the object, different requirements are set for the constructed models, and their evaluation is conducted with different experimental methods.

3. DESCRIPTION OF OBJECT STATE CHANGES

The dynamic state of the object can be, in the easiest case, described with a model of 1 degree of freedom – Fig.1. A conventional description of this model are known relations (1-4) indicating that vibrations well reflect the state of the machine. A description of this model can be achieved within m, k, c categories, or through a, v, x researches.

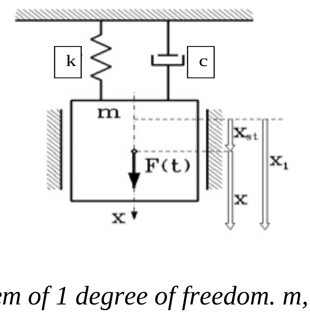


Fig.1. Model of a system of 1 degree of freedom. m, k, c = vibration process (a, v, x)

$$m\ddot{x} + c\dot{x} + kx = F(t) \tag{1}$$

$$x = A\sin(\varpi \cdot t + \phi) \tag{2}$$

$$v = \frac{dx}{dt} = A\varpi\cos(\varpi t + \varphi) \tag{3}$$

$$a = \frac{d^2x}{dt^2} = \frac{dV}{dt} = -A\varpi^2\sin(\varpi t + \varphi) \tag{4}$$

Identification of his model (1) from the experimental side is the a, v, x measurements for different time moments, which reflects the changes of the object state and is widely applied in vibration diagnostics. The solution of the task in the m, k, c, categories, however, requires a number of solution conversion of the equation (1) for determining:

$$c_{kr} = 2m\varpi \qquad c_{kr} = 4\Pi mf$$
$$k = m \cdot \varpi^2 \qquad k = 4\Pi^2 mf^2 \tag{5}$$

Determining the value (5) requires realizing identification experiment from which the frequency f or frequency ω can be determined. Here is useful the simple identification or modal analysis directly giving the values of own frequencies ω from the stabilization diagram – Fig.2.

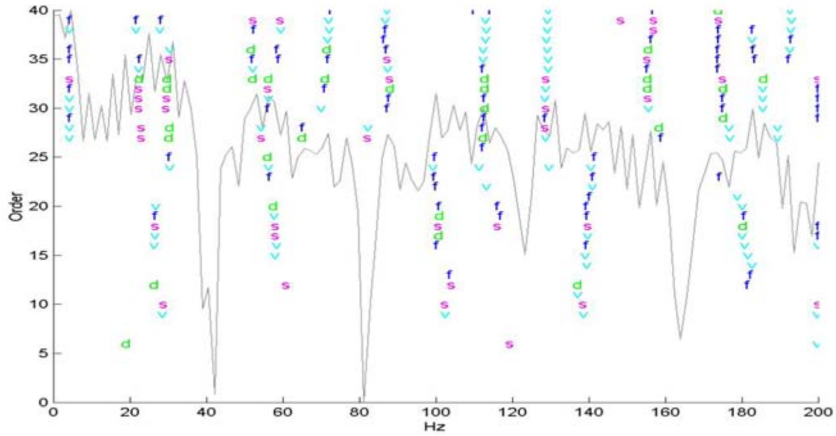


Fig.2. Stabilization diagram for ω determination

The problem becomes more complicated for models of many degrees of freedom (more than 3). Here also the problem of object state identification can be solved from the measurement side (a, v, x), Chile from the side of determining m, k, c own problem needs to be solved.

$$\left(K - \omega^2 M\right) \cdot q_0 = 0 \tag{6}$$

Equation (6) presents a linear system of homogeneous algebraic equations:

