Journal of Engineering and Applied Sciences 11 (Special Issue 2): 3153-3166, 2016
ISSN: 1816-949X

Technical State Control of Workpieces and Gas Engine Finished Parts Using Measuring-Diagnostic Unit

M.F. Nizamiev, I.V. Ivshin and O.V. Vladimirov
Department of Technical Sciences, Kazan State Power Engineering University,
Krasnoselskaya St. 51, Kazan, Russia

Abstract: A Measuring and Diagnostic Unit (MDU) is designed and developed with a special software for technical condition monitoring concerning blanks, finished parts and prospective gas engine mechanisms. Theoretical and experimental studies were performed in respect of blanks, finished parts and gas engine mechanism vibration characteristics to determine their technical condition with MDU use. The method of defect determination was proposed concerning blanks, finished parts and mechanisms of gas engines with MDU use.

Key words: Measuring and diagnostic unit, software, vibration characteristics, TC turbine casing, electromagnetic gas feeder, gas engine

INTRODUCTION

The control of gas engine technical state is an important way of product quality improvement and operating cost reduction. Modern methods of a gas engine technical condition monitoring allow to identify a defect at an early stage of its appearance, to predict its development and to determine the amount of maintenance and repair works. A vibration method is the most objective one and sensitive to defects among numerous existing technical condition monitoring methods which allow to apply computer technologies (Ivshin, 2009; Belov *et al*., 1996).

The vibration characteristics of an engine contain quite a lot of information about the technical condition of an engine, its components and parts. The existing methods of vibration diagnostics need to be improved. The development and improvement of vibration diagnostics methods for the determination of a gas engine parts, assemblies and mechanisms technical condition is an actual problem.

MATERIALS AND METHODS

Measuring and diagnostic unit to monitor the technical condition of gas engine blanks and finished parts: In order to determine the technical condition of parts, assemblies and mechanisms by vibration parameters on the basis of the department “Power supply of industrial enterprises” at “Kazan State Power Engineering University” a measuring and diagnostic unit (7) was designed and developed. This unit includes measuring devices and a software-algorithmic support. The measuring equipment includes acoustic emission transducers 1 with matching devices 4, laser vibrometers 2, multi-function input-output module 5, personal computer 6 (Fig. 1). Software and algorithmic support includes software 7 developed in graphic programming environment LabVIEW 13.0 (Blum and View, 2008).

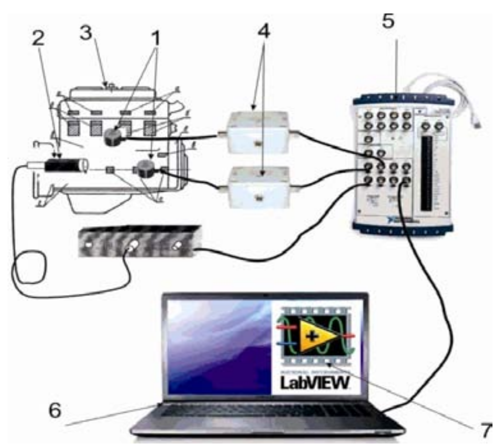

Fig. 1: Measurement and diagnostic system scheme: 1) acoustic emission converter; 2) Laser vibrometer; 3) The object of study; 4) Matching devices; 5) Multifunction input-output module; 6) Personal computer; 7) “National Instruments” software

Corresponding Author: M.F. Nizamiev, Department of Technical Sciences, Kazan State Power Engineering University, Krasnoselskaya St. 51, Kazan, Russia

The peculiarity of designed measuring equipment is the use of laser vibrometers as measuring sensors. Laser vibrometers allow a remote measuring of vibration parameters at different product points for in a dangerous zone (chemically corrosive, high temperature, radiation, etc.) to measure the vibration parameters of small objects, without an object surface pretreatment.

Laser vibrometers allow vibration measurement in the test points of an operating engine at a distance up to 5 meters as well as the elimination of an engine operating mechanisms numerous noise impact on studied fluctuations. The main parameters of an inverter:

- Frequency range from 2 Hz-30 kHz
- Vibration speed measurement range: up to 400 mm sec^{-1}
- Dynamic range $\nless$70 dB
- The distance to an object 0.5-5 m
- Sensitivity 25 mV/(mm sec^{-1})

Measuring devices detect vibrations and convert them into an electrical signal which is supplied to a multifunctional input-output module where it is digitized and sent to a personal computer with installed software. A digitized signal obtained from the multi-function inputoutput module is converted into an amplitude spectrum using a fast Fourier Transformation Procedure (FFTP) and analyzed by software and algorithmic software. MDU software and algorithmic support consists of the following components combined into one custom package (Vankov *et al*., 2015; Ivshin, 2012):

- Reference spectra development program
- Spectra and reference comparison program
- Technical state control programs

All these components are combined in a single integrated frame, the work record is provided with the possibility of record results and signal processing mode viewing. The report on a product state is performed automatically, without a user intervention, which eliminates the subjectivity in decision making.

Reference spectra development program designed to generate a reference spectrum of non-defective products and a confidence interval for the comparison characteristic with the trusted operation level of 0.95. The reference spectrum is developed according to test results of a fairly large batch of serviceable products which are sample of the population andincludes the most common vibration characteristics. In order to generate a reference spectrum the method of a robust weighing is used (Hampel *et al*., 1989). The development of a reference spectrum is the process of frequency transition from the aggregate of initial spectra amplitude at a given frequency (a1, a2, a3, ..., am) to a single (generalized, reference) value as. It is assumed that a standard will contain only common data characteristic for the entire set of data spectra andwill not contain any (random) features of a single spectrum. The program of spectrum comparison with a reference (Fig. 2) is designed for difference evaluation of each original spectrum of recorded signals from a reference spectrum. The program works as follows:

