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MULTI-CHANNEL HARDWARE AND SOFTWARE COMPLEX FOR MONITORING AND ANALYSING VIBROSIGNALS

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The description of complex construction and operation principles for vibrosignal analysis is presented. The distinguishing feature of the complex is application of the wavelet analysis method. Peculiarities of wavelet transformation when solving the problems of mechanical system vibrodiagnostics in comparison with the Fourier analysis are shown. Hardware and software model of measuring complex has been created; its tests have been carries out.

Introduction

Decrease in maintenance cost, increase in reliability, efficient and safe operation of mechanical equipment can be also provided by creation of equipment monitoring and diagnostics system based on the principles of non-destructive inspection. One of the directions based on these principles is vibroanalysis of moving armature of mechanisms and units. In the market a large number of devices and systems allowing for monitoring and analysis of mechanical system of different kind are presented. However, when choosing them the consumer comes up against the different limitations connected with capacities of suggested equipment. For example, wavelet-analysis in diagnostic devices of mechanical systems has just begun to be used and in most devices it is not presented, absence of support for local communication line, absence of the history of performed measurements, absence of possibility to localize the spot of destruction process in the mechanism etc.

Development of multi-channel programme-production unit for monitoring and analysis of vibrosignals sets the purpose of designing extendable system with good parameters and possibility to apply wavelet-analysis to the signals generated from mechanical system and devices as well as multichanneling, possibility of connection in one monitoring network, presence of spectral-temporary wavelet-analysis [1], operation in real time, wide frequency range, localization of events by the method of time localization, automation of unit tracking in controlled devices, introduction of transformation history.

Application of wavelet-transformation for the analysis of harmonic signals

Wavelet-analysis is coming into use in vibrodiagnostics and until now is few and far between measuring devices and complexes. Along with conventional methods of digital signal processing application of wavelet-transformation in signal analysis extends the capabilities of investigation. The traditional Fourier transformation is a useful mathematical apparatus for analysis and synthesis of simple and periodic signals. It displays the advantage of easy realisation over wavelet-transformation. On the other hand, wavelet-transformation permits for revealing the signal peculiarities in the case when the Fourier-transformation is insensitive to signal peculiarities. Fig. 1 shows the example of periodic time signal with surge at positive half-period. Below its spectra are presented: the Fourier-spectrum (Fig. 2) and wavelet-spectrum (Fig. 3). It is seen from the Fourier-spectrum that only one harmonic is distinctly isolated characterising periodic signal. It is difficult to judge on the presence of high-frequency surge. The reduced wavelet-spectrum was obtained by means of discrete version of integral wavelet-transformation using the Gaussian wavelet of the second order – «Mexican hat» [2, 3]. This analyzing wavelet was chosen experimentally as one giving good results applicable to the signals analysed. The Gaussian wavelet-functions are partial derivatives from the Gaussian function and are defined by the following relationships:

$$\psi_m(t) = (-1)^{m+1} \cdot d_t^m \left[\exp\left(-\frac{t^2}{2} \right) \right],$$

$$\widehat{\psi}_m(\omega) = m \cdot (i\omega)^m \cdot \exp\left(-\frac{\omega^2}{2} \right),$$

where $d_t^m = d^m[f(t)]/dt^m$, $m \geq 1$. In our case $m=2$.

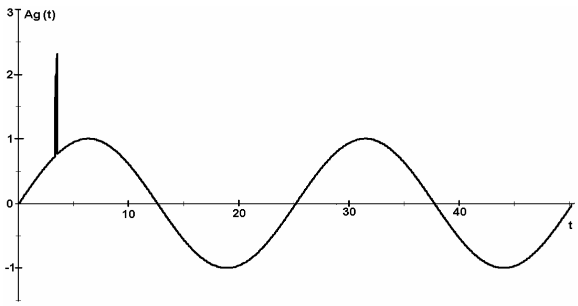

Fig. 1. *Example of periodic signal with the surge at positive half-period*

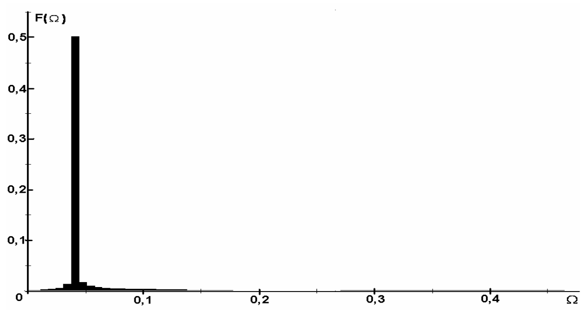

Fig. 2. *The Fourier spectrum of periodic signal with the surge at positive half-period*

