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STATISTICAL PROCEDURES FOR STATE DEGRADATION TESTING BY VIBRATION METHODS

Statystyczne procedury badań degradacji stanu metodami drganiowymi

Abstract. *This paper presents selected problems of the statistical evaluation of machines with the use of vibration diagnostics methods. The state of knowledge of this issue indicates the need to update the description and improve the issues related to the acquisition and processing of data, the analysis of the effectiveness of diagnosis procedures, optimization of the set and selection of diagnostic parameters, with statistical support. New proposals of statistical software solutions and various aspects of theoretically justified partial procedures indicate important problems for a good diagnosis.*
Keywords: statistical procedures, condition assessment, models, symptoms, optimization.

Streszczenie. *W tej pracy przedstawiono wybrane problemy statystycznej oceny stanu maszyn z wykorzystaniem metod diagnostyki drganiowej. Stan wiedzy tej problematyki wskazuje na potrzebę aktualizacji opisu i doskonalenia zagadnień związanych z akwizycją i przetwarzaniem danych, analizą skuteczności procedur diagnozowania, optymalizacji zbioru i selekcji parametrów diagnostycznych, przy wsparciu statystycznym. Nowe propozycje programowych rozwiązań statystycznych i różne aspekty procedur cząstkowych uzasadnionych teoretycznie wskazują na ważne problemy warunkujące dobrą diagnozę.*
Słowa kluczowe: procedury statystyczne**,** ocena stanu, modele, symptomy, optymalizacja.

1. Introduction

The increasing demand for methods and means of technical diagnostics, which are a tool for a modern method of creating "quality" of machines and devices, meets the contemporary conditions of business activity, including the particularly well-used potential of technical facilities [1, 10]. In mechanical engineering, the developing technical diagnostics based mainly on the use of information about changing condition can supervise the safety hazard and the progressive destruction of the machine throughout its life cycle. Supervised changes in the state with the use of diagnostic methods prevent the causes and effects of failures, and often also failures [2, 5, 17].

A clear impulse for the increase in demand for diagnostic methods and means was the introduction of a market economy in the country, where the requirements in terms of quality, logistics and marketing radically changed the criteria of machinery and technical equipment supervision. The growing demand for diagnostics also coincides with the emergence of new applications of the achievements of microelectronics, computer technology, statistics, fractal theory, neural networks, and artificial intelligence - effectively supporting diagnostic possibilities. A diagnostic system is a team of diagnosticians, a set of methods and means of obtaining, processing, presenting, and collecting information, as well as a set of objects, their models, and algorithms for diagnosing, generating, and forecasting states. It also includes the relations between these elements and is designed to make reliable decisions about the belonging of the examined object to a specific class of states. The methods and means of modern technical diagnostics are a tool for diagnosing the condition of technical systems, which is the basis for operational decisions [3, 7, 19].

In this work, selected problems of the assessment of the condition of machines during the life of objects are discussed, emphasizing the issues of quality development, modeling as well as automation and control in operation, in the aspect of developing damage. The special role of supporting decisions with the use of statistical methods was devoted to considerations covering the issues of classical vibration diagnostics, distinguishing places inspiring the limitations and threats of statistics. References for the needs and types of statistical support for research are indicated in the following groups of problems:

1. Where are we - domain, area, why vibrations?
2. Modeling and experiments - models, simplifications, measurements, and errors - statistical evaluations?
3. Why statistics - incomplete and uncertain information, dedicated statistical procedures of the area of knowledge?
4. Vibration diagnostics - many measures (excess), dedicated procedures, inference - the role of statistical evaluations?
5. Statistical research system - dedicated procedures and algorithms for the field of knowledge?
6. Application practice - diagnostic operation strategy, statistical evaluation, management, and quality tools.

These many assumptions and simplifications for models and modeling, as well as incomplete and uncertain information with many measurement errors in experiments, as well as during processing and inference justify taking up the problem of the role and significance of statistics in the practice of vibration diagnostics [5,11,16].

