АВТОМАТИЗАЦІЯ ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ

STAND FOR CHECKUP AND DIAGNOSTICS OF THE STATE OF INDUSTRIAL OBJECTS

СТЕНД КОНТРОЛЮ ТА ДІАГНОСТУВАННЯ СТАНУ ПРОМИСЛОВИХ ОБ'ЄКТІВ

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Анотація. Висвітлено розроблення, дослідження та впровадження алгоритмічного, апаратурного та програмного забезпечення пристроїв контролю та діагностування складних динамічних промислових об'єктів. У ході досліджень вибрано промисловий об'єкт, визначено його основні технічні характеристики, розглянуто його базові вузли, виявлено найвразливіші місця. Такими виявились нагрівачі зон нагрівання, що відповідає інфранизькочастотним процесам, та підшипники кочення редуктора подвоювача, що відповідає високочастотним процесам.

Як система контролю та діагностування вибрана двоступенева система із первинним та вторинним статистичними перетвореннями. Цільовою функцією первинного статистичного перетворення вибрано функцію автокогерентності, на вхід якої надходять часові реалізації сигналів із вузлів промислового об'єкта, а на виході отримуємо вектор складових (шумових і функціональних) показника функції автокогерентності, які одержано у результаті дисперсійного розкладання. Вторинне статистичне перетворення реалізовано на базі лінійної дискримінантної функції, що дає змогу приймати рішення про результати контролю та діагностування.

Практичну реалізацію системи контролю та діагностування виконано на базі мікропроцесорного комплекту Arduino NANO із залученням персонального комп'ютера та вимірювальних каналів вібрації та температури. Для виконання алгоритмів контролю та діагностування скористались пакетом прикладних програм LabView.

Ключові слова: контроль; діагностування; вейвлет-перетворення; авто когерентність; вирішувальна функція; LabView; Arduino NANO.

Abstract. An article focuses on the development, research and implementation of algorithmic, hard- and software devices for controlling and diagnosing complex dynamic industrial objects. In the course of the research, the industrial object was selected, its main technical characteristics were determined, its base units were examined, and the most vulnerable sites were identified. There were the heaters of the heating zones, which correspond to the infra-frequency processes, and the bearings of the rolling gear reducer, which correspond to the high-frequency processes.

A two-level system with primary and secondary statistical transformations was selected as the control and diagnostic system. The target function of the primary statistical transformation is the auto-coherence function, to which the inputs of time signals from the nodes of the industrial object are received, and at the output, the vector of the component (noise and functional) indicators of the auto-coherence function is obtained by dispersion decomposition. Secondary statistical transformation is implemented on the basis of linear discriminant function, which allows making decisions about the results of control and diagnostic.

The practical implementation of the monitoring and diagnostic system is based on the Arduino NANO microprocessor kit, involving a personal computer and measuring channels of vibration and temperature. LabView software packages were used to perform the control and diagnostic algorithms.

Key words: Checkup; Diagnostics; Wavelet transform; Auto-coherence; Solving function; LabView; Arduino NANO.

Introduction

Improving the effectiveness of control devices and diagnosing the state of complex industrial objects with uncertain dynamic properties is an important scientific and practical task. In order to solve it, a number of issues related to the ultimate goal setting, the choice of technical objects (processes) of the study, the formation of the objective function, the detection of constraints on the parameters of industrial objects and control and diagnostic devices, the choice of research methods are to be solved.

The researches were conducted within the budget theme NDR K 6102 "Development of promising information-analytical technologies for control and diagnostic under conditions of a priori uncertainty" (DR 0119U002553) by the Department of Information and Measuring Technologies and Systems of the National Technical University "Kharkiv Polytechnic Institute" on two types of technological processes, namely: high-frequency (from 10 kHz) and infra-low-frequency (up to 1 Hz). These processes correspond to vibration and temperature parameters, respectively, and are the most used under industrial conditions.

A double-screw press extruder for molding plastic products was selected as the basic industrial object to study these processes [1]. This technological object consists of: an electric motor, a reduction gear, a redaction gear-branching device, screw conveyors, heating zones, a receiving hopper, a frame, an output matrix, and a control panel. In order to carry out the technological processes described by the equipment, it is necessary to ensure the advance of the input material from the receiving hopper along the heating zones to the output matrix together with the execution of grinding, heating, and mixing of raw materials. Accidental process termination leads to significant technical and economic losses.