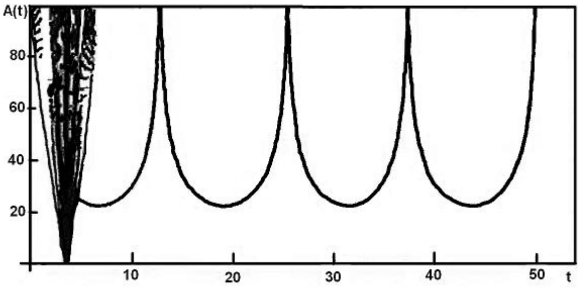

Fig. 3. *Wavelet-spectrum of periodic signal with the surge at positive half-period*

It is seen from the wavelet-spectrum that the signal is periodic in time. This fact is demonstrated by the presence of repetitive «parabolas» in spectrogram. The surge at one of the half-periods is particularly expressed in spectrogram; it is seen in the form of «reversed» triangle. The presence of the given acute peak in spectrogram allows us not only to judge about nonlinearity in the signal, but also to determine its position.

Then, in Fig. 4 the example of compound signal with frequency and amplitude modulation is presented. Below the Fourier-spectrum (Fig. 5) and wavelet-spectrum (Fig. 6) are shown.

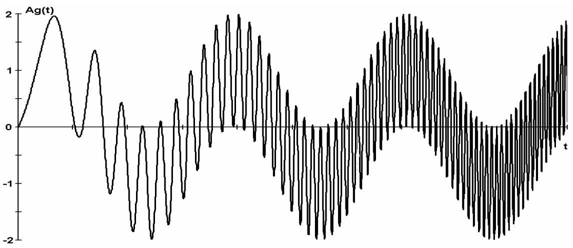

Fig. 4. *Example of compound model signal*

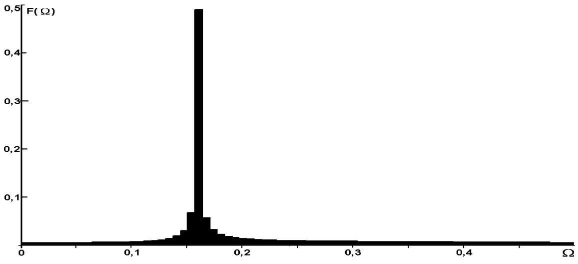

Fig. 5. *The Fourier spectrum of compound model signal*

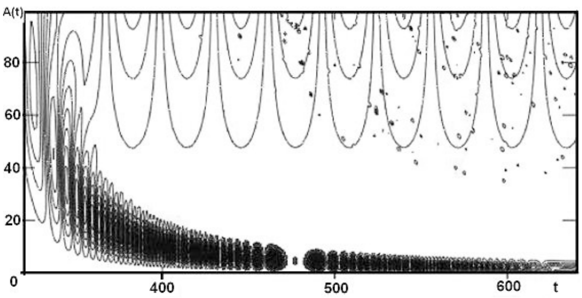

Fig. 6. *Wavelet-spectrum of compound model signal*

Only one clearly defined harmonic characterising modulated periodic signal is evident from the Fourier-spectrum. To judge the presence of the second modelling sinusoid with variable time frequency from this Fourier-spectrum is impossible. The wavelet-spectrum of analysed model signal (Fig. 6) demonstrates that there are two signals: the signal with constant low-frequency harmonic («parabola» above) and the signal with increasing frequency in time (the bottom of spectrogram). It is evident that modelling signal changes smoothly, without jumps. Thus, the Fourier analysis of the reduced model signal does not allow for revealing some local features, whereas, wavelet-analysis clearly defines them with the accuracy to the time of appearance. The crucial role in wavelet-analysis is played by the choice of base wavelet. Using different wavelet-functions one can reveal and underline particular properties of the signal analysed to a fuller degree extending the capabilities of analysis.

Hardware component

When designing hardware component of the complex we have taken into account that the part of equipment which is not specific one and whose tasks do not include standard functions, such as data storage, results display on the screen, human interface etc, is to consists of ready standard units. This permits for decreasing the design time since it gives the possibility to use the standard means. Simplified structural diagram of the hardware component is presented in Fig. 7. Complex hardware component consists of multi-channel processor module of primary data collection and processing connected with the secondary processing module and screen output by Ethernet interface. Application of Ethernet interface and special-purpose communication protocol makes possible to attach some homogeneous primary modules to one secondary module that makes the complex structure extensible and allows for monitoring significant number of units and aggregates.