2. Recognition of damage to objects

Damage is one of the important events occurring in the process of using facilities, determining the reliability, efficiency of use and the process of technical maintenance, as well as the scope of technical diagnostics needs. Technical diagnostics, apart from tribology, reliability, safety theory and exploitation theory, is one of the basic sciences about the rational exploitation of objects. Understanding the physical phenomena occurring during the functioning of the machine makes it possible to determine the qualitative relationships between the destructive processes taking place and the state of the machine. The large dispersion of the initial properties of the machine, as well as the uncertainty and continuity of aging and wear processes clearly define the goals and tasks of machine diagnostics, which must develop a specific set of diagnostic methods and means.

All the wear phenomena of machines is dealt with by tribology, and its basis is the assumption resulting from the tribo-vibro-acoustic model about the proportionality of the vibration level to the advancement of wear processes. In this work, the assumption was made about the existing relations between the object model described by parameters m, k, c (m - mass, k - stiffness, c - damping), and the quantities describing the vibration process a, v, x (a - acceleration, v - velocity, x - displacement). These assumptions are the basis for the developing and improved vibration diagnostics, more and more often used in monitoring and assessing the condition of many machines and devices.

Detailed considerations in vibration diagnostics have been presented in many books [3, 11, 12, 15, 18] and publications [11, 13, 14, 16, 17, 19]. For the assessment of the condition of the object, the available different types of diagnostics may use the same baggage of inference methods, ranging from deterministic to artificial intelligence. The main problems of vibration diagnostics include: • acquisition and processing of diagnostic information; • building models and diagnostic relationships; • diagnostic inference and limit values; • classification of machine states; • predicting the time of the next diagnosis; • visualization of decision information.

The basic and useful in diagnosing set of diagnostic parameters is obtained from the set of initial parameters as a test result and focuses on the reduction of information in the process of selecting measures (state symptoms) confirming the information contained in the change in the state of the machine.

This is the basic task of good diagnostics, and the determination of the set of symptoms in the diagnosis process should enable: • supervising changes in the state of the machine during operation; • the available and required amount of information on the state of the machine; • appropriate variability of parameter values during operation; • reliable statistical data and effective analytical methods for highlighting important parameters.

Good symptoms of the condition are the basis for the construction of procedures and a diagnostic system. Therefore, the diagnostic system becomes the subject of separate considerations, and the diagnostic properties of such systems require specialist development and description (with mathematical formalization).

3. Statistical procedures for supervision of state changes

The control tools for the considerations are statistical procedures creating a measurement system in the study of vibration energy propagation measures (acquisition, ordering, redundancy, modeling and presentation of test and measurement results). The development of information techniques and their rapid penetration into research laboratories enable their wide application during the implementation and processing of the obtained results. Planning and implementation of research, acquisition and processing of results, their presentation and substantive elaboration may be correct only with computer support. These issues in the form of the minimum necessary statistical knowledge are presented in various studies within the scope of research and cause-and-effect inference, with considerable support with information techniques [1, 4, 8, 9].

Basic statistical research uses many methods of qualitative and quantitative analysis of the obtained data. These include analysis of variance, correlation analysis, regression analysis, factor analysis, discriminant analysis, time series analysis, canonical analysis, and others, available in various statistical informational procedures [15]. The MATLAB program is used for basic engineering applications used in the analysis of results. This program is used for computer calculations, combining data registration and processing, specialized calculations, visualization, and an easy-to-use programming environment [1, 7].

The program includes the following applications: mathematical algorithms and their calculation, creation of own calculation algorithms, modeling and simulation algorithms, data analysis and visualization, graphic engineering applications, application for creating own programs, creating their interface and graphical data analysis. SIMULINK, Signal Processing Toolbox, STATGRAF, STATISTICA and other software packages make it possible to obtain basic knowledge of a given scope and apply this knowledge to problem solving [2, 10].

The presented sample system programs are used for statistical data analysis, creating graphs, operating on databases, performing data transformation, and creating applications. The programs contain files that allow you to perform various analyzes (with a choice of many sample data sets) and create graphs, measures, and models. For the purposes of vibration research, a proprietary, dedicated statistical research system was created, including many different procedures and software implementation for the purposes of vibration process acquisition, vibration process processing, vibration measurement interdependence studies, sensitivity testing of the distinguished symptoms, cause and effect inference and analysis results visualization.