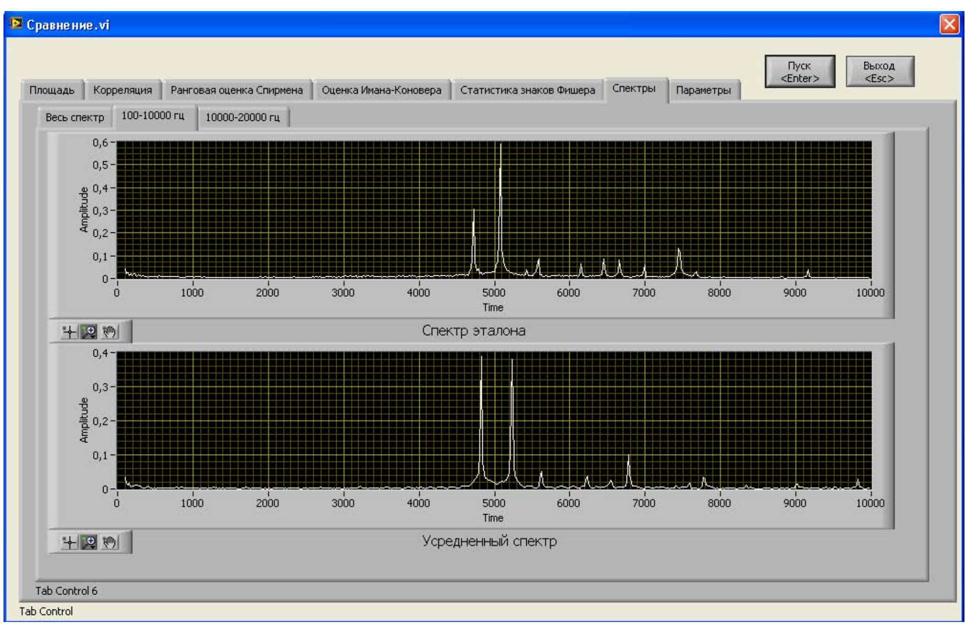

Fig. 2: Front panel appearance of spectrum and reference comparison program

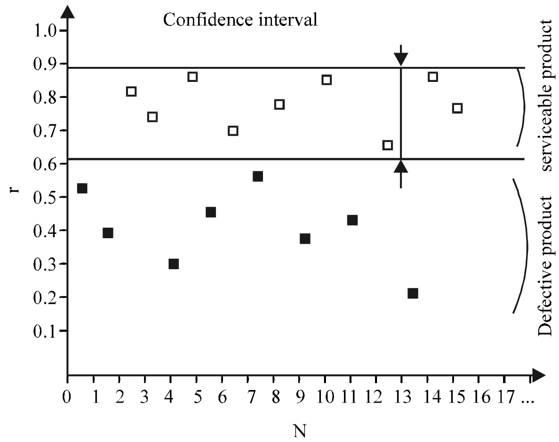

Fig. 3: The principle of decisive rule "pass-fail" using the example of the Spearman correlation ratio (r Spearman correlation ratio, N-product number)

- A reference file and sensor signals are read
- A spectrum is generated for each signal
- Comparison ratios are calculated for each spectrum using target comparison functions
- It is determined whether the comparison coefficients are within the boundaries of a confidence interval

The following elements are used as objective comparison functions for vibration signal spectrum in developedprograms (Busarov, 2009):

- Range area
- Correlation coefficient
- Nonparametric Spearman rank evaluation
- Iman-Conover evaluation
- Fischer sign statistics

Technical condition control program is designed to evaluate the differences between the current range of signals and a reference one in the automatic mode.

When the program starts with the measurement channels the vibratory responses of impacts are recorded (product number and code is specified in a file name, file format-.txt). After recording, the program automatically generates a spectrum, calculates the target functions of comparison for a reference and a current spectrum andalso compares them with the confidence interval boundary in an automatic mode by FFT algorithm for each signal.

In order to determine if a product is a "useful" or a "defective" one (Fig. 3) an approach is used characteristic of anomaly rejection procedures: the program interprets the set of calculated values for certain statistics (p_1, p_2, ..., p_m) as the plurality of an abstract parameter measured values and applies the following procedure to this set of values (Orlov, 2004; Hastings and Peacock, 1980):

- To calculate median value $\overline{p}$ evaluation
- To calculate the estimate of S distribution as a median absolute deviation
- To establish a confidence interval for a set level of α significance:

$$\overline{p} \pm S \cdot t(1-\frac{\alpha}{2}, m-2)$$

Where:

T (α, m) = Student's distribution's
α = Quantile with m degrees of freedom

If comparison ratios are within the boundaries of the confidence interval, the research object is considered as "fit" one, if they fall outside the confidence interval, a product is recognized as a "defective" one. Thus, using the developed software and algorithmic support, the spectrum of parts, components and assemblies of a gas engine was analyzed. A computer program registration certificate is obtained for the program-algorithmic support.

RESULTS AND DISCUSSION

The control of gas engine parts, units and assemblies: Objects of research the turbocharger turbine cases for a prospective gas engine, an electromagnetic gas dispenser and a gas engine.

The control of a gas engine turbocharger turbines technical condition: In order to determine the technical condition of engine component blanks in the software package of finite element simulation ANSYS the calculation of natural oscillation frequencies of the turbocharger turbines, which allowed to determine an informative part of the research object signal spectrum (Vankov, 2004; Basov, 2002).

Objects of study TCR turbine casing of a prospective gas engine (5 control casings), the defects are presented in Table 1. The turbine with a double-threaded body made of ductile cast iron (HF 50) is designed to convert exhaust gas energy into the kinetic energy of the turbocharger rotor rotation.

In order to perform the modal analysis of a research object (a defective and non defective one), it was decided to model TCR No. 4 turbine housing defect, i.e., to provide mechanical risks as shown on Fig. 4. The main differences between the modes (difference area) in the frequencies of natural oscillations for a defect-free and a defective TCR turbine housing are presented in Table 2.

Table 1: TCR casing defects

TCR turbine casing No.	Defect description
1	Serial manufacture (without a defect)
2	Without painting of one internal core
3	Without painting of both internal rods
4	Mechanical risks
5	Without painting of inner rods with mechanical risks

Table 2: Natural oscillation frequencies of a turbocharger turbine casing

Modes	The frequencies of turbine turbo charger defect-free casing (Hz)	The frequencies of defective turbocharger turbine casing (Hz)	Frequenc difference defect-free
1	871.92	873.03	-1.11
2	1448.4	1447.9	0.50
3	1862.9	1858.0	4.90
4	1964.1	1962.8	1.30
5	2702.9	2697.2	5.70
6	2983.6	2950.5	33.10
7	4436.6	4336.0	50.60
8	4597.7	4477.8	69.90
9	4744.1	4733.7	10.40
10	5196.9	5090.0	6.90
11	5285.7	5253.6	32.10
12	5391.8	5316.7	75.10
13	5531.3	5512.6	18.70
14	6058.2	6012.4	45.80
15	6190.5	6165.2	25.30
16	6254.9	6225.9	29.00
17	6650.6	6463.0	187.60
18	6732.6	6682.7	49.90
19	6911.4	6829.6	81.80
20	7008.6	6947.7	60.90
21	7285	7178.0	1070.00
22	7586.2	7486.2	100.00
23	7945.3	7921.0	24.30
24	8130.9	8118.0	12.90
25	8499.1	8352.1	147.00
26	8708.3	8702.5	5.80
27	8858.1	8796.4	61.70
28	9144.9	9045.7	99.20
29	9307.8	9304.0	3.80
30	9460.6	9364.3	96.30
31	9684	9573.2	110.80
32	9769.7	9749.2	20.50
33	10019	9936.8	82.20
34	10115	10118	-3.00
35	10281	10230	51.00
36	10786	10662	124.00
37	10855	10842	13.00
38	11130	11070	60.00
39	11292	11264	28.00
40	11708	11594	114.00
41	11815	11797	18.00
42	11912	11894	18.00
43	12110	12050	60.00
44	12205	12113	92.00
45	12365	12273	92.00
46	12543	12499	44.00
47	12634	12579	55.00
48	12910	12828	82.00
49	12973	12905	68.00
50	13153	13005	148.00
51	13305	13258	47.00
52	13445	13426	19.00
53	13822	13540	282.00
54	13975	13776	199.00
55	14081	13952	129.00
56	14189	14045	144.00
57	14273	14219	54.00
58	14386	14325	61.00
59	14563	14507	56.00
60	14715	14691	24.00
61	14790	14736	54.00
62	15077	15066	11.00

