Assessment properties of the coherence function on combustion engines technical state

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RESUMEN

El problema del diseño y la explotación de máquinas modernas es el reconocimiento del estado técnico bajo condiciones de operación. Por lo tanto, definir el modelo dinámico correcto es el principal reto dentro de la industria.

Las condiciones del diagnóstico del estado técnico con la función de coherencia radican en que el proceso debe ser lineal y estacionario en el dominio del tiempo. Los métodos actuales de diagnóstico para motores de combustión se basan en mediciones de valores de dirección de corriente. El vibrodiagnóstico de motores de combustión es un método alternativo que usa el análisis de los procesos vibratorios generados dentro de los motores permitiendo evaluar la su condición usando la sensibilidad estimada de sus procesos vibratorios.

La estimación del estado técnico de motores de combustión con chispa de encendido para el estudio de vibración es posible mediante la propiedad de la función de coherencia.

Palabras clave – **Función de coherencia, motor de combustión, transformada rápida de Fourier, vibrodiagnóstico.**

ABSTRACT

The problem with design and exploitation of modern machines and technical devices is the recognition of the technical state in operating conditions. Therefore, defining the correct dynamic model is the main inquiry within the industry field.

The main condition of the diagnostic process with coherence function is that the processes must be linear and stationary in the field of the dynamic time. The present methods for diagnosing the technical state of combustion engines are based on measurements of value steering currents. The vibrodiagnostic of combustion engines is an alternative method that uses the analysis of vibration processes generated in combustion engines, enabling the assessment of the engine condition by using the sensibility estimate of its vibration processes.

The estimation of the state of combustion engines with sparkle ignition for the research of vibration measures is possible thanks to the utilization of the property of the coherence function.

Keywords - **Coherence function, combustion engines, fast Fourier transform, vibrodiagnostic.**

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These problems are only part of a research project related to the identification of the dynamic state of machines. The project was funded by University of Technology and Life Sciences in Bydgoszcz - Faculty of Mechanical Engineering. Project number: WND-POIG.01.03.01-00-212/09.

I. INTRODUCTION

The actual tendency to develop method end techniques for the diagnosis of vehicles has resulted in the increase of interest and demand of the technical state analysis in the exploration of systems [1] [2] [3] [4], machines and devices that are at the time becoming more and more complex. The destruction processes of technical systems pose the need to monitor changes in their states. Methods and means of modern technical diagnostics are tools for diagnosing the state of machines DSEM, which is the basis for decisions at every stage of their existence [5] [6].

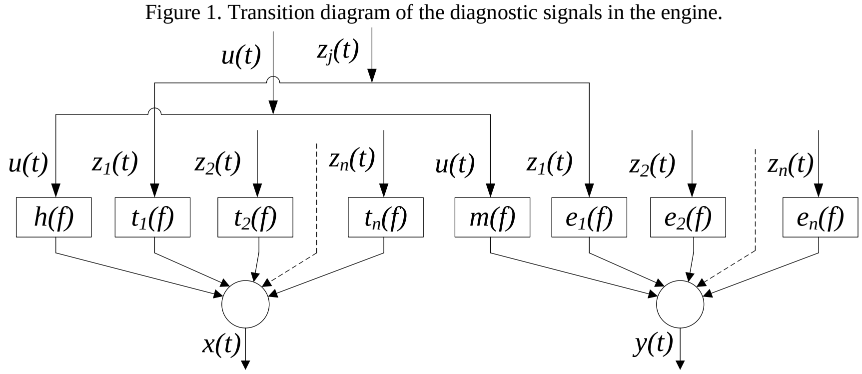
Researches relative to vehicles diagnostic focus around the following investigative problems in the peculiarity of vibration processes in combustion engines [7]:

- the analysis of vibration processes for sorted temporary sections connected with the ignition period for the control of the burning process in the engine;
- the temporary and ghostly selection of vibration processes for the control of the technical state of elements in the engine;
- the investigation of the changing factors of the value of vibration process diagnostic parameters; and
- the technical state of the engine, operational and constructional factors, appearing in nearly every investigation on vibrodiagnostic.