The main components of this statistical support system are:

- LMS Test Xpress software for vibration measurements,
- results visualization and data transfer programs (import unv, Excel),
- SYMPTOMS PROGRAM for determining vibration estimators,
- software for measuring the sensitivity of measures: OPTIMUM (qualitative research) and SVD (quantitative research),
- software for studying complex relationships (correlation) and relationship models (regression),
- system of building inference models (Excel, MATLAB, BEDIND);
- research IT system - integration of statistical methods.

To achieve the objectives of the above-mentioned tasks, an engineering application was developed that allows for the statistical generation of dedicated sets of variable symptoms of the degradation state of the examined objects [12,13,15].

4. Innovative statistical procedures in vibration diagnostics

All the studied mass phenomena are characterized by certain regularities that are difficult to study and not all of them are detected and investigated. The statistical evaluations used for this characterize the quantitative side of the studied phenomena in inseparable from their qualitative side. It should be remembered that in nature there are no numbers used by statistics, only things and processes [2, 6, 15].

Statistical methods using numerical description make it possible to make the necessary generalizations of a large amount of detailed information. By applying generalized statistical methods to make the necessary generalizations in the statistical description, order is introduced in the apparent chaos of random events. This allows for the detection of regularities in the form of cause-effect relationships occurring in the studied phenomena [2, 11].

The massiveness of data requires the use of computer aided methods and means of modeling, acquiring, processing, inferring, visualizing, disseminating, and storing information. The current development of science requires engineers to use modern computer applications, thanks to which it becomes possible to perform complex calculations and analyze the obtained results in a short time [15].

The obtained research data (uncertain, incomplete, random) are subject to analysis and assessment of regularity in the field of mass phenomena. To distinguish the main components of the observation matrix, the obtained results are combined into control charts, which are subjected to painstaking tests in the field of:

- data presentation:

- statistical series: detailed, distributive, temporary;
- statistical charts: line, bar, point;

- statistical tables: working - statistical material processed.

- using statistical tools to describe the data structure:

- arithmetic mean - mean value,
- geometric mean - relative changes of a given feature,
- dominant - the most probable value,
- range - the difference between the maximum and minimum value of a given feature,
- standard deviation - distance of the feature from its arithmetic mean,
- variance - arithmetic mean of the square of the standard deviation,
- coefficient of variation - the degree of differentiation of a feature in the entire population,
- asymmetry coefficient - determines the direction and strength of the asymmetry,
- concentration factor (kurtosis).

These analyzes determine the initial and justified selection of qualitative measures, processed further to distinguish the components of the main model. Statistical analysis of the obtained data is also the basis for many interesting descriptions and trends of the analyzed events.

The considerations presented briefly cover selected issues from the area of the use of statistical procedures in the study of vibration measures to assess the state of wear of machines. The indicated procedures are particularly important in research, where the multidimensionality of diagnostic signals requires a wide application of various statistical procedures at the stage of processing and decision making. The basis of the IT system is the MATLAB program used to determine the symptom matrix, software tools for reading and exporting files to the unv format, for the implementation of OPTIMUM algorithms, computer algorithm for distribution analysis (SVD) and the program for analyzing the state matrix using the MAC theory [18].

The elements of a detailed, statistically supported methodology for vibration, include tasks in the following areas:

• measurement data - a method of data registration for the purposes of processing, data bank, statistical analysis,
• observation matrices - scoreboards, data ordering (dimension lessness through normalization, measurement scales unified by precision constants),
• elements of statistics - measures for data presentation (numerical, graphical, location measures, dispersion, interdependencies, regression in cause-effect modeling),
• software - MATLAB and STATISTICA procedures,
• methods of information selection (PCA, OPTIMUM, SVD) and cause and effect modeling and forecasting,
• reliability testing measures: technical availability, failure intensity, time to and between failures ii),
• elements of artificial intelligence in vehicle research: advisory systems, fuzzy sets, neural networks in the classification of states, genetic algorithms in the optimization of sets.