The tasks of the primary module include vibration detector data digitization, their pre-processing, and data preparation for sending them to the secondary module. To solve these problems the primary module should contain analogue-digital transformer, microprocessor and MAC+PHY Ethernet controller. The basic characteristics of the measured parameters are defined by the most part of operating characteristics of vibration detector; therefore, the measurement error and primary module influence on vibration detectors are minimized. As a rule, an accelerometer transforming acceleration into electrical signal is used as a vibration detector. In the market there is a great choice of element base for realisation of the primary module. Let us dwell on one of the possible realisations. Module of the primary processing can be designed on the bases of microcontroller of MSP430 family (Texas Instruments) and CS8900A as a MAC+PHY Ethernet controller (Crystal Semiconductor Corporation). The module realised on this element base is capable of solving the problems put for it.

As a secondary module it is appropriate to apply the computer with operation system Linux control with mainboard of mini-ITX format (size 170×170 mm) and touch LCD. For example, the plate EMB-9680 of Evalue Technology Company has a wide functionality and

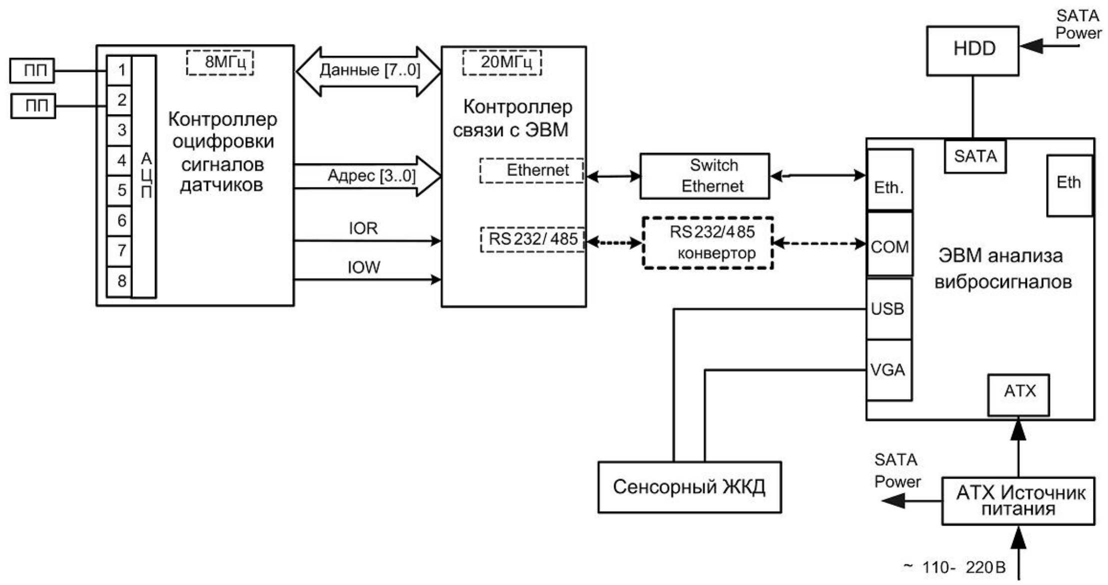

Fig. 7. *Simplified structural diagram of the complex hardware component*

АЦП – analogue-digital transformer; МГц – MHz; Контроллер оцифровки сигналов датчиков – Controller of detector signals digitization; Данные – Data; Адрес – Address; Контроллер связи с ЭВМ – Controller of connection with computer; Конвертор – Convertor; ЭВМ анализа вибросигналов – Computer of vibro-signals analyses; Сенсорный ЖКД – Touch LCD; ATX источник питания – Power supply