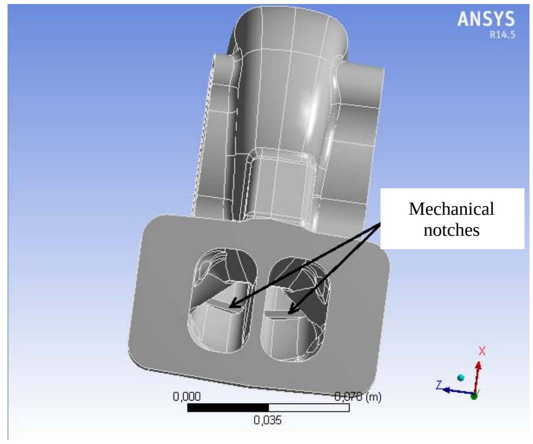

Fig. 4: Turbine compressor turbine defective case

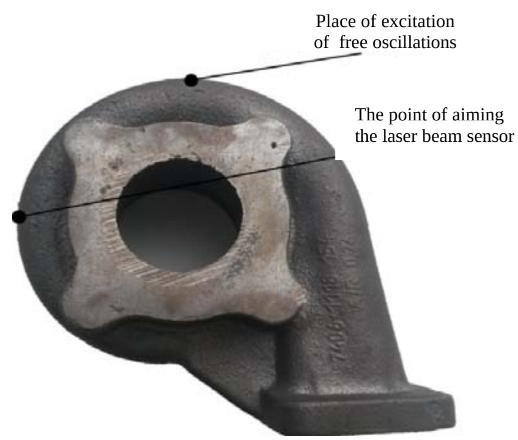

Fig. 5: TCR turbine housing with a laser beam sensor pointing point and free oscillation excitation place about 5 mechanical strokes were produced along

The analysis of the modal analysis results showed that the most informative frequency ranges, characterizing the presence of mechanical risks in TCR turbine housings make 6-8 and 12-14.2 kHz (Vladimirov *et al*., 2015). The obtained results were used in a series of experimental studies using MDU.

The preparation, set-up and regulation of equipment applied in a measuring unit was carried out prior to experimental studies according to the requirements set out in the technical documentation, the instruction on specific instruments operation and GOST. The laser sensor was placed at the distance of 2 m from the object of study, the laser beam was pointed to a turbocharger turbine housing, as shown on Fig. 5 without the preliminary preparation of an object surface.

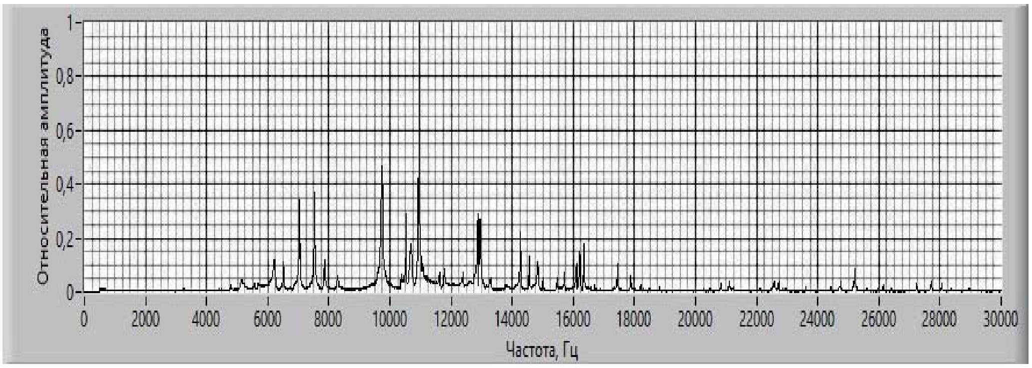

Fig. 6: Standard spectrum of TCR turbine casings

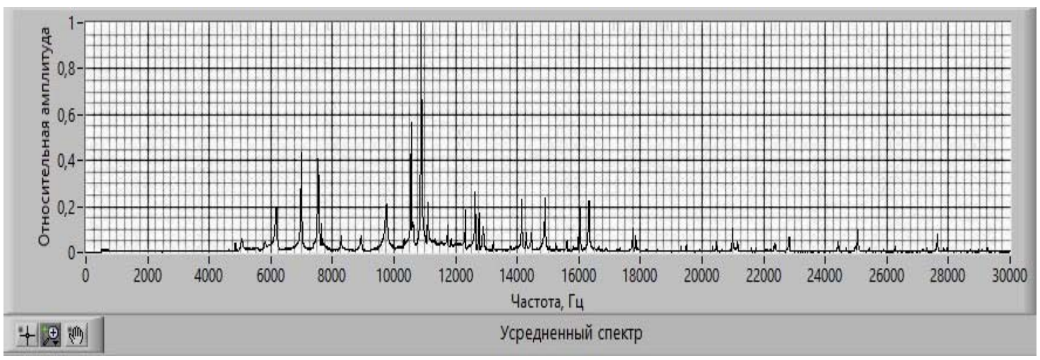

Fig. 7: TCR No. 4 defective case spectrum

The following parameters were set to record a signal:

- Time interval for signal recording - 20 sec (5 strokes)
- Sampling frequency-6000 counts
- The parameters of registered signal pulse emission (sensitivity 10; minus count pulse start-10, multiplication of height 0.4; the addition of height 0)

TCR turbine housing with an impact hammer from the height of 5 cm without an effort under the gravity force effect. The oscillation parameters were recorded by a laser vibrometer. The first series of experiments was conducted in order to develop a reference spectrum. The reference spectrum was developed on the basis of 10 tests for a defect-free gas engine of TCR casing (Fig. 6).

The second series of experiments was conducted in order to obtain the spectra of control (defective and defect-free ones) cases and their comparison with a reference spectrum. The spectrum of control defective product (TCR No.4 casing) is presented on Fig. 7. According to the procedure described above, 5 test objects were analyzed (1, 4 defective and a defect-free TCR housing).

The comparison of the spectra was performed in the frequency range of 6-8 and 12-14.2 kHz. correlation coefficient, Spearman's rank evaluation and Iman-Conover evaluation were chosen as the target functions of spectrum comparison. The results of reference and control spectrum comparison for TCR No.4 housing according to the criterion of comparison, the evaluation of Iman-Conover are presented on Fig. 8.

The values of comparison ratios are presented on figures along Y-axis and the numbers of mechanical impacts along X-axis, the dotted line are the boundaries of a defect-free confidence interval, the solid line is an averaged comparison factor. The solid line (the average ratio of control (defective) housing comparison is below the dotted line (confident interval limits of defect-free (reference) housing). Thus, spectra have significant differences respectively, that is, TCR turbine housing is recognized as a defective one.