It is difficult to discuss the individual tasks in detail in one study, so the decisive elements and the general algorithm for processing information from vibration tests are shown in Fig. 1.

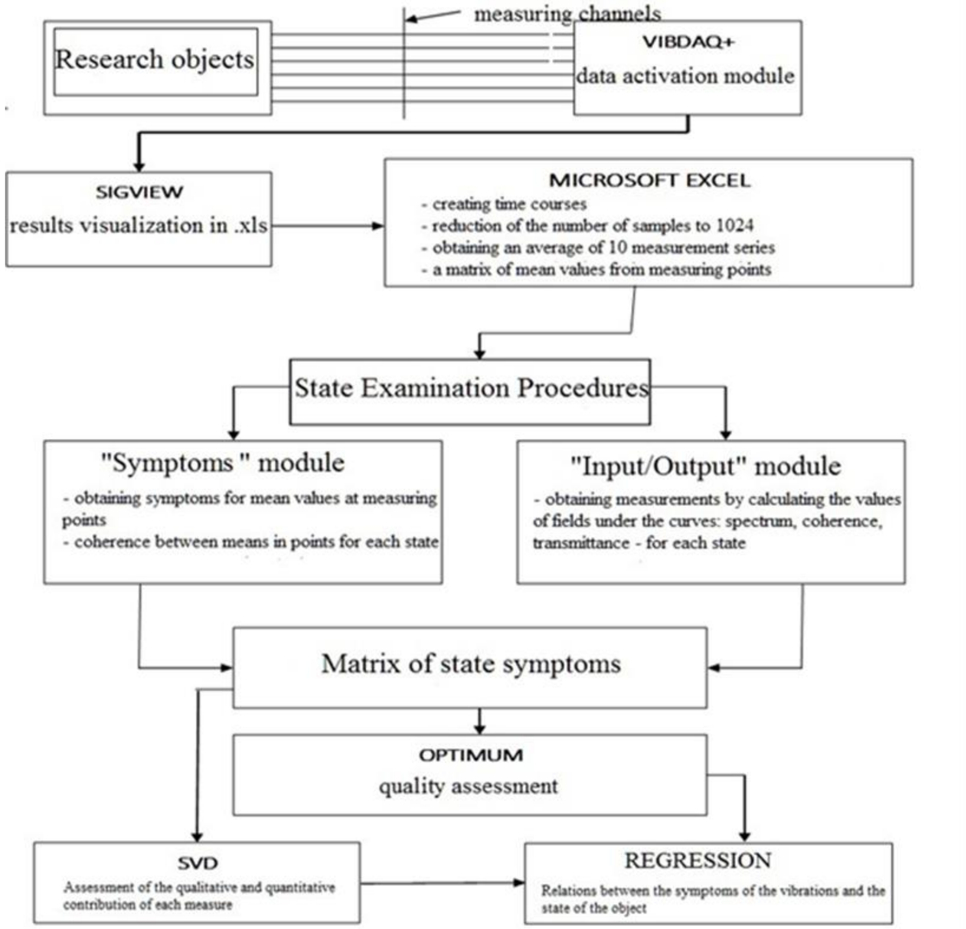

Fig. 1. Vibration test algorithm with elements of statistical procedures

In general, the proposed methodology of testing the wear state includes detailed procedures for system development, data acquisition and processing as well as statistical inference - repeated in many different problems of testing many signal measures.

The control tools for the considerations are the proposed statistical procedures that make up the vibration energy propagation measurement system (acquisition, ordering, redundancy, modeling and presentation of test and measurement results) [1, 3, 12]. Innovative and exemplary information selection procedures for the multidimensional observation matrix in the qualitative and quantitative assessment are presented in the OPTIMUM and SVD algorithms.

4.1. The ideal point method - OPTIMUM

Measured signals represent the space of observation, and indirectly the development of damages in the structure or construction machine. Using optimization, you can characterize the sensitivity of measured symptoms to state changes based on distance measurements from the ideal point [9, 15]. The algorithm presented below enables statistical evaluation of individually elaborated symptoms, resulting in the final qualitative ranking list of their sensitivity and usefulness shown in Fig. 2.