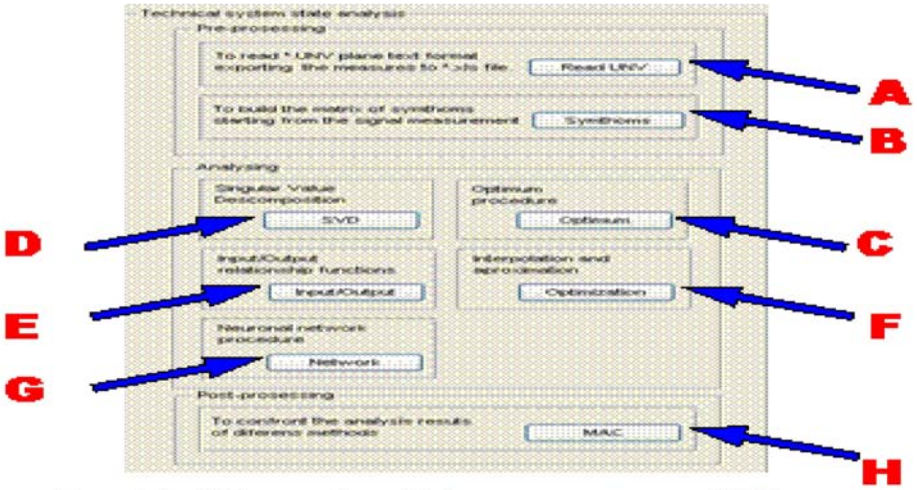
$$\begin{aligned}
&\left(k_{11} - \omega^2 m_{11}\right)q_1 + \left(k_{12} - \omega^2 m_{12}\right)q_2 + \cdots + \left(k_{1n} - \omega^2 m_{1n}\right)q_n = 0 \\
&\left(k_{21} - \omega^2 m_{21}\right)q_1 + \left(k_{22} - \omega^2 m_{22}\right)q_2 + \cdots + \left(k_{2n} - \omega^2 m_{2n}\right)q_n = 0 \\
&\qquad \ldots\ldots \quad \ldots\ldots \quad \ldots\ldots \quad \ldots\ldots \quad \ldots\ldots \\
&\left(k_{41} - \omega^2 m_{41}\right)q_1 + \left(k_{42} - \omega^2 m_{42}\right)q_2 + \cdots + \left(k_{nn} - \omega^2 m_{nn}\right)q_n = 0
\end{aligned} \tag{7}$$

A solution for $q \neq 0$ exists when the main matrix determinant $\left(K - \omega^2 M\right) = 0$, i.e. $\det\left(K - \omega^2 M\right) = 0$. Solving the system of equations (7) own values can be determined, and from them the frequencies of own vibrations, indispensable for the object identification ($\lambda = \omega^2 = \frac{k}{m}$).

4. IDENTIFICATION RESEARCHES SOFTWARE (SIBI)

More and more frequently conducted identification researches of machine dynamic state, used for the evaluation of the state changes, fault development and location of the occurred state causes, were the basis for creating a specialized software system. It allows acquiring and processing measurement data, creating many measures of diagnostic signals, examining their diagnostic sensitivity, statistic processing and diagnostic concluding. The program was named Information System of Identification Researches (System Informatyczny Badań Identyfikacyjnych – SIBI).

The structure of the program is a module construction which includes the following modules (Fig.3.):



Rys. 4.1. Główne okno dialogowe programu SIBI

Fig.3. Main dialog box of SIBI program

A. **READ UNV** module which allows processing data from **UNV** format into **XLS** format.

B. **SYMPTOMS** module which allows defining, determining and creating matrix of many measures of vibration processes.

Modules A and B are part of software responsible for acquiring and processing vibration processes in order to acquire observation matrix of vibration estimators.

C. **OPTIMUM** module uses the method of ideal point for individual evaluation of the sensitivity of measured symptoms of vibration processes.

D. **SVD** module used for determining generalized damage measures, and for the evaluation of damage development. Using the SVD method allows a multidimensional description of the state of the examined object.

E. **INPUT/OUTPUT** module used for the analysis of similarities between vibration processes, and for determining different exploitation measures of the examined object.

F. **OPTIMIZATION** module used for creating models and data in genesis (with approximation and interpolation methods), diagnosis and prognosis of object states.

G. **NETWORK** module using neuron nets for state classification on the basis of obtained results in the form of time rows.