Accidental process termination in press extruders is usually caused by the failure of the bearings of the reduction gear-duplicator or the overheating of the heaters in the heating zones. The control of the condition of the rolling bearings (high-frequency processes) and the heaters in the heating zones (infra-low-frequency processes), together with the identification of the breakage type, allows improving the technical and economic indicators during equipment operation. Checking and diagnosing the rolling bearings condition and heaters is carried out by a two-level stand with primary converters and an electronic interface unit at the lower level of the hierarchy and a coordinator who decides on the result of control or diagnostic at the top level. It becomes a problem to develop appropriate algorithmic, hard- and software for such a stand.

Downsides

The problems of controlling and diagnosing industrial sites are not new. There are many algorithms and monitoring and diagnostic devices available today. However, progress does not stay still; new technologies and equipment are emerging all the time, such as the significant development in recent years of applied wavelet transform theory, which is provoking the creation of new algorithms and monitoring and diagnostic devices.

The objective of the work

The objective of this work is to increase the efficiency of control devices and state diagnostic of complex industrial objects with restrictions on the time of observation, the amount of measurement information, the number of informative features, the number of training samples.

1. Development of algorithmic ware, software, and hardware

1.1. Development of algorithmic ware

To solve control and diagnostic problems, the following two models of statistical transformation are used:

– the primary statistical transformation to obtain a system of informative parameters;

– the secondary statistical transformation to choose the decisive rule – the decision-making algorithm.

The model of primary statistical transformation is shown in Fig. 1 [2].

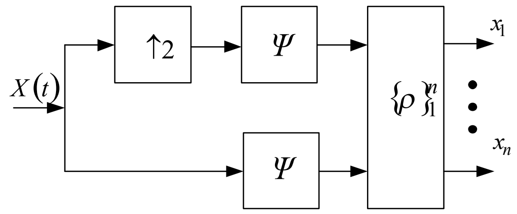


Fig. 1. Structural diagram of the primary statistical transformation: here: $\uparrow 2$ is the differentiation procedure; Ψ is the procedure of analog wavelet transform; $\{\rho\}_1^n$ is the procedure for calculating the auto-coherence indices by the scale and shift of wavelet transform

The scheme of Fig. 1 allows determining the characteristics of the primary transformation procedures: ξ – spectrum of the output process; η – spectrum after output differentiation; ρ_W – spectral non-stationarity of the process (auto-coherence). In the course of the research, a representative form of the auto-coherence function – the target function [3] was synthesized:

$$\rho_W = \frac{1+\lambda_D\lambda_\omega^2+\rho\left(1+\lambda_\omega^2\right)\sqrt{\lambda_D}}{\left[\left(1+2\rho\sqrt{\lambda_D}+\lambda_D\right)\left(1+2\rho\lambda_\omega^2\sqrt{\lambda_D}+\lambda_D\lambda_\omega^4\right)\right]^{-1/2}}, \quad (1)$$

where λ_D is the dispersion ratio of the wavelet transform process; λ_ω is the frequency ratio of the wavelet transform process; ρ is the linear correlation between the spectral components of the wavelet transform process.

We form the functional and noise components of the objective function. To do this, we present the two-dimensional implementation of the wavelet spectra of the primary statistical transformation model as follows:

$$\begin{cases} \delta_{ij} = W_\xi^2\left(a_i, b_j\right), \\ \varphi_{ij} = W_\eta^2\left(a_i, b_j\right), \end{cases}$$

where $i=\overline{1,M}$, $j=\overline{1,L}$. The average value for the frequency and time variants, taking into account the processes $\xi(t)$ і $\eta(t)$ has the form:

$$\begin{cases} \overline{\delta}_j = \overline{W}_\xi^2\left(b_j\right), \\ \overline{\delta}_i = \overline{W}_\xi^2\left(a_i\right), \\ \overline{\varphi}_j = \overline{W}_\eta^2\left(b_j\right), \\ \overline{\varphi}_i = \overline{W}_\eta^2\left(a_i\right). \end{cases}$$

Then the sum of the products of the spectra deviations δ_{ij} and φ_{ij} from the averages $\bar{\delta}$ and $\bar{\varphi}$ is determined as

$$Q=\sum_{i=1}^{M}\sum_{j=1}^{L}\left(\delta_{ij}-\bar{\delta}\right)\left(\varphi_{ij}-\bar{\varphi}\right).$$