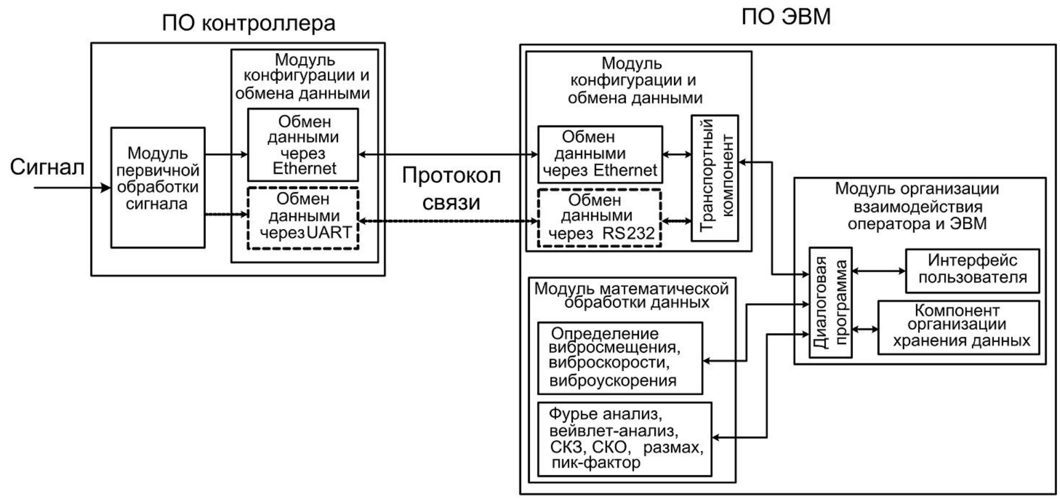

Fig. 8. *Simplified structural diagram of the software*

Сигнал – Signal; Модуль первичной обработки сигнала – Module of signal primary processing; Модуль конфигурации и обмена данными – Module of configuration and data exchange; Обмен данными через Internet – Data exchange through Internet; Обмен данными через UART – Data exchange through UART; Протокол связи – Connection protocol; Транспортный компонент – Transport element; Модуль математической обработки данных – Module of mathematical data processing; Определение вибросмещения, виброскорости, виброускорения – Definition of vobro-displacement, vibro-rate and vibro-acceleration; Фурье анализ, вейвлет-анализ, размах, пик-фактор – The Fourier analyses, the wavelet analyses, range, peak-factor; Модуль организации взаимодействия оператора и ЭВМ – Module of interaction organization between operator and computer; Диалоговая программа – Dialogue program; Интерфейс пользователя – User interface; Компонент организации хранения данных – Component of data storage organization

low cost. It supports the processors Intel Pentium M and Celeron M with the frequency of system bus 400/533 MHz. The model EMB-9680 is designed on the bases of chip set Intel 915GM (southbridge ICH6-M) and provided with built-in graphics controller Intel Graphics Media Accelerator 900 (Intel GMA 900), network controller 10/100 Ethernet. Maximum memory capacity of DDR SDRAM is 1 Gb, it is acceptable to connect two devices with SPI Serial ATA (capacity up to 150 Mb/sec). The plate is intended for the operation with control of Linux operation system. Thus, hardware component is partially realised in standard solutions significantly accelerating development and permitting for quick adaptation of the complex for quick-changing technologies.

Software part

The software consists of functional programme modules transforming vibro data, their primary processing, networking to the device of the secondary processing, analysis and retention of the data obtained. In Fig. 8 the simplified structural diagram of software consisting of two main modules is presented: software of controller (primary module) and software of computer (secondary module). In its turn, the controller software (primary