The transition diagram of the diagnostic signals in the engine is shown on Figure 1. The main reasons to address this subject of study [8] [9]:

- analysis of the suitability of the property of the coherence function in the vibrodiagnostic of internal combustion engines;
- develop a system for the identification, analysis and reasoning of the technical state of combustion engines;
- propose a new method for diagnosing the technical state of combustion engines using the properties of the coherence function; and
- quickly identify the internal combustion engine damage with the proposed testing method.

Figure 1. Transition diagram of the diagnostic signals in the engine.



Source: W. Bartelmus [1].

II. RESEARCH METHOD

The coherence function γ_{xy}^2 is defined as a measure of cohesion between two vibrodiagnostic processes signals $x(t)$ and $y(t)$ uses Welch's averaged, modified periodogram method [2], see Eq. (1)

$$\gamma_{xy}^2(f) = \frac{\left|G_{xy}(f)\right|^2}{G_{xx}(f) \cdot G_{yy}(f)} \tag{1}$$

The magnitude squared coherence $\gamma_{xy}^2(f)$ is a function of the Power Spectral Density (PSD) $G_{xx}(f)$ and $G_{yy}(f)$, of the signals $x(t)$ and $y(t)$ respectively, and the Cross Power Spectral Density (XPSD) $G_{xy}(f)$ of $x(t)$ and $y(t)$. The function at time domain known as Transfer Function estimation (TF), h_1, h_2, then (Eq. (2) and Eq. (3))

$$\begin{aligned} G_{xy}(f) &= h_1(f) \cdot h_2^*(f) \cdot G_{uu}(f), \\ G_{xx}(f) &= \left|h_1(f)\right|^2 \cdot G_{uu}(f), \\ G_{yy}(f) &= \left|h_2(f)\right|^2 \cdot G_{uu}(f), \end{aligned} \tag{2}$$

and

$$\gamma_{xy}^2(f) = \frac{\left|h_1(f) \cdot h_2^*(f)\right|^2 \cdot G_{uu}^2(f)}{\left|h_1(f)\right|^2 \cdot G_{uu}(f) \cdot \left|h_2(f)\right|^2 \cdot G_{uu}(f)} \leq 1. \tag{3}$$

The magnitude of $\gamma_{xy}^2(f)$ values are a function of frequency in the range $[0,1]$, it means $0 \leq \gamma_{xy}^2(f) \leq 1$. Contrary to the TFE, γ_{xy}^2 always operates signals if $x(t)$ and $y(t)$ come from the same source. If there is no damage into the mechanical system then the coherence function values have tendency to have one unit values, $\gamma_{xy}^2(f) \cong 1$, but on the other hand if there is damage then $\gamma_{xy}^2(f) \cong 0$. The focus is on the sensibility of $\gamma_{xy}^2(f)$ to localize physical damages. The $\gamma_{xy}^2(f)$ model of diagnosing combustion engines is shown on Figure 2.