The results of technical condition monitoring according to 5 control objects (Table 1) are presented on Fig. 9. The dots indicate the averaged comparison ratios for a corresponding TCR housing. An average comparison rate of TCR No. 1 housing (serial version) is within the boundaries of the confidence interval (solid

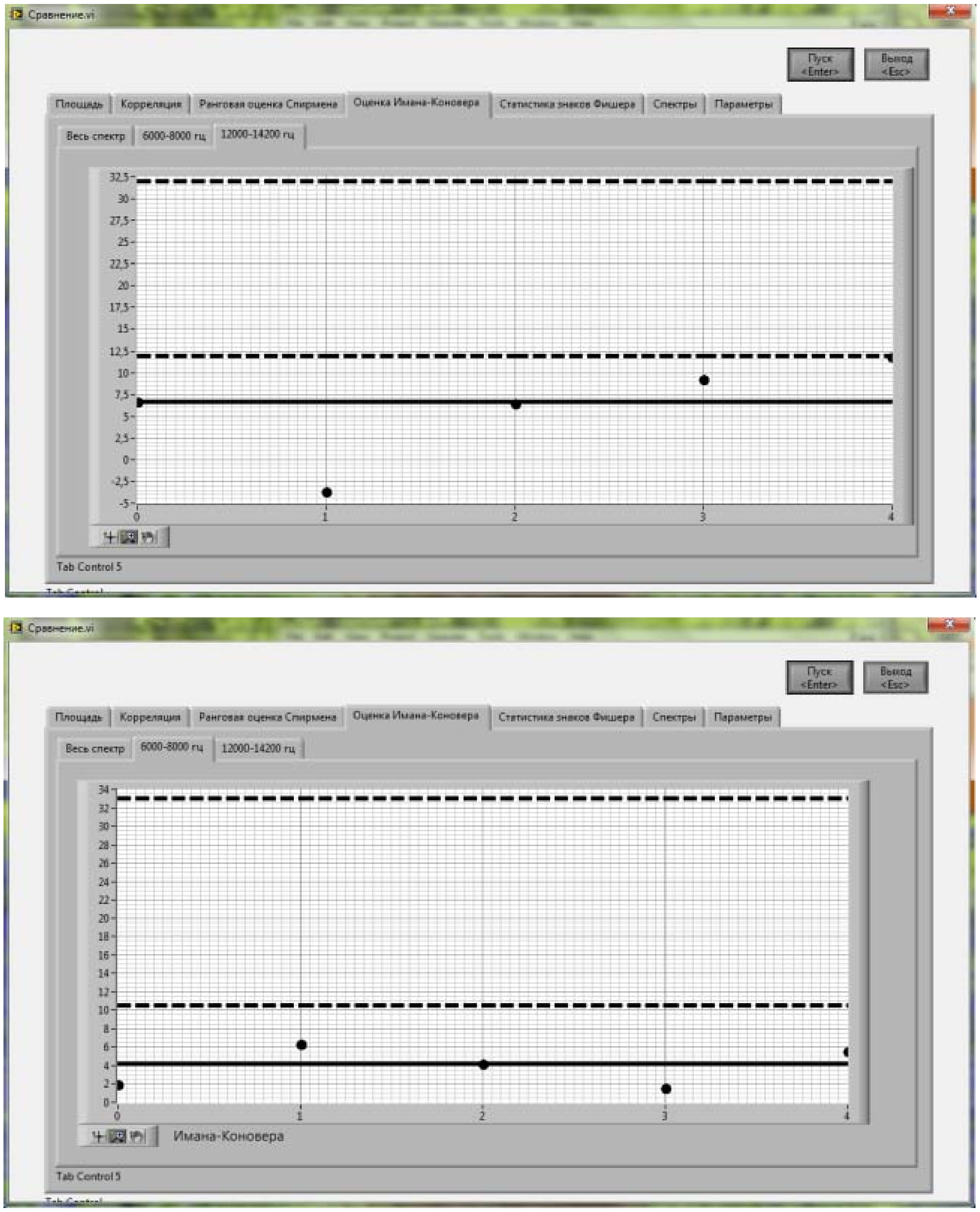

Fig. 8: Spectra comparison results (TCR No. 4 casing) in the frequency range of 6-8 kHz (on the left) and 12-14.2 kHz (on the right) (Iman-Conover evaluation)

line). Thus, the housing is recognized is a defect free one, the housing No. 2-5 have artificial defects and they are identified using a developed MDU with the confidence level of 95%.

Experimental data analysis showed a steady determination of a defect in TCR turbine housing using adeveloped MDU according to 3 criteria and confirmed the possibility of this method use to control the technical condition of TCR turbine housing in auto mode.

Control of gas dispenser technical condition for electromagnetic gas engine: The object of study is an Electromagnetic Gas Dispenser (EGD) of a gas engine. The dispenser tests were conducted using an engineless stand.

In order to study the vibro-acoustic characteristics of EGD engine the following stand operation were chosen: the time interval of a dispenser operation was set - 40 m sec and 54.5 m sec which corresponds to 3000 and

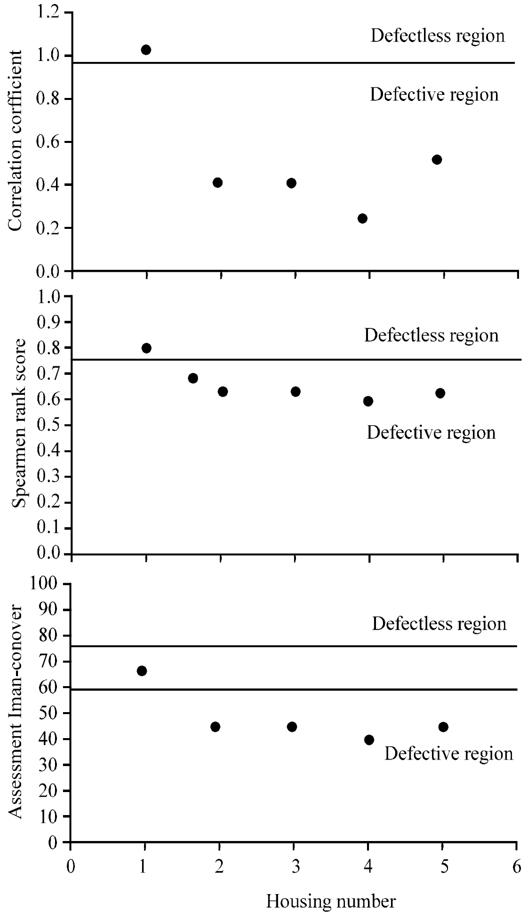

Fig. 9: The results of diagnosis according to comparison criterion correlation; a) Spearman rank evaluation and b) Iman-Conover evaluation

2200 rev min^{-1} of an engine crankshaft; in order to simulate a fault condition of an object under study, the power of dispensers was turned off. Prior to the beginning of tests the time interval of signal recording with the duration of 20 sec was set, the sampling rate was 40,000 samples. Signal registration was carried out simultaneously by two laser vibrometers, along two channels, from a serviceable and a faulty dispenser.

Laser vibrometers were pointed on dispensers uniformly in one point and were set at the distance of 2 m from research facilities (Fig. 10). About 5 time measuring of oscillation parameters was performed, the duration of which made 20 sec. Five sites with the duration corresponding to two turns of a crankshaft, from which an average spectrum was developed during each 20 sec signal. In order to develop spectra, to analyze and compare them according to target functions the following parameters were set:

Fig. 10: Installation of laser vibrometers (on the left) and the location of a vibrometer laser beam pointing on gas dispensers (on the right)

- Sampling signal length to obtain a spectrum was chosen based on the characteristics of applied sensors and made 16384 counts
- sampling rate made 40,000 counts
- confident probability 0.95
- Frequency ranges were selected on the basis of conducted initial experiments andmade 0-5 kHz on the part of a spectrum and 0-20 kHz on the entire spectrum
- Spectrum normalization was performed additionally

Averaged spectra signals were formed for a serviceable and a faulty EGD at a given rotation frequency of a crankshaft 2200 and 3000 rev min^{-1}. The results of the reference and the control spectra comparison of an electromagnetic gas dispenser at a crankshaft rotation speed of 2200 rev min^{-1} are presented on Fig. 11-13.