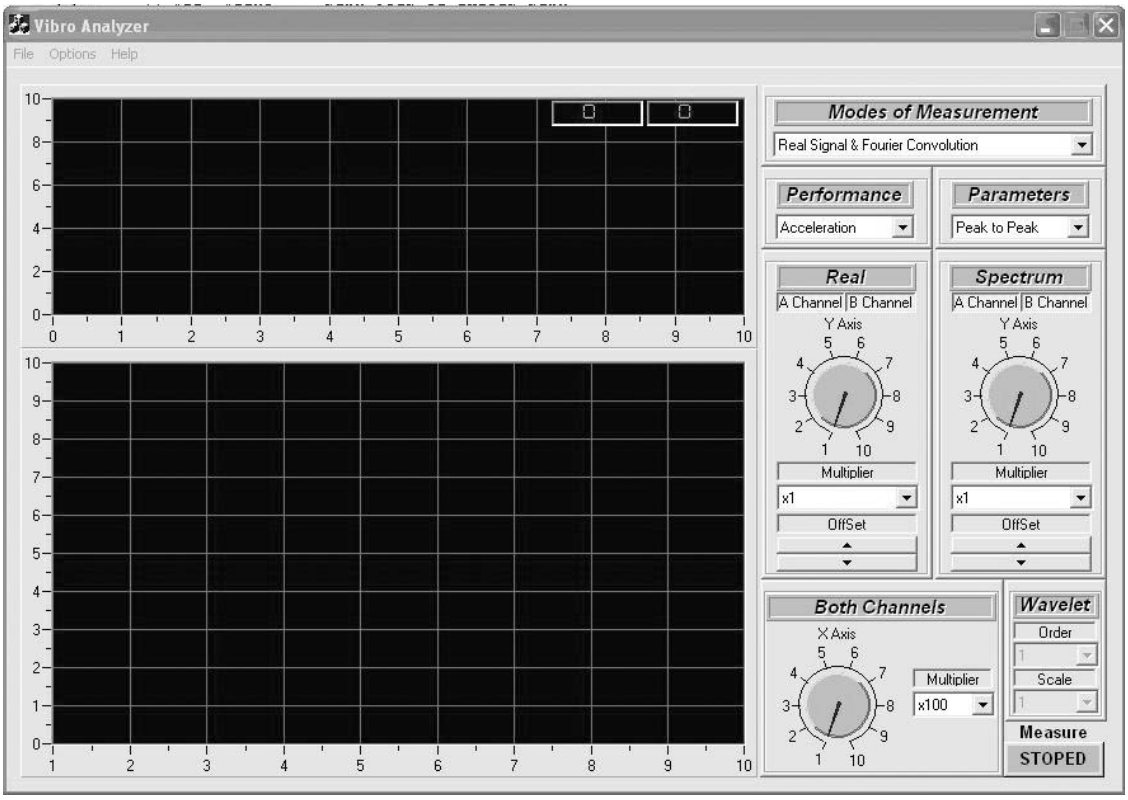

Fig. 9. *The appearance of user interface of vibroanalyser programme*

module) consists of two parts: module of signal primary processing and configuration and data exchange module. The module of signal primary processing is realised in vibroanalyser prototype [4]. The configuration and data exchange module provides the connection of controller with computer by communication interface.

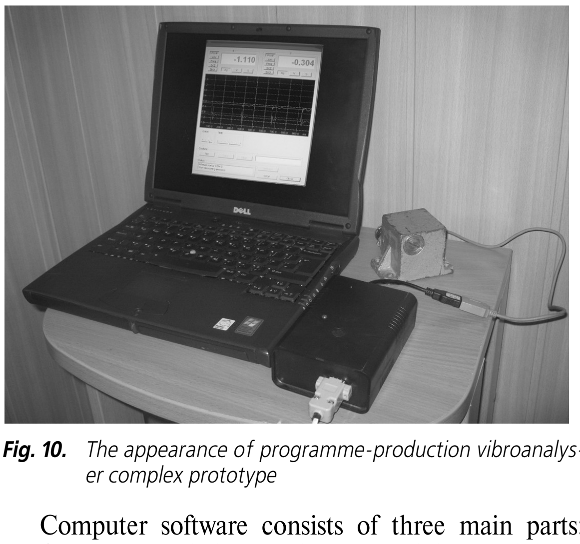

Fig. 10. *The appearance of programme-production vibroanalyser complex prototype*

Computer software consists of three main parts: configuration and data exchange module, module of mathematical data processing, module of operator and computer communication. The configuration and data exchange module has similar function as the controller module of the same name has. A distinguishing feature of the module is the presence of transport element for interfacing software with different kinds of hardware communication interface. The function of the mathematical data processing module is to investigate the signal behavior in oscillograph mode, estimation of vibrosignal basic parameters, behaviour of the Fourier- and wavelet-analysis. Controller and computer are connected by means of developed communication protocol due to which one can use the branched system of data collection from the primary modules. In Fig. 9 the appearance of vibroanalyser executable code is shown.

User's application on display screen reflects the signal in real time mode, its spectrum and one of the parameters simultaneously: mean-square value, mean-square deviation, peak-to peak or peak factor. Let us enumerate the main function realized in the program:

1. transformation selection (Fourier or wavelet), base wavelet, its scale (or range of scales);
2. measured vibroparameter selection (acceleration, velocity or displacement), as well as the parameter characterising the signal (mean-square value and deviation, peak-to-peak, peak factor);
3. change in gain in along the ordinate and abscissa;
4. signal or its spectrum reflection/concealment for separate channel;
5. addition of constant element to the signal or its spectrum.

Additional functions: hardware interface selection, run/shutdown of measurement, record/reading the file data and their screening, clocking the operation of primary processing modules, monitoring of the system equipment state.