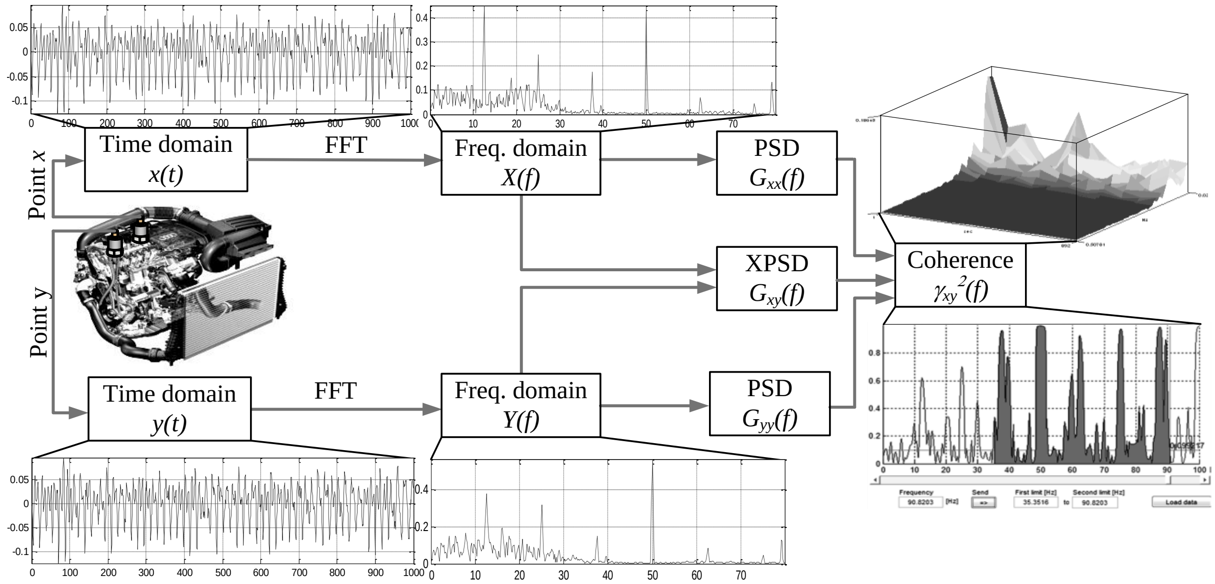
The $\gamma_{xy}^2(f)$ as a measure of cohesion between two (2) signals is a suitable method to estimate the combustion engines technical state because of the fact that the instant new damage appears is reflected in the change of the properties of the signal and $\gamma_{xy}^2(f) \to 0$.

$\gamma_{xy}^2(f)$ could be used in tests with inferences relative housing in rolling bearings on the basis of the coherence coefficient between strength extortions and vibrations received on the external road. The ability of $\gamma_{xy}^2(f)$ to discriminate the housing can be completely sufficient for the aims of the diagnostics [4]. The use of $\gamma_{xy}^2(f)$ in diagnostics does not only apply to cases of straight lines, but is equally useful in situations of vibration and noise propagation.

The main condition of the diagnostic process using $\gamma_{xy}^2(f)$ is that the processes must be linear and stationary in the field of the dynamic time, t. Even so, a larger possibility of uses of the diagnostic coherence functions can be found in non-stationary or non-linear mechanical arrangements.

The newest example of this last field is detecting the space in the steams of kinematics mechanisms or machines [3].

Figure 2. $\gamma_{xy}^2(f)$ model of diagnosing combustion engines.



Source: Authors.

The research is focused on establishing the variation level of $\gamma_{xy}^2(f)$ at given characteristics frequencies, the value of correlation of vibration processes and TFE, which together with the size estimate of the field are used to build the Symptom Observation Matrix, *SOM* . The *SOM* is implemented in an algorithm development called Computer System of Identification Investigations (SIBI). The assessment on the change of the technical state of the engine is possible by means of the research method proposed.

This method involves a complete measuring chain (see Figure 3), a data acquisition system and SIBI software to analyze the technical state of combustion engines. The research method proposed demands following the next rule set to obtain accurate results:

- coherence method for evaluating the technical state of combustion engines requires the selection of the diagnostic frequency signal;
- diagnosed engine elements can be attributed to specific components of the signal with bandwidth and center frequencies corresponding to the characteristic frequency;
- use of coherence methods for diagnosing the state of the engine forces the engine to carry out research while working to nominal load;
- vibration processes are received from selected points on the combustion engine;
- reduction of signal reception points is carried out by using the coherence function test on the basis of which it is possible to rank the points of reception in terms of quantity of information transmitted; and
- analysis of vibration processes are received at selected points and allow to determine the co-factor for the coherence of the characteristic frequency ranges and the value of the field in the course of the coherence function in the width of these bands.

