Research of vibroacoustic signals in diagnostics of technical condition of engines of beet harvesters combines

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Abstract. The authors of the experimental studies have proved from the possibility of vibration signals to detect the faults and changes in the parameters of the technical condition of engines of beet harvesters combines at the primary stages of their occurrence. Ensuring the predicted reliability of the conclusions, regarding the technical condition of the mechanisms and system of the engine, it can be achieved using the statistical evaluation of the correspondence of the temporal frequency fragments of the vibroacoustic signals and their correspondence to the rotational speed of the crankshaft. The authors investigated the difference between physical models and methods of the mathematical description in different parts of the frequency range and proved the feasibility of dividing it into three frequency subbands: low (0–200 Hz), medium (200–1000 Hz) and high (1 to 10–20 kHz). The authors found out that the series of harmonic signals of engines are characterized by the amplitudes, frequencies and initial phases, whose algebraic sum of ordinates at any given time is equal to the ordinate of the non-sinusoidal signal. Therefore, the Fourier series should be written as the sum of an infinite number of harmonic components of different frequencies. To distinguish the spectrum of the vibroacoustic signal in the diagnosis of the technical condition of engines of beet harvesters combines, it is necessary to use a Fast Fourier Transform. The processing of vibroacoustic signals in the diagnosis of the technical condition parameters of engines of beet harvesters combines is carried out using digital filters, which are implemented by the author's algorithm.

1. Introduction

One of the areas of development of mobile diagnostic systems for estimating the state of internal-combustion engine is the speed of collection and reliability of information, as well as reduction of cost of hardware equipment and software [1]. The problem of the use of vibration analysis methods is the lack of easy-to-use systems of analysis of vibroacoustic signals [2]. Proposed in the article system of input and processing of analog signals is intended for measuring and digital processing of vibroacoustic signals during vibrodiagnostics [3].

The possibility of detecting faults in the initial stages of their occurrence with low labor and material costs determine the perspective of diagnosing the state of internal-combustion engine by vibration...
signals [4]. Implementation of predicted reliability of the conclusions [5], regarding to the state of mechanisms and systems, can be achieved by using statistical evaluation of the correspondence of temporal frequency fragments of vibroacoustic signals and their correspondence to the frequency of rotation of the crankshaft [6].

The use of modern compact measuring modules with low energy costs enables designing and manufacturing of diagnostic devices in mobile version for installation directly on the tool during testing [7]. Thereby, research aimed at developing a methodology for diagnosing mechanisms and systems based on the evaluation of vibroacoustic signals generated in the internal-combustion engine during operation, as a method of control is quite relevant for agriculture [8]. To develop a virtual device for input, generation, simulation, and digital processing of vibroacoustic signals during vibrodagnosis of internal-combustion engine of beet harvesters combines.

2. Materials and methods

One of the methods of establishing the correspondence between the defect vector at the input of mechanical system and the vector of diagnostic features at the output is to perform experiments using working and defective objects of diagnostics [8]. However, the internal structure of the object of diagnostics, which is usually considered as a "black box", is not analysed in detail. This approach requires considerable time and material resources [9]. In order to reduce the amount of expensive and long-term experimental researches, diagnostic modelling of defects is carried out, so the physical or diagnostic interpretation of the connection of the state space of an object with the space of diagnostic features and is established with the use of diagnostic model of the object [10]. The complexity of the vibroacoustic processes generated by the machines, the difference between physical models and methods of their mathematical description in different parts of the frequency range were the basis for dividing it into three frequency subbands: low (0-200 Hz), medium (200-1000 Hz) and high (from 1 to 10-20 kHz). The vibrations of internal-combustion engine frame are complex, caused by the impulse excitation and multichannel propagation of oscillations, also by the presence of uncontrolled "noise". Therefore, during vibroacoustic diagnosis of internal-combustion engine is a difficult task to separate the signals and isolate the signal from the connection [11]. The modern world dictates its new rules and approaches on options of instruments for vibroacoustic research. Most researchers and institutions do not have sufficient financial resources to purchase an expensive oscilloscope or spectrum analyzer. The use of known modelling systems such as LabView and MathLab for modelling processes also has some disadvantages.