Using dispersion decomposition: a) frequency-time – $Q=Q_1^{(a)}+Q_2^{(b)}$, b) time-frequency – $Q=Q_1^{(b)}+Q_2^{(a)}$, we obtain the functional and noise components of the auto-coherence function (1):

$$\begin{cases} Q_1^{(a)}=L\sum_{i=1}^{M}\left(\bar{\delta}_i-\bar{\delta}\right)\left(\bar{\varphi}_i-\bar{\varphi}\right), \\ Q_2^{(b)}=\sum_{i=1}^{M}\sum_{j=1}^{L}\left(\delta_{ij}-\bar{\delta}_i\right)\left(\varphi_{ij}-\bar{\varphi}_i\right), \\ Q_1^{(b)}=M\sum_{j=1}^{L}\left(\bar{\delta}_i-\bar{\delta}\right)\left(\bar{\varphi}_i-\bar{\varphi}\right), \\ Q_2^{(a)}=\sum_{i=1}^{M}\sum_{j=1}^{L}\left(\delta_{ij}-\bar{\delta}_j\right)\left(\varphi_{ij}-\bar{\varphi}_j\right) \end{cases} \quad (2)$$

The components (2) of the objective function (1) are the initial vector of the primary statistical transformation. This vector is supplied to the block of secondary statistical transformation, which scheme is shown in Fig. 2.

To implement the decision algorithm, we consider parametric discriminant functions: euclidean distance, linear, and quadratic. Studies have shown that a linear discriminant function having scalar representation has the form [4] is most appropriate for the case [4]:

$$g(x)=\sum_{i=1}^{n}\frac{\left(m_i^{(0)}-m_i^{(1)}\right)}{\sigma_i^2}\left[x_i-\frac{\left(m_i^{(0)}+m_i^{(1)}\right)}{2}\right], \quad (3)$$

where $m_i^{(0)}$, $m_i^{(1)}$ are the estimates of conditional averages for this i-n component $x(i)$, $i=\overline{1,n}$; σ_i^2 – variance estimation $x(i)$. By expression (3) a diagnostic solution γ_i is formed:

$$\begin{cases} \gamma_0 : \text{working object;} \\ \gamma_j : \text{object has } j\text{-}n \text{ functional disorder.} \end{cases} \quad (4)$$

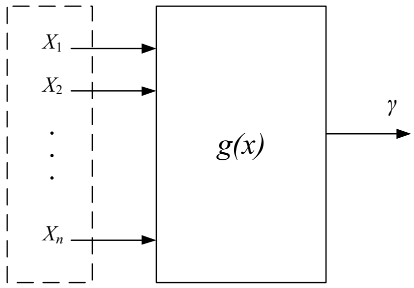


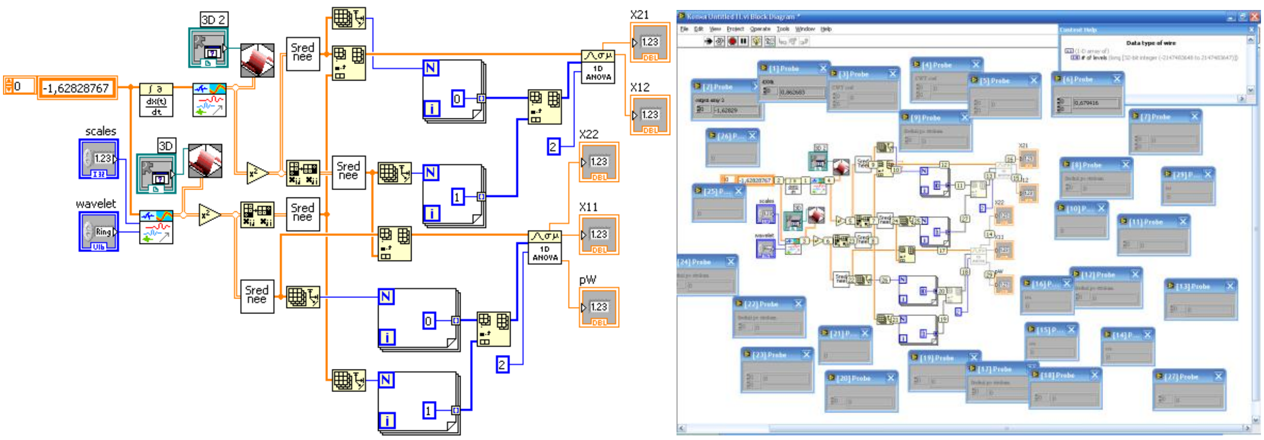
Fig. 2. Structural diagram of the secondary statistical transformation