III. Processing and Results

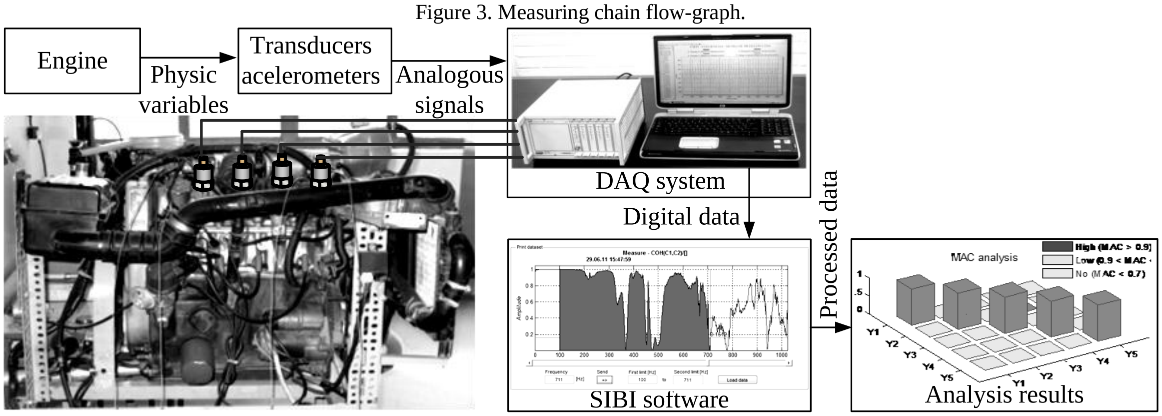
The research object was a combustion engine (No. 138C.2.048) with 1.4l swept capacity, power 55kW @ 830r.p.m., commonly assembled to Fiat Uno 75i.e., the combustion engine is situated in the investigative laboratory of combustion engines in UTP Bydgoszcz (see Figure 3). A set of tests has been developed using the object of research in the laboratory, a total of 33 technical states were simulated with damages of spark plug and injectors on the individual cylinders of engine and the combination of these damages.

During the experimental research, uniform and fixed conditions in the engine are needed in order to guarantee the success of the analytical process. The research was performed under the following conditions:

- 830r.p.m. was executed measurements for the rotatory speed of the engine;
- for neutral gear, temperature of the trunk of the engine carried out 71ºC;
- the dynamic state of the engine is described 30 measuring files; and

- the investigations were executed using two measuring channels for the fulfillment of the state of FFT.
  The measuring track consisted of:
- two acceleration sensors ICP Model: 352C68;
- two lead series 002; and
- data acquisition system VIBDAQ+.

Figure 3. Measuring chain flow-graph.



Source: Authors.

The physical vibration performance has been measured and processed in DAQ system. Then the signals in the time response from DAQ system were imported to a real-time signal software package, and then to SIBI tool for digital processing. Next, the modular structure of SIBI is shown (see Figure 4):

- import database module: import from universal (.UNV) and excel (.xlsx) formats (see Figure 5.b);
- observation matrix, SOM Module: build the matrix of symptoms to use for a get a estimate of vibration process (see Figure 5.c);
- OPTIMUM module procedure (see Figure 5.d);
- SVD module: Singular Value Decomposition process (see Figure 5.e);
- output relationship functions is the most important module of this program (see Figure 5.f). In this application we make get a data which we need for coherence function analysis; and
- regression module: the technical state of the research object was verified through own and related symptoms.