Let's consider Digital signal processing and the use of different devices to solve these problems [12]. The Digital signal processor (also known as DSP) is a microprocessor that performs mathematical operations on streams of digitalized signals in real time. To process analog signals is necessary to digitalize them (figure 1) using the analog of digital conversion with incoming anti-aliasing filters, and then send the digital data stream to the signal processor. After performing the necessary mathematical operations, the signal can be converted back to analog using a digital-to-analog converter and a corresponding smoothing filter. Conventional ready-made devices, such as oscilloscopes, use specialized DSP-based systems with limited functionality [13]. However, as an oscilloscope, you can use a regular computer with a data collection board installed in it. In this case, the board digitizes the analog signals, and the digital data processing function is transferred to the central processing unit. At the heart of this modular approach, which reflects the concept of virtual instruments (virtual instrumentation), is powerful software that can be adapted for use on a standard PC to implement a ready-made device with the required functionality.

Powerful virtual appliance development tools have enabled people with different levels of professional skills to quickly design and implement completed test and measurement systems. Until recently, specific design tools and extensive professional experience were required in the design and implementation stages of engineers. Historically, measuring test systems have typically consisted of separate finished devices, such as oscilloscopes and signal generators, which have limited functionality and are only used for a specific set of measurement tasks. Among these limitations are three main: 1) the
inability to collect data with the required accuracy and speed; 2) a limited set of data acquisition and processing functions built into the device; 3) insufficient visualization of the measurement process due to the limited screen capabilities of the instrument.

3. Results and discussion

The analog signal obtained as a result of this conversion using the advanced direct connectis converted into numerical values in a binary number system, that is, in the form of zeros and ones. However, today's computers are already equipped with powerful sound cards, which are the necessary equipment needed to work with vibration. A modern sound cards with a sampling rate of 96 or even 192 kHz allows you to control frequencies of up to 100 kHz (Nyquist frequency $F_S=2F_{max}$, far beyond the audio frequency). The idea of using a PC sound card is not new. The virtual measurement system created on its basis uses sound card as analog-to-digital and digital-to-analog converters, allowing to digitalize the analog signal and then to qualitatively analyze it and carry out its processing. These are a two-beam oscilloscope and spectrum analyzer or frequency meter etc. At the Department of technical service and engineering management named after Mykola Momotenko of NULES of Ukraine, based on these considerations was made an attempt to develop a virtual device for digital processing of signals received from the sound card (figure 2).

The Virtual Digital Signal Processing program is developed for capturing the signal received at the computer sound card input, processing the signal using DSP algorithms, and outputting the processed signal through the sound card output. The program is based on the intuitive principle of visual programming, which allows the user without knowledge of programming languages and DSP algorithms to create arbitrary signal processing schemes, during working with visual components (processors), and developers of digital signal processing programs can save time for developing and adjusting their programs. This technique develops that it is always possible to pick up a number of harmonic signals with such amplitudes, frequencies and initial phases, whose algebraic sum of ordinates at any given time is equal to the ordinate of the non-sinusoidal signal. The Fourier series is written as the sum of an infinite number of harmonic components of different frequencies.

$$U(t) = U_o + SUM \left( U_m \cdot \sin(k \cdot \omega \cdot t + \psi) \right),$$

where: $k$ – harmonic number; $k \cdot \omega$ – angular frequency of the k-th harmonic; $\psi$ – the initial phase of the signal; $U_o$ – zero harmonic.
Figure 2. DSP Virtual Device Main Window.

A high-frequency Fourier transform is usually used to isolate the spectrum of the vibroacoustic signal. The obtained spectral density results (figure 3) can be used for further analysis and processing using digital filters, which are implemented according to the algorithm (figure 4).

Figure 3. Processing implementation (spectral density, filtration).

The program functions and can be used: low pass filter (LowPass) transmits components in the lower range and reduces the components of the upper frequencies; high pass filter (HighPass) transmits
components in the upper range and reduces the components of the lower frequencies; bandpass filters (BandPass) transmit components that correspond to a particular bandwidth; notch filter (BandReject) reduces the amplitudes of the components of a certain band (barrier). The program is not a finished product, and its functionality is gradually improving and expanding (algorithms are optimized, new processors are created, bugs are fixed, etc.). At the moment, the main tasks that the program allows to solve are: signal visualization (display of a signal on a graph depending on the amplitude with time); spectral analysis (display of the spectral density diagram); frequency filtering of the signal (influence on the signal of LF, HF, bandpass and notch filters). The program also has handlers that allow you to estimate the signal level, the frequency of the fundamental harmonic, the correlation coefficient of 2 signals and so on. Using a virtual instrument, you can create and simulate different processes (figure 5) using generators, adders, signal multipliers, etc.