The spectra of a serviceable and a faulty dispenser have differences, as determined by target function ratio values output values beyond the confidence interval limits with the confidence level of 0.95. The performed series of experiments provided experimental data about the vibration parameters of a serviceable and a faulty (power is turned off) electromagnetic gas dispenser. The analysis of experimental data showed a steady determination of a faulty electromagnetic gas dispenser using a laser sensor according to all 5 comparison criteria

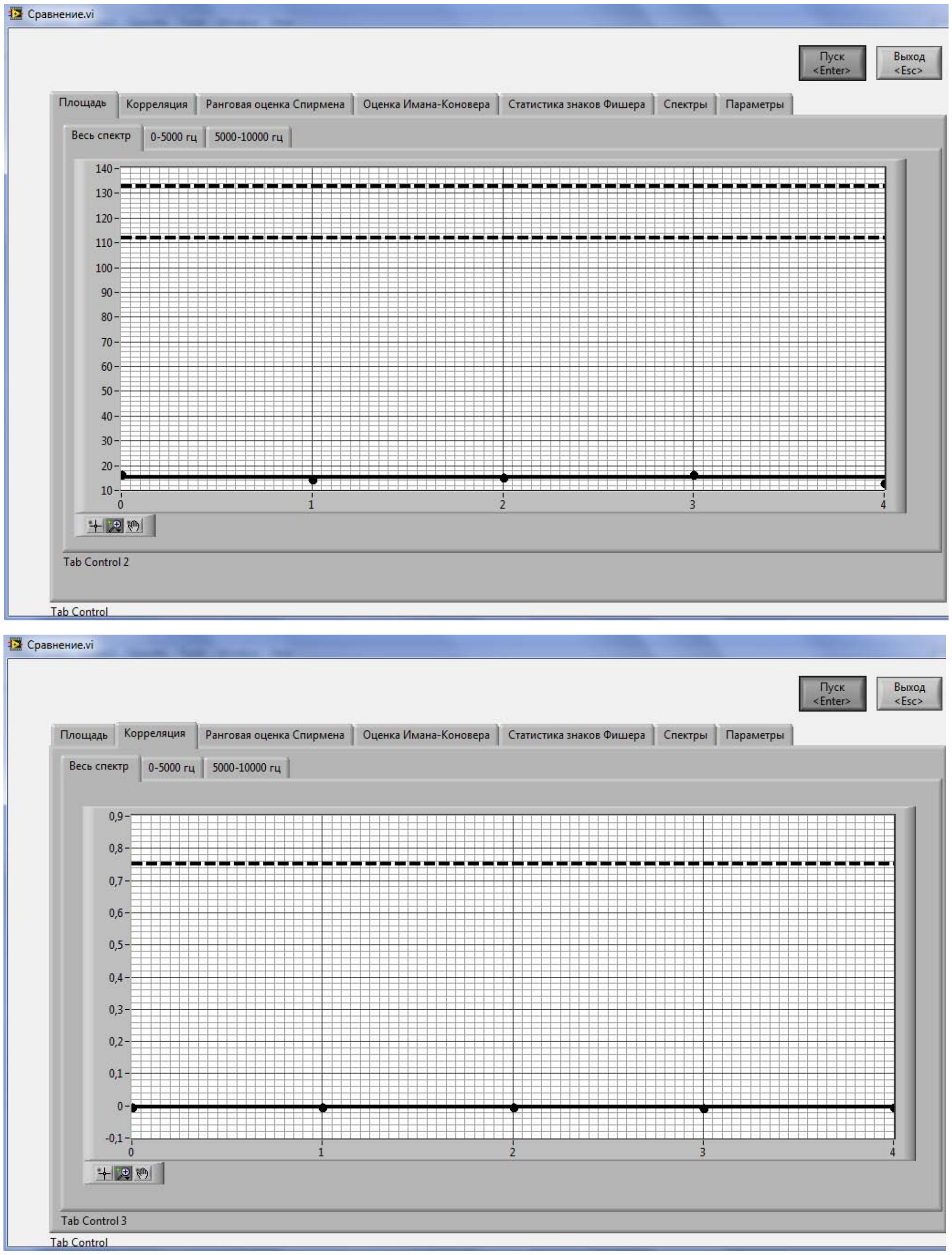

Fig. 11: The diagnostic results according to the following comparison criteria: spectrum area (on the left) and correlation (on the right)

and confirmed the possibility of this method use and MDU to monitor the technical condition of EGD in the automatic mode.

Gas engine technical state control: An object of study is the gas engine. The measurements were performed using an operating gas engine in two operation modes: the first mode - an engine operates in standard mode, the second mode -one of the engine cylinders is out of order (the gas dispenser power is turned off).

The research of an engine vibro-acoustic characteristics were performed on the engine stand. Stand operation modes: the rotational speed of a crankshaft makes 2200 rpm, the load makes 80%. The parameters of a