Figure 4. Procedure for support program research

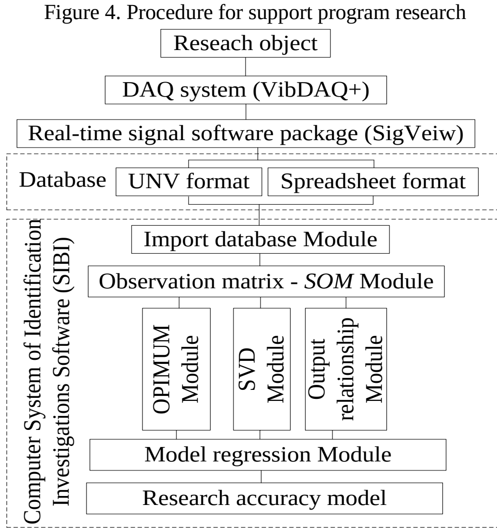


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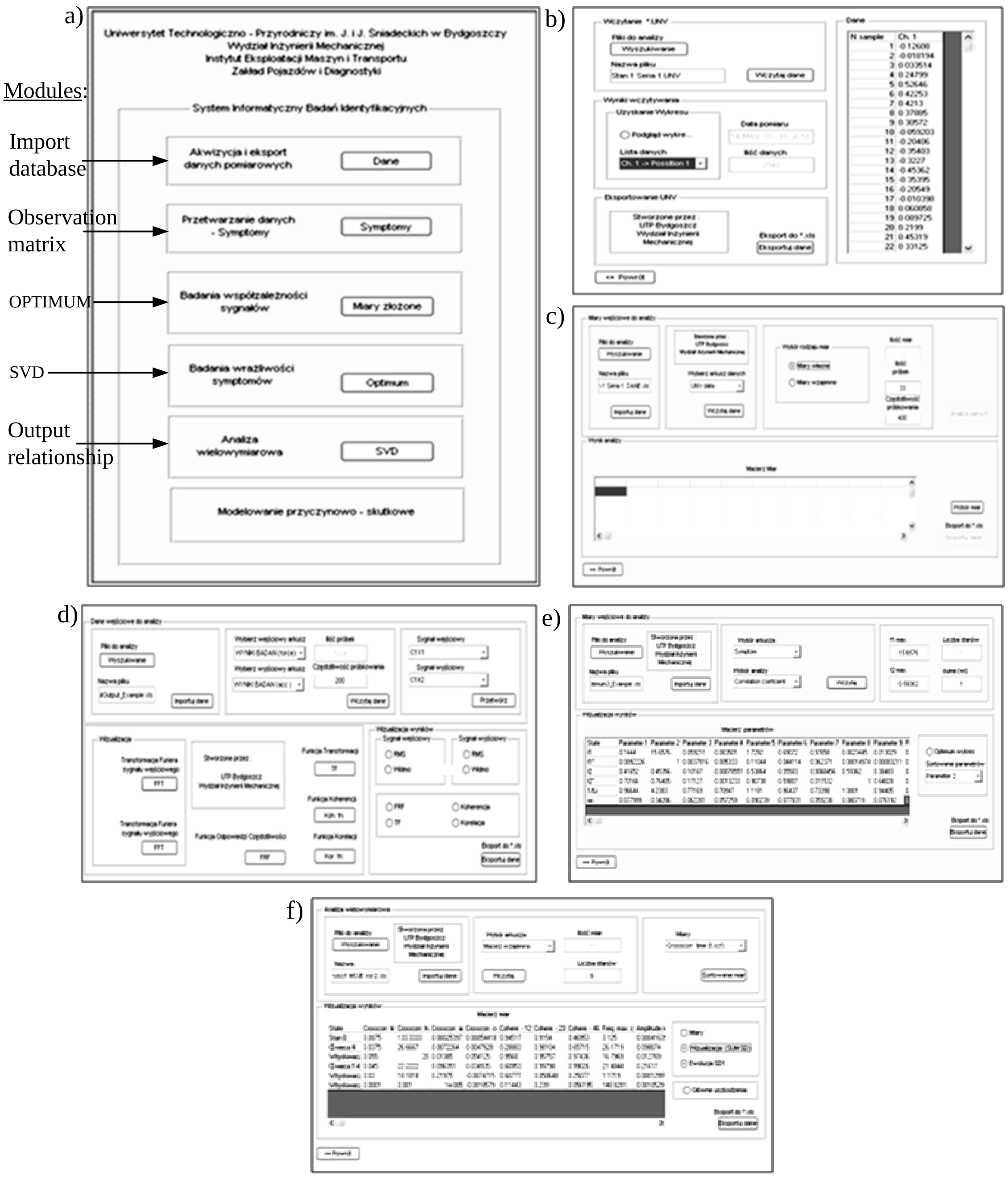
Figure 5. SIBI algorithm: a) SIBI main window; b) Import database module; c) Observation matrix, *SOM* module; d) OPTIMUM Module; e) SVD module; f) Output relationship module.