C, D, E, F, G modules are elements of 2 parts of the software allowing the performance of statistic concluding and cause-and-effect relations, as well as visualization of the obtained results.

5. CAUSE-AND-EFFECT MODELING

Many state measures acquired in experiments requires the reduction of over measurement, which is possible with the use of OPTIMUM procedure (statistic evaluation of separate measures) or SVD (for the multidimensional approach). Optimized set of symptoms is the basis of constructing cause-and-effect, most often regressive, multidimensional models (Fig.4).

$$y = -2{,}68061 w1 - 0{,}54083\, row1 - 0{,}49318\, x1 + 2{,}01273\, w2 + 0{,}35480\, row2 + 2{,}26940\, x2 - 0{,}02717\, H(f) + 0{,}06833\, H(f)L + 0{,}01696\, g2xy - 92{,}00391\, ARMS(t) + 12{,}99146\, bkurt + 239{,}69713\, Cs - 200{,}58670\, I - 44{,}37385$$

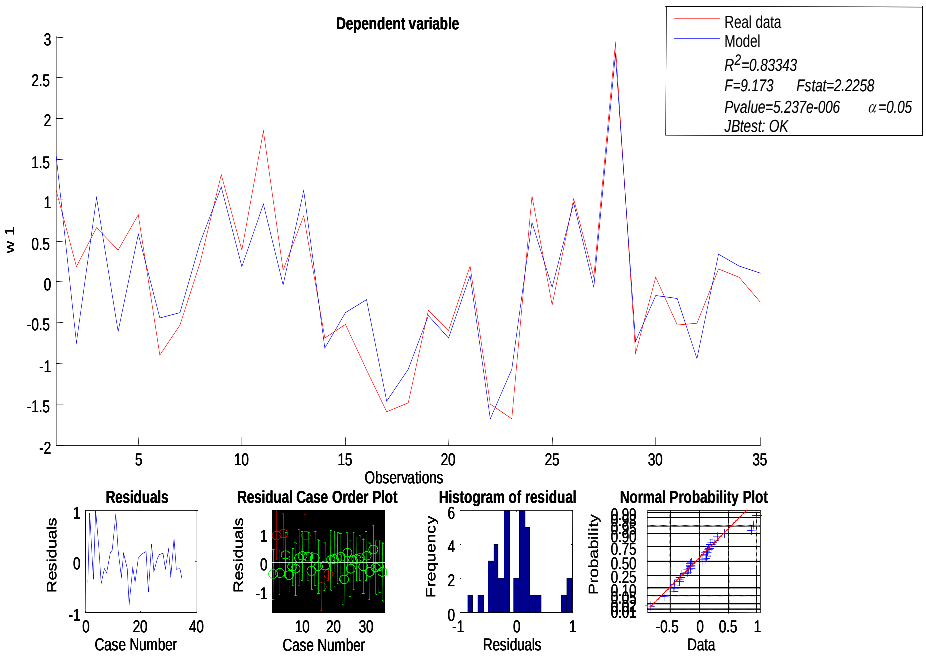


Fig.4. Regressive model determination

The wellness of the model is evaluated with the help of the determination coefficient R^2, and the number of component symptoms determines its accuracy – Fig.5.