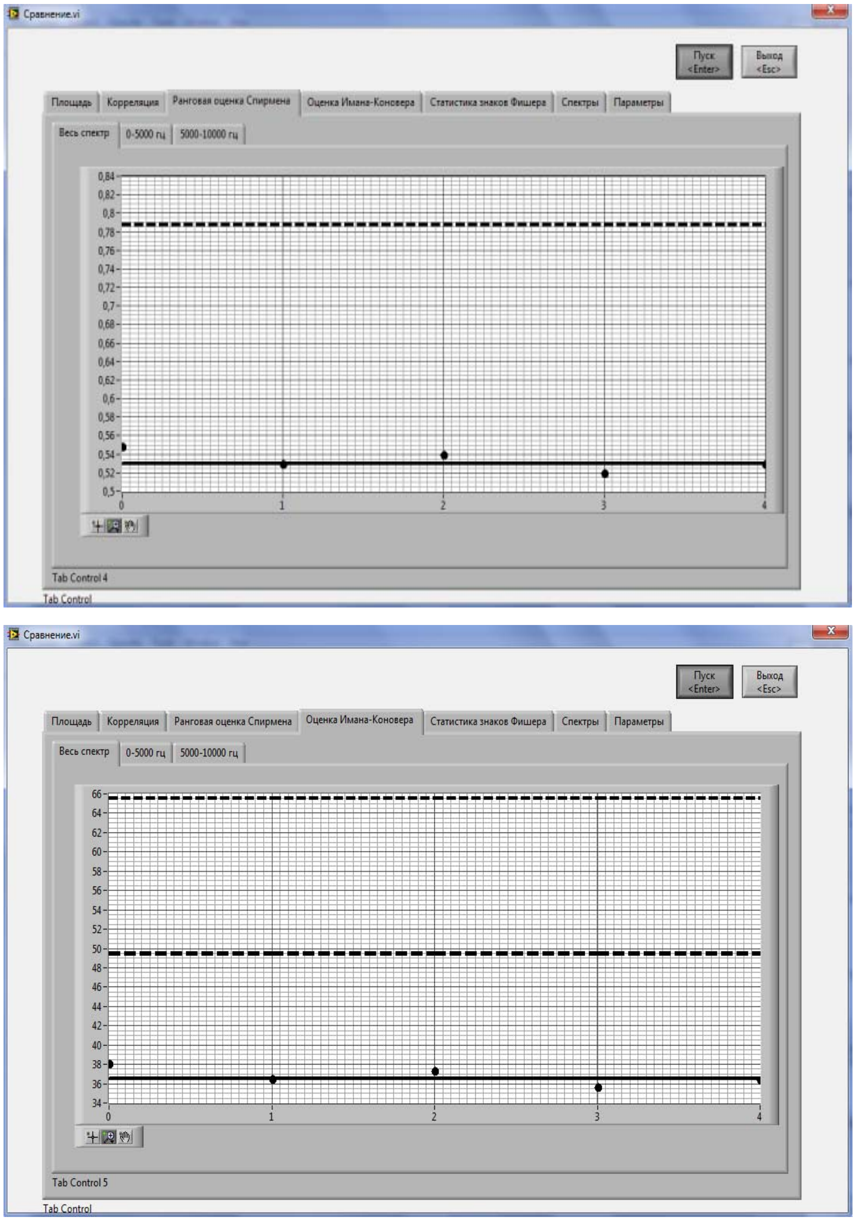

Fig. 12: The diagnostic results according to the following comparison criteria: Spearman rank evaluation (on the left) and Iman-Conover evaluation (on the right)

studied object fluctuations were detected by laser vibrometers. Signal record interval makes 20 sec, the sampling rate makes 40,000 counts.

Laser vibrometers were pointed on a gas engine in one point and set at a distance of 2 m from a studied object (Fig. 14). The record was carried out through three channels: two channels are laser vibration transducers LV-2, the third channel is the crankshaft position sensor.

An inductive position sensor of a crankshaft consists of a housing made of alloyed steel and a sensing element, consisting of a permanent magnet and a coil. When there is a pass close to the magnetic mass sensor electromotive force is induced in a coil and an electric impulse appears. A metal plate is installed on the engine flywheel, which forms an electric pulse during a gas engine operation passing near the rotation sensor. The position of this impulse corresponds to the position of 8° before a top dead center in the first cylinder (the flywheel is in a triggered lock position).

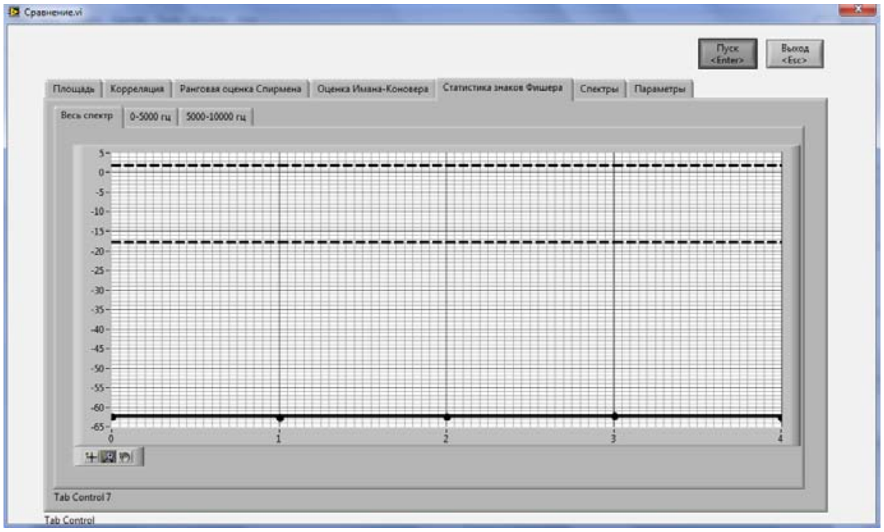

Fig. 13: The diagnostic results according to the following comparison criterion: Fischer sign statistics

Fig. 14: Installation of laser vibrometers (left) and place the guidance of the laser vibrometer at the head of the gas engine block (right)

In order to develop spectra, analyze and compare them according to target functions the following parameters were set:

- Signal sampling length to obtain the spectrum was chosen on the basis of applied sensor characteristics and made 16384 counts
- Sampling rate made 40,000 counts
- Confident probability-0.95
- Frequency intervals, in which spectrum processing will be performed-(0-0.2) kHz

After experimental studies the signals from a working gas engine were obtained during the operation of all cylinders (Fig. 15a) and when the gas dispenser power is turned off on the cylinder No7 and 8 ("broken cylinder") (Fig. 15a). Position sensor, fixed the position of the first cylinder piston 8° prior to top dead center (red light on Fig. 15). Vibrometer laser rays were pointed to a cylinder unit head in the area of cylinder 7 and 8, respectively.

The analysis of an operating engine signals with turned off cylinders and without shutting down (Fig. 16) shows that after the turning off of the cylinder No.7 gas dispenser the signal form changed (Fig. 18). The signal amplitude increased this can be explained by the fact that at the time of the cylinder turning off the amplitude of engine vibrations increased.

The vibroacoustic engine characteristics were also obtained at the time of gas dispenser power turning off. The operator turned off the gas dispenser power for this in one of the cylinders. About 5 time measurement of vibration parameters was performed for 30 sec. During each 30 sec signal 5 sites with the duration corresponding to two turns of a crankshaft were chosen from which an average spectrum was developed. Averaged signal

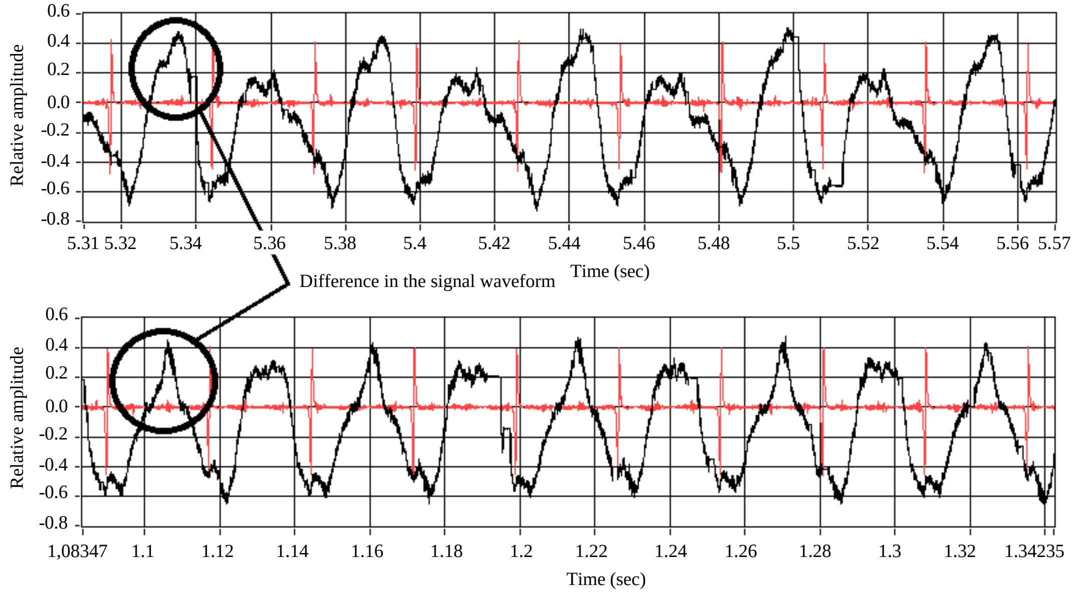

Fig. 15: Laser vibrometer signal from a running engine: a) The head of the engine unit near the cylinder No. 7; b) The head of the engine unit near the cylinder No. 7 (gas dispenser power is turned off)