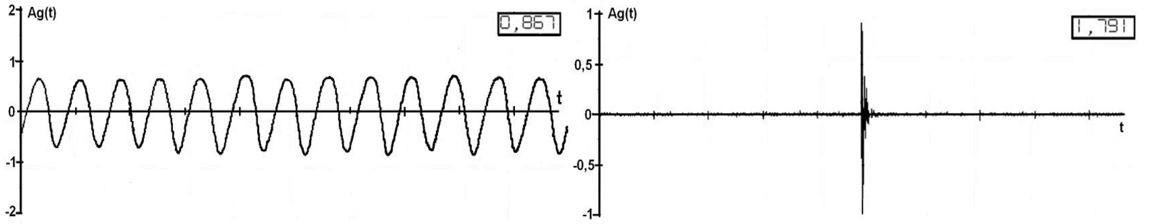

Fig. 11. *Graphs of harmonic and pulse signals at the prototype output*

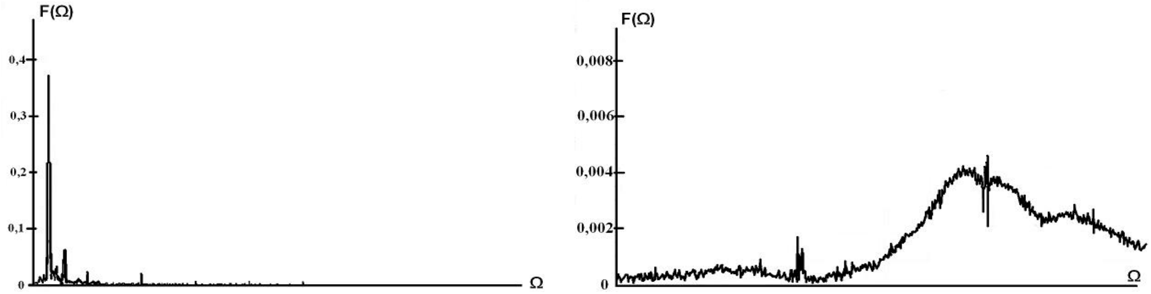

Fig. 12. *Fourier-spectra of harmonic and pulse input signals produced at prototype*

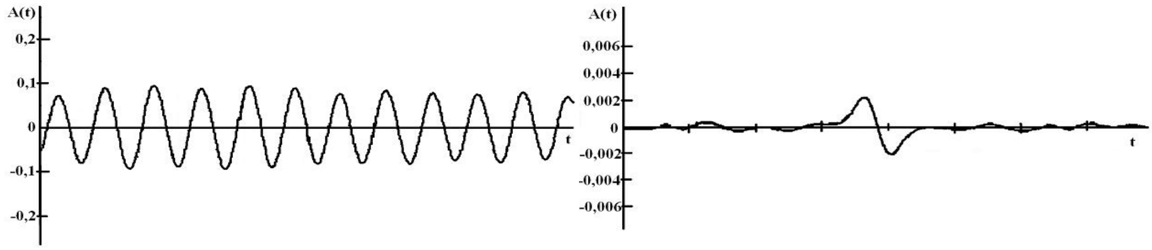

Fig. 13. *Tails of wavelet-spectra of harmonic and pulse input signals generated at prototype*

Operating complex prototype

Laboratory prototype of vibroanalyser programme-production complex has been developed in the course of laboratory research on non-destructive control of movable parts and units. Fig. 10 demonstrates the appearance of operating prototype of programme-production vibroanalyser complex.

The prototype of primary processing module [4] is performed on the basis of ADXL210 accelerometer, debugging set AsmegaM of ArgusSoft production and specially developed software. As a module of secondary processing a personal computer with the specially developed software in C/C++ language is used. Let us give the examples of the signals and the results obtained by operating prototype at their processing in real time mode. In Fig. 11 the graphs of harmonic and pulse input signals produced from the module of primary processing are shown. In Fig. 12, 13 the Fourier- and wavelet-spectra of these signals respectively are presented.

Conclusion

The use of wavelet-transformations in programme-production unit of vibroanalyser makes possible to perform frequency-time analysis of vibrosignals. As the experiment has shown, the transformation permits for the study of properties in measured vibration signals in details. The differences in the Fourier and wavelet-spectra self-descriptiveness are presented by the example of test signals. Measurements of vibrosignals for more number of points and branched system of data collection on the state of diagnosed equipment becomes possible owing to communications protocol specially designed for network between the module of secondary processing and a set of modules of primary processing. On the basis of realised prototype of programme-production complex the laboratory investigations and tests necessary for production of serial device sample have been made.

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