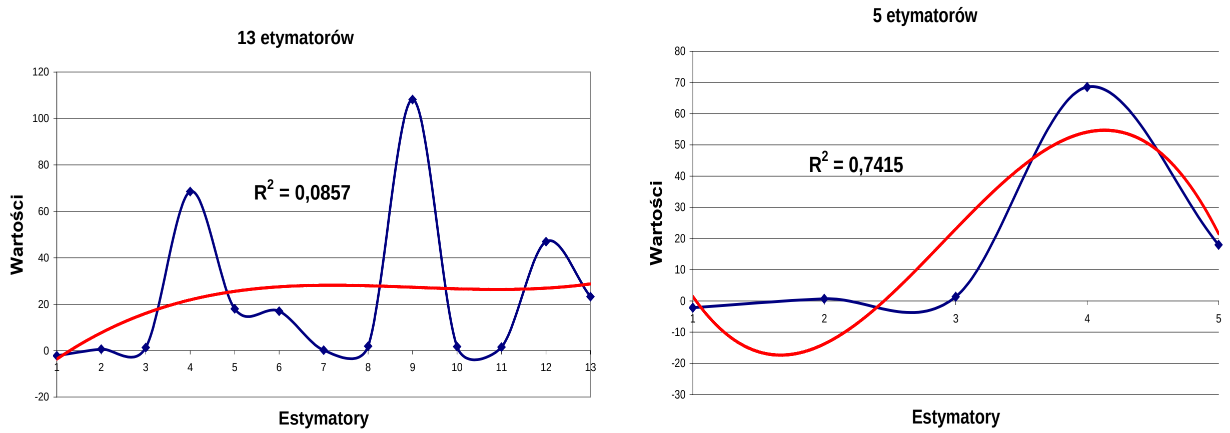


Fig.5. Number of measures v. accuracy of the model

6. CONCLUSIONS

Presented in this work considerations concern the modeling of object dynamic state with the use use of description and researches within the range of identification, distinguishing modal analysis and ideas directly supporting different methods of forming machine dynamics.

The knowledge of the dynamic state and structure of the system allows to describe its behavior, and allows creating prognosis models of the system behavior in the function of dynamic evolution time, based on the model of the technical state symptoms growth. Most often, however, there are no known equations describing behaviors of the system in the function of dynamic evolution time, which accounts for the need to apply new tools to examine the dynamic state. There is, therefore, the requirement to experimentally verify analytical technical models as the proper one is a model which is verified in practice. An experiment is, therefore, often only an inspiration for further researches leading to the optimization of the construction.

LITERATURE

1. Bendat J.S., Piersol A.G., *Methods of analysis and measurement of random signals,* [in Polish] PWN, Warszawa, 1996.
2. Broch J.T., *Mechanical Vibration and Shock Measurements*, Brüel & Kjaer, 1980.
3. Cempel C., *Vibroacoustical Condition Monitoring,* Ellis Hor. Ltd., Chichester, New York, 1991.
4. Cholewa W., Kiciński J., *Technical diagnostics. Reverse diagnostic models,* [in Polish] Wydawnictwo Politechniki Śląskiej, Gliwice 1997.
5. Eykhoff P. *, Identification In dynamic systems,* [in Polish] BNInż. Warszawa.1980.
6. Giergiel J., Uhl T.*, Identification of mechanical systems,* [in Polish] PWN, Warszawa, 1990.
7. Kaźmierczak H., Kromulski J.*, Methods of parametric identification in application into construction diagnostics, Exploitation problems,* [in Polish] 6/93 MCNEMT Radom 1993.
8. Morrison F., *Art of dynamic systems modeling,* [in Polish] WNT, Warszawa, 1996.
9. Tylicki H., *Optimization of the process of vehicle mechanical state prognosis,* [in Polish] Rehabilitation thesis, No 86, ATR Bydgoszcz, 1999.
10. Uhl T., *Computer-enhanced identification of mechanical construction models,* [in Polish] WNT, Warszawa 1997.
11. Żółtowski B., *Diagnostic identification of technical objects. Problems of machines exploitation,* [in Polish] Z.1 (105), PAN, 1996.
12. Żółtowski B., *Computer enhancement of identification,* [in Polish] ZN P.Św. nr.49, 1996 (s.55-71).
13. Żółtowski B., *Machine diagnostics basics,* [in Polish] Wyd. ATR, Bydgoszcz, 1996.
14. Żółtowski B., *Multidimensional monitoring of the track-vehicle interface of a railway system,* Besanson, 2007.
15. Zoltowski B, Castañeda L, *Monitoreo Multidimensional de la Interfase Vía-Vehículo de un Sistema Ferroviario* Congreso Internacional de Mantenimiento – ACIEM – Marzo 2007, Bogotá, Colombia.