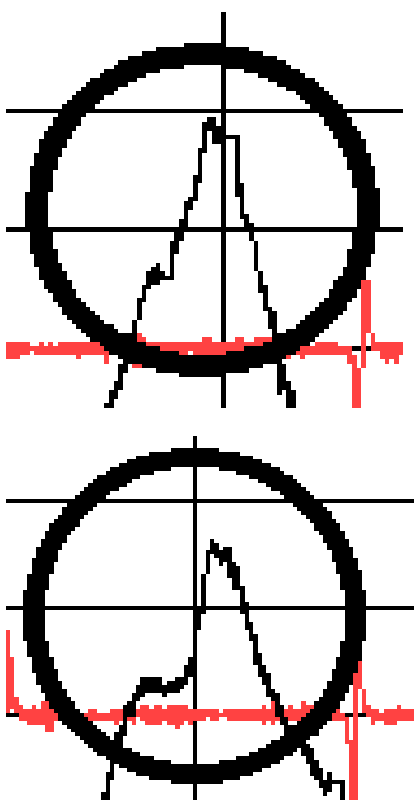

Fig. 16: Laser vibromemeter signal LV-2 from the running engine: a) The cylinder works; b) Dispenser power is turned off

spectra of an operating engine were developed during the operation of all cylinders and when one of the cylinders of the engines was out of order (gas dispenser power is turned off) (Fig. 17).

Engine spectra in the absence of power on a cylinder gas dispenser were compared with reference spectra. The analysis of operating engine spectra during the operation of all cylinders and at the absence of power on cylinder No. 7 dispenser showed that there was the redistribution of energy by frequencies, as evidenced by the mode appearance at the frequency of 55 Hz. The main spectrum frequency is 36 Hz which corresponds to the set number of engine crankshaft rotations (2200 rev min^{-1}).

The results of engine spectra comparison in the absence of power on the gas dispenser of the cylinder No. 7 ("broken cylinder") with the reference spectra of the engine are shown on Fig. 18 and 19. The serviceable and defective engine (with "broken cylinder" defect) spectra have differences as determined by the excess of objective function coefficient values beyond the limits of a confident interval with the level of confident probability equal to 0.95.

After the series of experiments the experimental data were obtained about the vibration parameters of an operational gas engine and for the engine with "broken cylinder" defect. Experimental data analysis showed a stable determination of this defect using a laser sensor according to 4 criteria and confirmed the possibility of MDU use to control the technical condition of a gas engine.

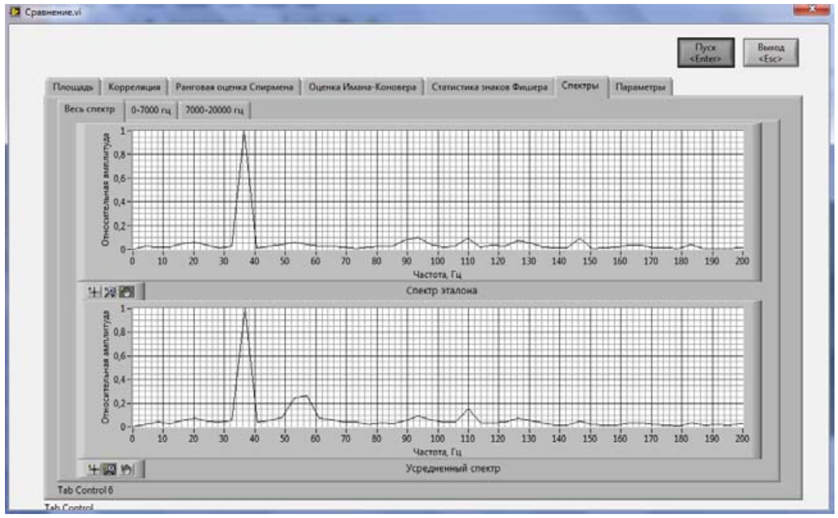

Fig. 17: The spectra of running engine signals (the engine is operating normally and the cylinder No. 7 of the engine is out of order (the gas dispenser power is turned off)

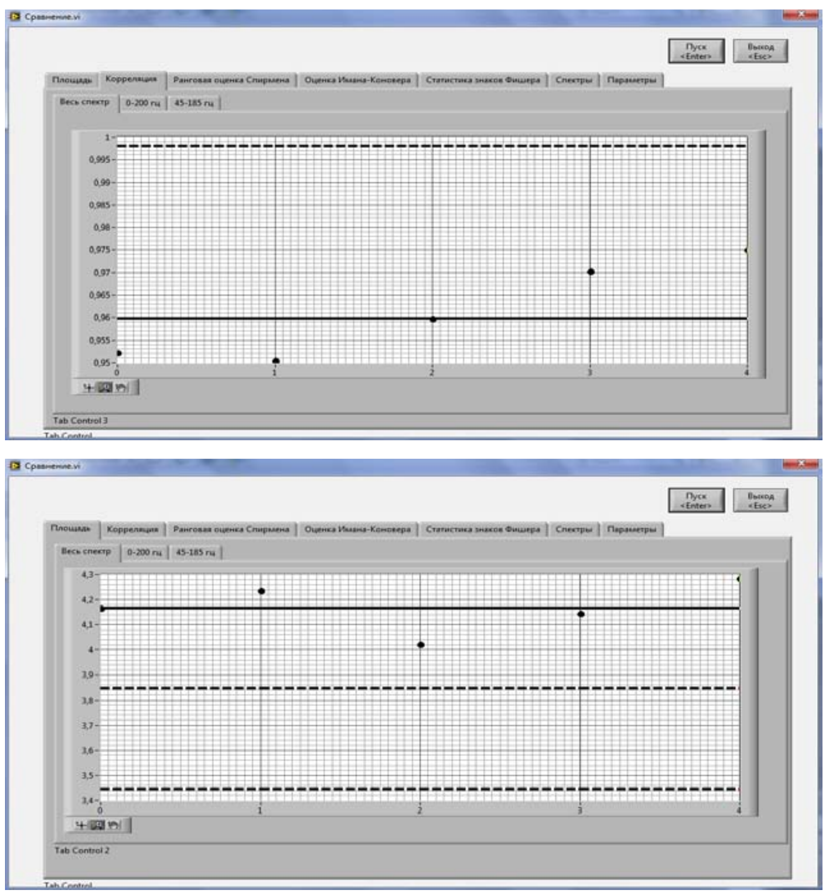

Fig. 18: The results of diagnostics according to the following comparison criteria: the spectrum area (on the left) and correlation (on the right)