1.2. Software

To automate the procedure of control and diagnostics according to the developed algorithm, we choose a package of LabView applications, which has proven the effectiveness of its use in solving engineering application problems. The implementation of primary statistical conversion using LabView (program and debugging procedure) is presented in Fig. 3 [5].

Fig. 4 presents the software implementation of the secondary statistical transformation.

When implementing the described programs, a virtual device for monitoring and diagnosing the state of industrial objects (Fig. 5) was created, its front panel is shown in Fig. 6 [5].



a *b*

Fig. 3. Primary statistical transformation software

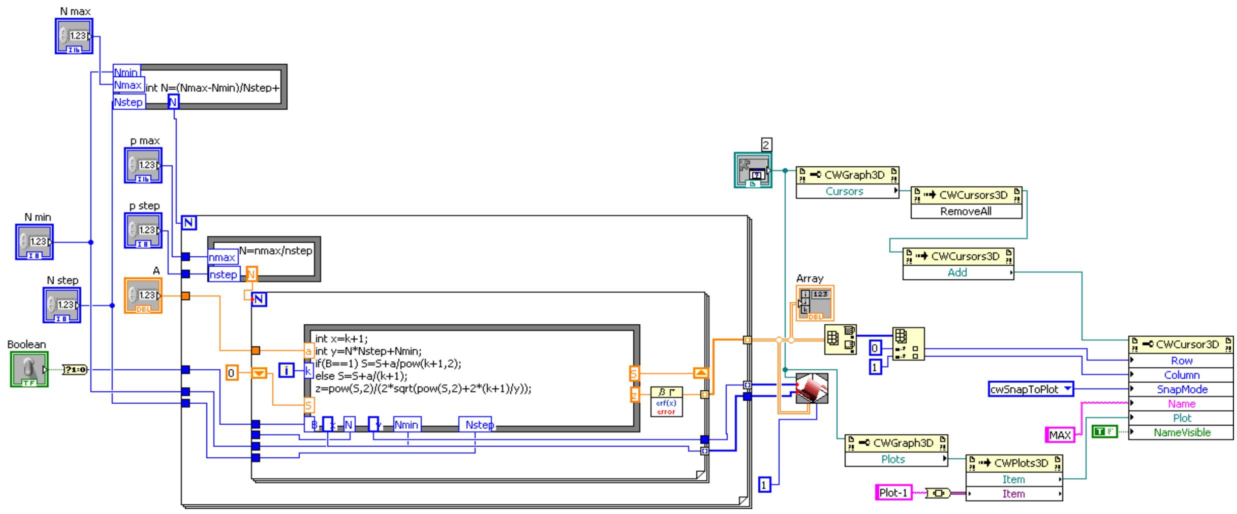


Fig. 4. Software implementation of secondary statistical transformation

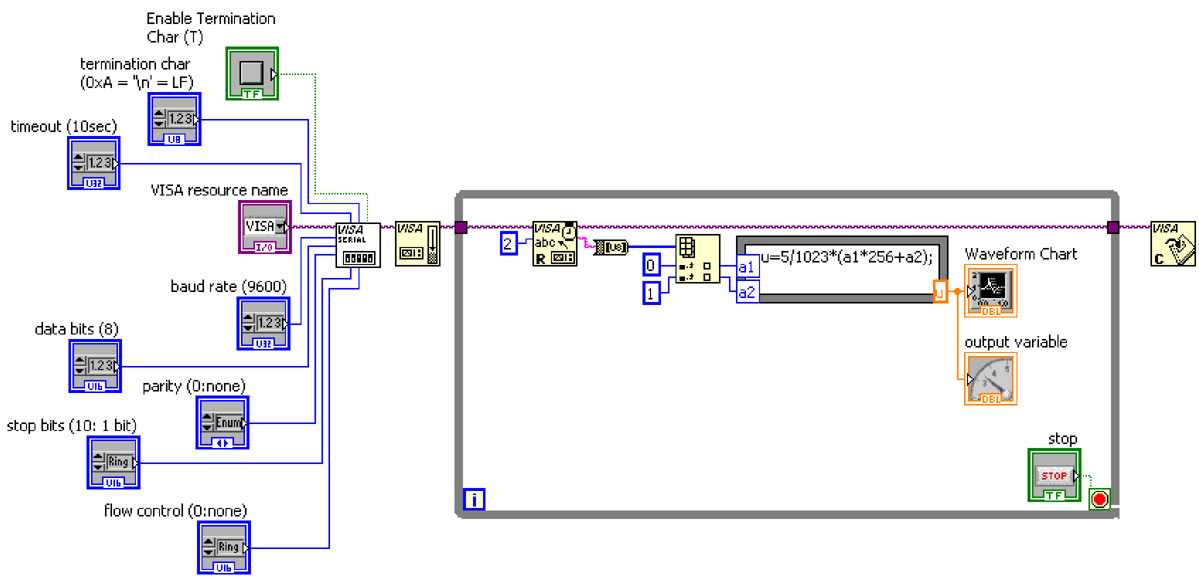


Fig. 5. LabView Virtual Control and Diagnostic Program

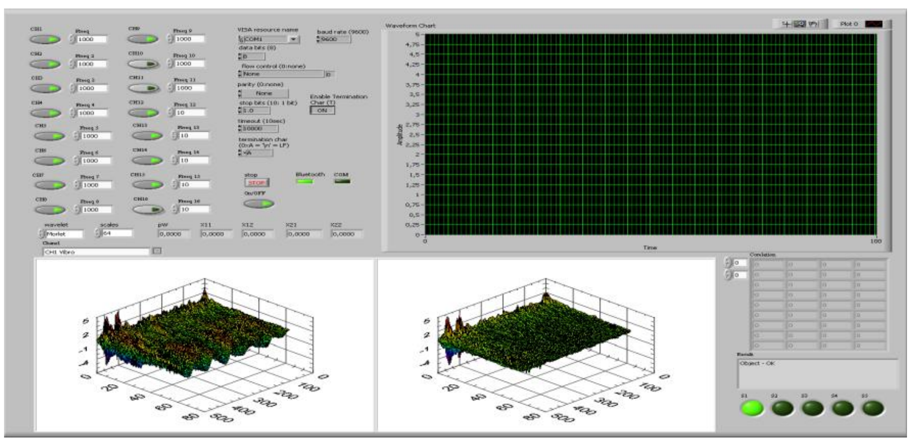


Fig. 6. The front panel of the virtual control and diagnostic device

The virtual control and diagnostic device has the following controls: COM port setting – Enable Termination Char, termination char, timeout, VISA resource name, baud rate, data bits, parity, stop bits, flow control; setting of measuring channels – Push Button (channel status – on/off), Numeric control (measurement frequency); state of the Push Button industrial monitoring and diagnostic device (channel status – on/off); virtual instrument stop – Button Stop, number of scales and type of mother wavelet using the Numeric “scale” and Enum “wavelet” controls respectively, the choice to display the wavelet spectra of ComboBox channels.

The following elements are used to indicate: Waveform Chart with data accumulation function, which allows observing changes of the measured value of the control and diagnostics device of the industrial objects state, indicator of Gauge instantaneous values, Numeric Indicator for display of calculated indices of the objective function of auto-coherence ρ_W, visualization in an ActiveX container that holds the 3D graph control, the covariance matrix is displayed in the Array indication element, and the control and diagnostic result is displayed by Round Led elements by states, and in text form in block String Indicator [6].

Hardware. To obtain the primary measuring signals reflecting high-frequency and infra-low-frequency processes, the hardware of the hierarchy lower level of the control and diagnostic device was developed. Fig. 7 presents a procedure for the formation of a stand consisting of blocks of temperature measurement and vibration, which send the measuring signals to the microprocessor platform Arduino NANO. An LCD screen, LEDs and a speaker are used for the display. The keyboard is used as controls. There are two interfaces to transmit the information received to the PC: Wired – COM port and Wireless – Bluetooth.

The developed control and diagnostics stand, which implements the procedures for monitoring condition of the nodes according to the output high-frequency and infra-low-frequency processes of a complex technological industrial object, is presented in Fig. 8 [7].