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The final observation matrix of the engine performance described 18 own-symptoms generated in SIBI (Observation matrix, SOM Module), and 15 related symptoms generated in SIBI (Output relationship Module), which include the properties of $\gamma_{xy}^2(f)$ [10]. Figure 6 presents the graphic interpretation of the engine state analysis with damage in the fourth cylinder.

Taking into account diagnostic sensibility of the symptoms, the OPTIMUM Module indicates the sensitivity of symptoms; diagrams for related symptoms are shown in Figure 7.

Figure 6. Graphic interpretation of the engine state analysis with damage in the fourth cylinder: a) Coherence function, $\gamma_{xy}^{2}(f)$; b) Frequency Response Function, $FRF(f)$; c) Transfer Function, $TF(f)$

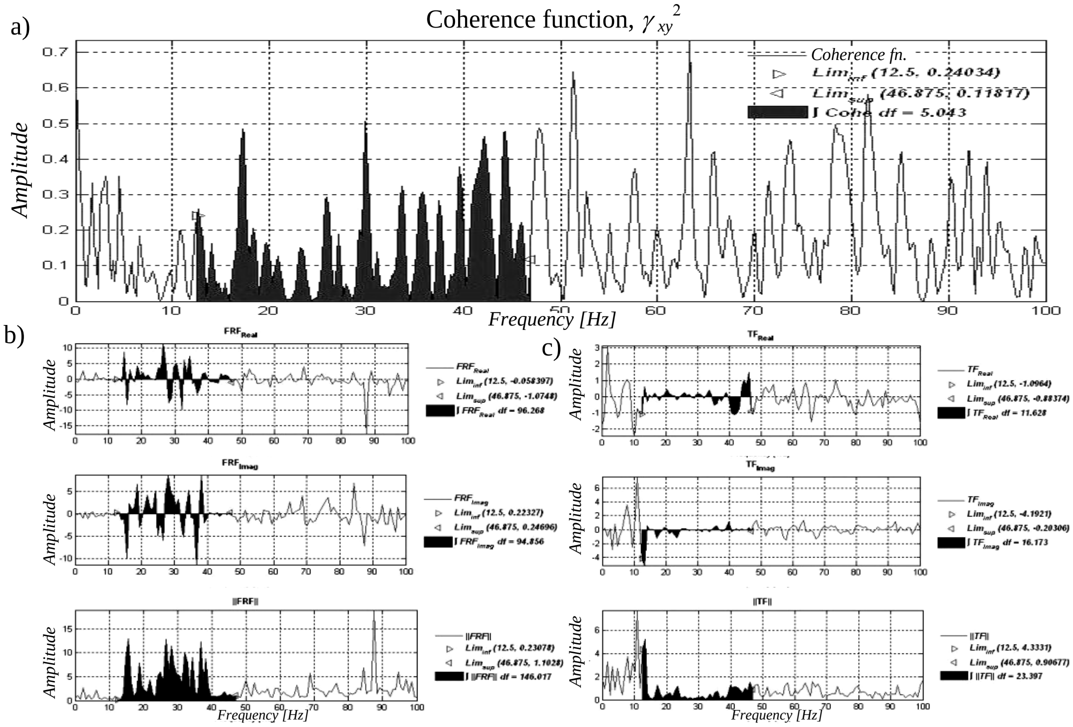

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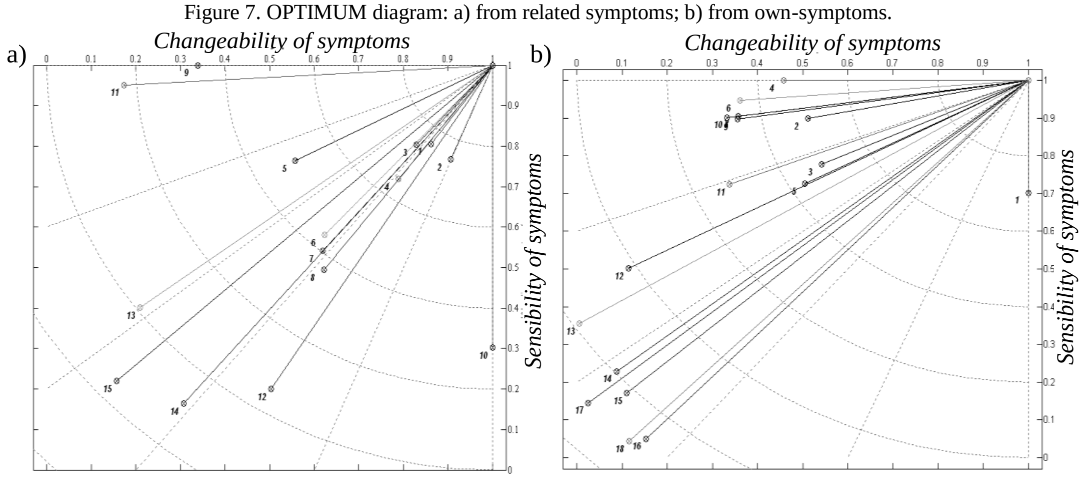
Figure 7. OPTIMUM diagram: a) from related symptoms; b) from own-symptoms.