![Figure 4. Listing of digital filters implementation.](image)

![Figure 5. Simulation of the total signal from generators and their processing.](image)

Each component handler has its own settings panel. In addition, the program can perform signal amplification, amplitude modulation, division of the spectrum into low and high components, set the time delay, the calculation of the correlation coefficient of two signals, etc. Other useful features include
storing information about the most recently saved projects, calibrating the signal, reading wave files recorded by other programs, changing the number of channels in the component handlers.

4. Conclusions
Virtual gadget technology is a method that has already proven itself for developing and building test systems. This unique approach offers enormous opportunities for design engineers who need the only one tooling environment for designing, testing and implementing ready-made solutions.

The virtual instrument for the introduction and digital processing of measurement information for the system of vibration diagnostics of diesel engines of beet harvesters combines offered in this article can be used in different scientific and industrial activities.

References
[1] Ivanov A, Konovalov V, Lyandenbursky V, Rodionov Y and Zakharov Y 2020 Diesel engine diagnostic training program E3S Web of Conferences 164 12009
[2] Partko S and Sirotenko A N 2020 Self-oscillation in agricultural mobile machine units Journal of Physics: Conference Series 1515 042084
[3] Rogovskyi I, Titova L, Novitskii A, Rebenko V 2019 Research of vibroacoustic diagnostics of fuel system of engines of combine harvesters Engineering for rural development 18 291-298
[4] Zhang F, Jiang M, Zhang L, Ji S, Su Q, Su C and Lv S 2019 Internal combustion engine fault identification based on FBG vibration sensor and support vector machines algorithm Mathematical Problems in Engineering 2019(4) 1-11
[5] Parkhomenko G G, Voinash S A, Sokolova V A, Krivonogova A S and Rzhavtsev A A 2019 Reducing the negative impact of undercarriage systems and agricultural machinery parts on soils IOP Conference Series: Earth and Environmental Science 316 012049
[6] Chausov M, Brezinova J, Pylypenko A, Maruschak P, Titova L and Guzanova A 2019 Modification of mechanical properties of high-strength titanium alloys VT23 and VT23m due to impact-oscillatory loading Metals 9(80) 2-18
[7] Hrynkiv A, Rogovskyi I, Aulin V, Lysenko S, Titova L, Zagurskiy O and Kolosok I 2020 Development of a system for determining the informativeness of the diagnosing parameters of the cylinder-piston group of the diesel engines in operation Eastern-European Journal of Enterprise Technologies 3(105) 19-29
[8] Rogovskyi I L, Titova L L, Trokhaniak V I, Marinina L I, Lavrinenko O T and Bannyi O O 2020 Engineering management of machine for formation of artificial shell on seed vegetable cultures INMATEH Agricultural Engineering 61(2) 165-174
[9] Dubbini M, Pezzuolo A, DeGiglio M, Gattelli M, Curzio L and Covi D 2017 Last generation instrument for agriculture multispectral data collection CIGR Journal 19 158-163
[10] Hrechanyi O, Kobrin Y, Vasilenko T, Ignatiev A, Kuzmenko R and Shevchenko I 2020 Using of frequency models for technical diagnostics disrepairs of metallurgical equipment Metallurgy 2(42) 94-99
[11] Bonfiglio P, Pompoli F and Simone D 2018 Vibro-acoustic condition monitoring of internal combustion engines: a critical review of existing techniques Mechanical Systems and Signal Processing 99 661-683
[12] Sirotenko A and Partko S 2019 The influence of initial parameters of pneumatic accumulator on the dynamic characteristics of the actuator during braking back pressure Journal of Physics: Conference Series 1399 044098
[13] Pinto P, Gouveia J and Ramos P 2015 Development, implementation and characterization of a DSP based data acquisition system with on-board processing Actalme Ko 4(1) 19-25