The stand was designed on the basis of a two-level system with local measurement information receivers at the lower hierarchy level (Arduino NANO) and a coordinator with functions of control and diagnostic algorithms (4) (LabView), at the top level.

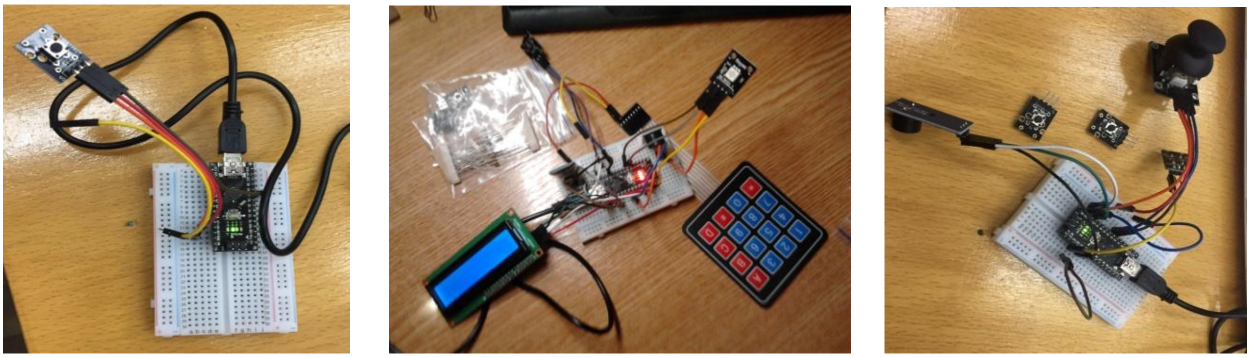


Fig. 7. The prototype of the control and diagnostic device

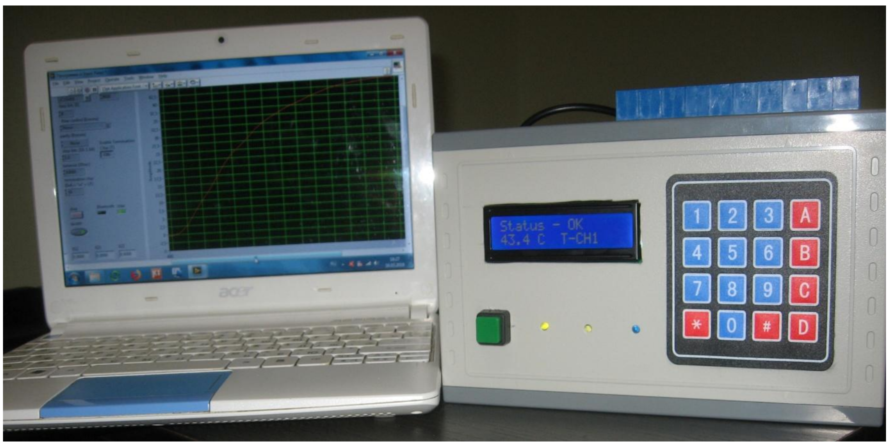


Fig. 8. Stand for monitoring and diagnosing the state of industrial sites

Results and discussion

In the course of the research, the following results were obtained:

– a probabilistic model of the auto-coherence index was developed and studied, taking into account the minimum values of the scale and shift of the spectral wavelet transform of the random components of the measuring signals of dynamic objects;

– the possibility of synthesizing the structure of the control and diagnostic device with linear discrimination of the parameters of the auto-coherence coefficients in the classification of high-frequency and infra-low-frequency measuring signals is substantiated;

– the LabView-enabled programming environment is defined and specialized software for solving specific problems of digital signal processing and modeling, building reliable control devices and diagnosing complex industrial objects is designed;

– checkup and diagnostic device necessary for the normal functioning of the synthesized algorithms are designed;

– hardware components (primary mechanical vibration transducers for high-frequency processes [8] and primary temperature transducers [9] for infralow-frequency processes) for monitoring and diagnosis devices are developed and patented.

Conclusions

The results of theoretical and practical research are implemented: at the state enterprise "Kharkiv Regional Scientific and Production Center for Standardization, Metrology, and Certification", at the Kharkiv Petro Vasylenko National Technical University of Agriculture, National Technical University "Kharkiv Polytechnic Institute".

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Conflict of interests

There was no conflict of interest when writing this article.

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