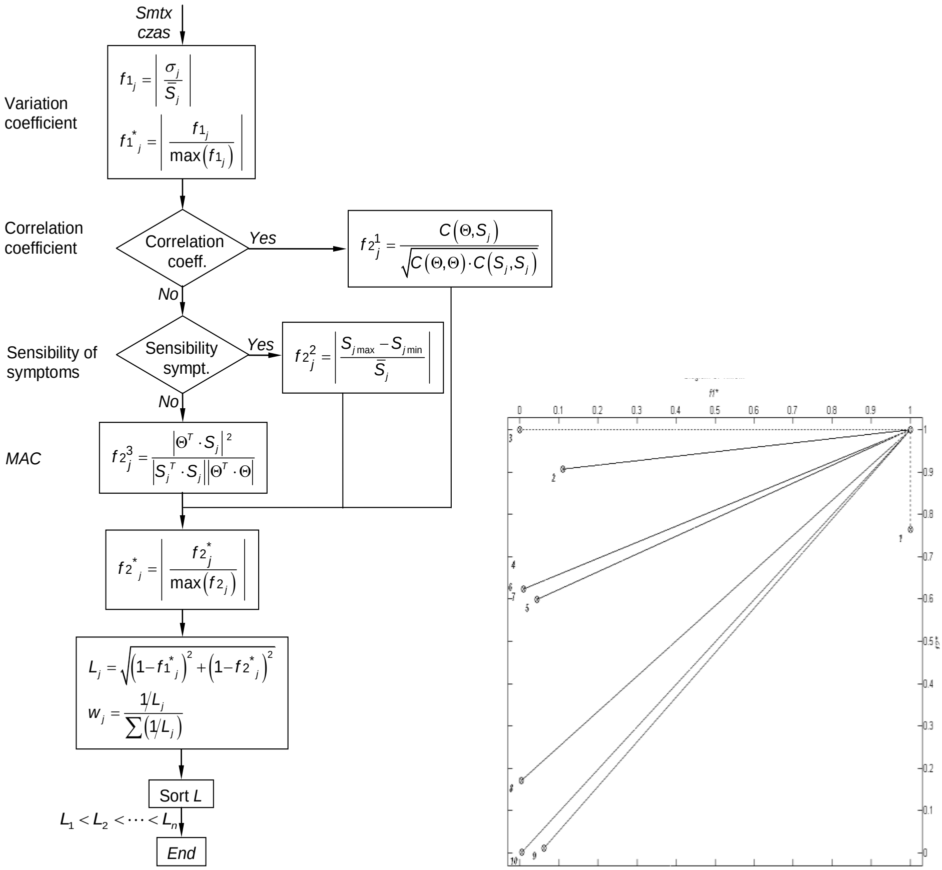

Fig. 2. OPTIMUM procedure algorithm and an example of its result [2, 11]

Having statistically significant good symptoms, it is possible to build cause and effect models on the state conclusion stage. However, the quality of the model depends on the number of measures taken, which can be indirectly estimated in the simplest regression models with the R^2 coefficient [2, 9, 15].

4.2. Multidimensional system observation - SVD

SVD (Singular Value Decomposition) is a numerical procedure for multivariate tracking of changes in an object's degradation state. The procedure uses all measured signals to assess changes in the state of the technical system under study, without losing any information possible to obtain. The algorithm of the method and an exemplary result of the applied procedure are presented in Fig. 3.