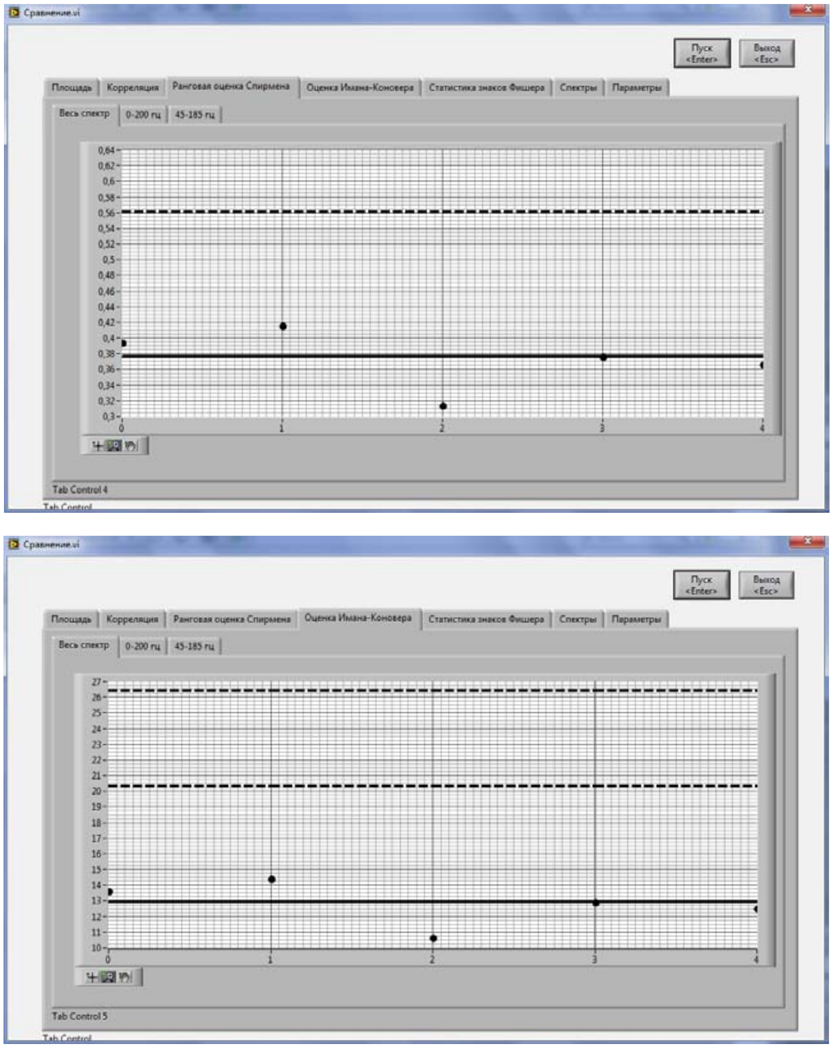

Fig. 19: Diagnostic results according to the following comparison criteria: Spearman rank evaluation (on the left) and Iman-Conover evaluation (on the right)

Summary: The designed and created measuring and diagnostic unit for the diagnosis of blanks and finished parts of the engine allows to: control the technical condition of parts, components and engine mechanisms, during the process of design, manufacture and in the process of operation and without the mechanism disassembling in the latter case; exclude the subjectivity during the evaluation of product technical condition;

- Use the statistical methods of information processing and decision-making
- use computer technologies
- eliminate the dependence on control terms, measurement errors and information processing
- automate the diagnostic process
- obtain an opinion about a defect in a documentary form

Measuring and diagnostic system is a standardized one and can be used for technical condition control concerning all pieces and parts of a complex shape as well as operating machines and mechanisms.

CONCLUSION

The result of the work is the design and the creation of a measuring and diagnostic system with special software to monitor the technical condition of blanks, parts and mechanisms of a prospective gas engine. Experimental studies were performed on the influence of TCR housing defects, an electromagnetic gas dispenser faults and an operating engine (“broken cylinder” defect) on vibration parameters. The analysis of experimental data showed a steady determination of these defects and faults data and confirmed the possibility of MDU use for the inspection of gas engine blanks, components and mechanisms.

ACKNOWLEDGEMENTS

R&D on the topic "The development of vibro-acoustic diagnostic system for the rapid control of perspective gas engine parts" in the framework of the project "The creation of KAMAZ engine series using alternative fuels with the power range of 300- 400 Hp and implementation potential concerning future environmental requirements" performed by the department "Power supply of industrial enterprises" (PSIE) at "Kazan State Power Engineering University" (FSBEI HVE "KSPEU") for the PJSC "KAMAZ" and "Kazan National Research Technical University named after A.N. Tupolev-KNI" (KNRTU-KNI) with the support of Russian Federation Ministry of Education and Science (2013-2015).

REFERENCES

Basov, K.A., 2002. Ansys in Examples and Problems. Mashinostroenie Publishers, Moscow, Russia.

Belov, E.V., I.V. Ivshin, A.V. Kochergin, D.N. Pervukhin and A.P. Tunakov, 1996. Diagnostics of gas-turbine engines by acoustic sensing of their components. Acoust. Phys., 42: 14-17.

Blum, P. and L. View, 2008. Programming Style. DMK Press, Moscow, Russia, Pages: 400.

Busarov, A.V., 2009. Diss of Techn Science Candidate. Kazan State Power Engineering University, Kazan, Russia, Pages: 154.

Hampel, F., E. Roncheti, P. Rausseu and V. Shtael, 1989. Robustness in Statistics: The Approach Based on Influence Functions. Mir Publishers, Moscow, Russia, Pages: 512.

Hastings, N. and J. Peacock, 1980. Handbook of Statistical Distributions. Statistical Book Publishers, Moscow, Russian, Pages: 96.

Ivshin, I.V., 2009. The development of test and functional methods for arms and military equipment control according to vibroacoustic parameters. Ph.D Thesis, Kazan Military Command Academy, Kazan, Russia.

Ivshin, I.V., 2012. Information-measuring system for technical condition control of operational mechanisms according to vibration parameters. Univ. Energy Challenges, 4: 128-135.

Orlov, A.I., 2004. Case Mathematics: Probability and Statistics-Basic Facts. M3-Press, Moscow, Russia, Pages: 110.

Vankov, Y.V., 2004. The methods and devices of product technical condition control according to natural oscillation parameters on the basis of finite element modeling and statistical criteria of spectrum comparison. Ph.D Thesis, Kazan Federal University, Kazan, Russia.

Vankov, Y.V., I.V. Ivshin, A.R. Zagretdinov and M.F. Nizamiev, 2015. Software and algorithmic support of KAMAZ engine TCR housing express control. Bull. Technol. Univ., 18: 141-143.

Vladimirov, O.V., A.R. Zagretdinov, I.V. Ivshin and M.F. Nizamiev, 2015. Research of defect influence on natural frequencies of power plant part oscillations. Proc. Higher Educ. Institutions Energy, 6: 66-74.