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The multidimensional analysis of the qualitative and quantitative assessment of the measured diagnostic signals was based on the SVD method. The results of the analysis for related symptoms (see Figure 8.a) and own-symptoms (see Figure 8.b) indicated the best symptoms describing the technical state of the engine.

The analysis of the research results showed how large is the portion of symptoms connected with the coherence function, therefore leading to the usage $\gamma_{xy}^{2}(f)$ in the diagnostic process of combustion engines.

Developing cause-effect relations and defining the relationship between the variables studied was determined by using multiple ownership regression functions [11] [12] [13] [14] (see Figure 9).

The study of the regressions defined the relationships between classified results of the research of this work through the utilization of the property of the multiple regression function [15]. The regression analysis showed the characteristics of the research objects and the good quality of parameters describing the technical state of the combustion engine [16] [17] [18].

Figure 8. Graphic interpretation of the analysis of SVD: a) from related symptoms b) from own-symptoms.

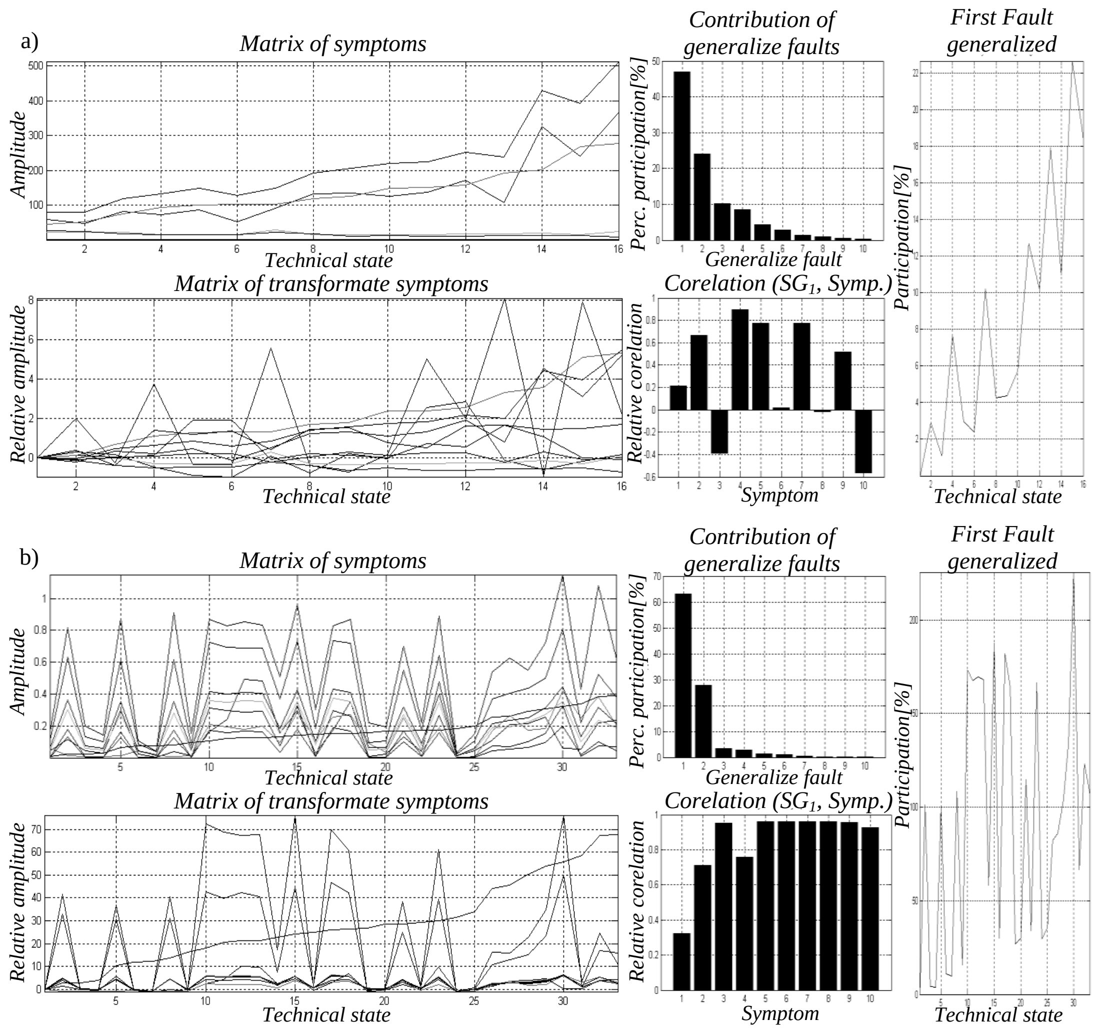

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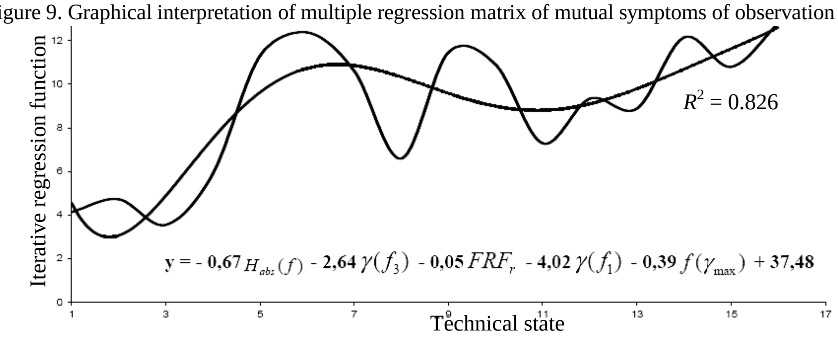
Figure 9. Graphical interpretation of multiple regression matrix of mutual symptoms of observation states



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IV. CONCLUSIONS AND FUTURE WORK

The present methods for diagnosing the technical state of combustion engines are based on measurements of value steering currents. The vibrodiagnostic of combustion engines is an alternative method that uses analysis vibration processes generated in combustion engines, enabling the assessment of the engine condition by using the sensibility estimate of the vibration process

The estimation of the technical state of combustion engines with sparkle ignition for the research of vibration measures is possible due to the utilization of the property of $\gamma_{xy}^2(f)$.

Cause-effect relations expressing quantitative relations between the studied variable symptoms results were qualified using the multiple regression function.

The analysis of the research results showed how large is the portion of symptoms connected with the $\gamma_{xy}^2(f)$, therefore leading to the usage of $\gamma_{xy}^2(f)$ in the diagnostic process of combustion engines.

The implementation of software requires: the acquisition of vibration processes, their processing, statistical inference and visualization, which facilitates the leadership of investigations and the study of results.

The investigation results introduced in this paper are only part of realized investigative project and they do not describe the whole investigative question, but only chosen aspects.

Suggestions for further research:

- extension of the internal combustion engine coherence testing method by modeling other damage elements of the internal combustion engine ignition spark;
- the use of measurement systems on different non-vibration symptoms of the technical state of combustion engines;
- develop a computer system that enables diagnostic decisions;
- extension of bench tests to other types of internal combustion engines, both spark ignition and diesel engines; and
- assess the usefulness of these methods on determining the coherence of other technical objects.

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