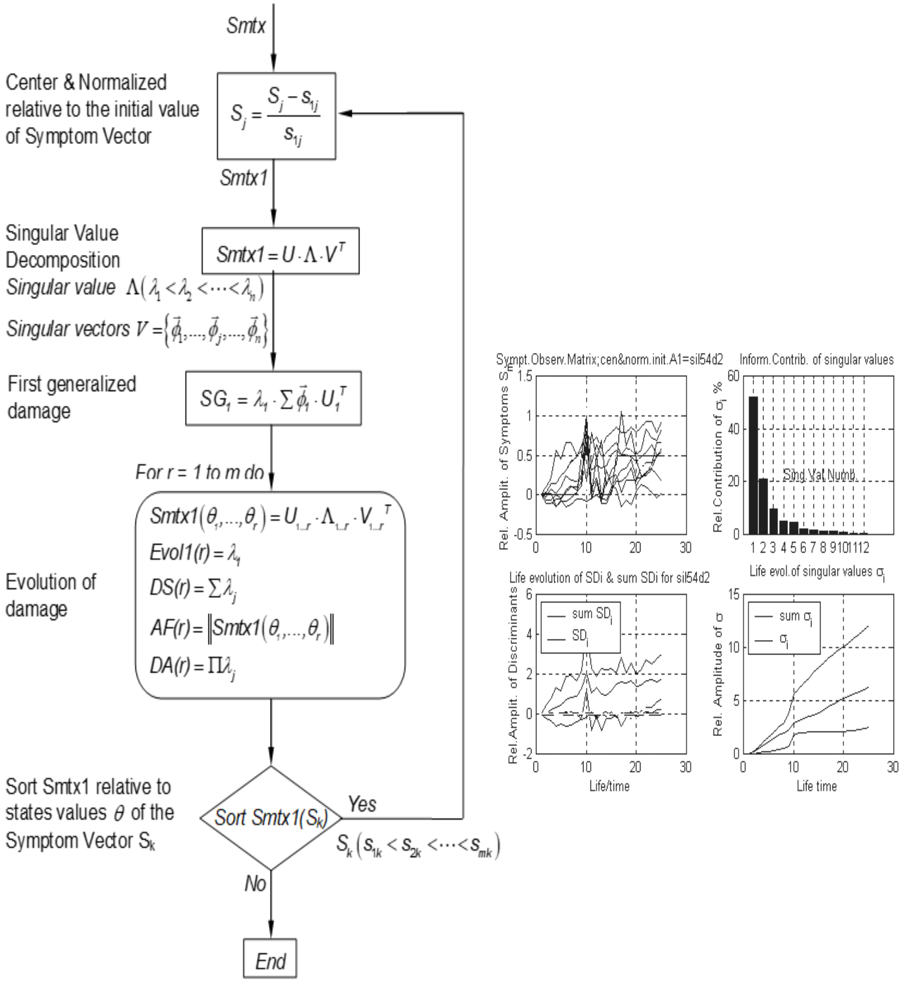

Fig. 3. The algorithm of the SVD procedure and an exemplary result of its operation [2, 5]

The SVD procedure in the newer software implementations is modular (base) and allows further development of the algorithm, automatically searching for unnecessary measurement symptoms for a given research topic.

5. Summary

During empirical observation of phenomena, there are almost always various types of simplifications and inaccuracies, and they concern almost every stage of the research. In the case of using the statistical approach, the researcher consciously or unconsciously agrees to a whole series of simplifications due to the lack of a better alternative. The statistical approach enables ensuring the possibility of generalizing the research results to a wider group of objects and determining the number of objects studied to achieve the goals.

The achievements of diagnostics in recent years, using the achievements of many fields of science, allow to treat it as a tool for shaping and assessing the quality of machines at all stages of their existence. The frequent need to monitor developing failures and to determine the limit states for the monitored symptoms of the state is presented here against the background of the basic problems of diagnostics in shaping the quality of machines throughout their life cycle.

The work defines a structured structure of statistical rules of the state diagnosis process, focusing on the diagnostic parameter optimization procedure as well as the methods of modeling and statistical inference in vibration diagnostics. The presentation of detailed procedures improving the existing diagnostic systems and strategies allows for an innovative influence on the methodologies and detailed plans for the operation of facilities. The use of statistical methods to support scientific research is not uniform and requires an independent approach to the specifics of specific fields - dedicated statistical procedures. The negation of statistics is due to insufficient knowledge about the real advantages and limitations of this approach - but the statistical approach often oversimplifies the actual course of the phenomena studied and the relationships between the factors that determine them.

Translating statistical conclusions (a statistically significant result) into substantive conclusions (effect of an action) requires special caution (it is not always simple). The benefits of the correct application of statistical methods in the development of research results (need and necessity) are determined by the standards of the field, both in terms of the scope of the tools used and the correctness of their application.

6. References

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