UDC 629.113

ON THE USE OF CASE OSCILLATIONS UNEVENNESS OF AN INTERNAL COMBUSTION ENGINE FOR EVALUATION OF ITS STATUS

E. Oksen, D. Oksen

Automobile and Road Institute of Donetsk National Technical University

Abstract

The methodology for the defect identification in systems and mechanisms of internal combustion engines based on the assessment of the case oscillations unevenness during the operation is provided. The design of piezometric converters for recording of the vibro-acoustic emission signals spreading in the case parts of the internal combustion engine is proposed. The equipment and software for the mobile diagnosing complex is developed.

Keywords: engine, diagnostics, vibro-acoustic emission, piezometric converter, diagnosing complex

Introduction

The ability to detect engine troubles at the early stages with the relatively low labor inputs determines the necessity of diagnosing internal combustion engines (ICE) by vibro-acoustic emission signals, developing in the case parts [1-2]. The reliability of conclusions about the condition of mechanisms and systems at the same time can be achieved by the statistical evaluation of correspondence of time-frequency fragments of the observed vibro-acoustic emission signals with the crankshaft rotation frequencies. The modern compact measuring modules with the low power consumption enable to manufacture the diagnosing equipment in a mobile version for installation directly on a vehicle during its test. Thus, the researches on developing the methodology for tools and systems diagnostics, based on the estimation of vibro-acoustic emission signals forming in the ICE case during the operation as a nondestructive testing method are topical for the industry.

1. Formulation of the problem

Troubleshooting in the ICE systems and mechanisms during the operation by vibro-acoustic emission signals is complicated by the difficulty in detection of the signal generated by a defect in the sufficiently powerful noise of the running engine. In its turn, the nature of vibro-acoustic signals is determined by the processes in the cylinders, the state of kinematic pairs in mechanisms (defects in contact surface, the availability and the quality of lubricant), the deviations from nominal dimensions and material properties of kinematic links.

The algorithm for recognition of a signal generated by a defect must take into account [3]:

- engine workload degree;
- vehicle speed;
- engine rotating velocity.

The used acoustic emission signal converters in their sensitivity in the investigated frequency range should [4]

- match the spectrum of the signals;
- ensure the rapid installation on the engine case parts;
- provide the reliable acoustic contact.

In this paper the issues of the development of the methodology for the defect identification in mechanisms and systems of internal combustion engines based on the statistical assessment of correspondence of time-frequency fragments of vibro-acoustic emission signals, formed in the case parts, with the crankshaft rotation frequency are considered.

The aim of the work is to reduce the costs for troubleshooting in the ICE mechanisms at the early stages of their appearance by the vibro-acoustic emission signals, formed in the case parts.

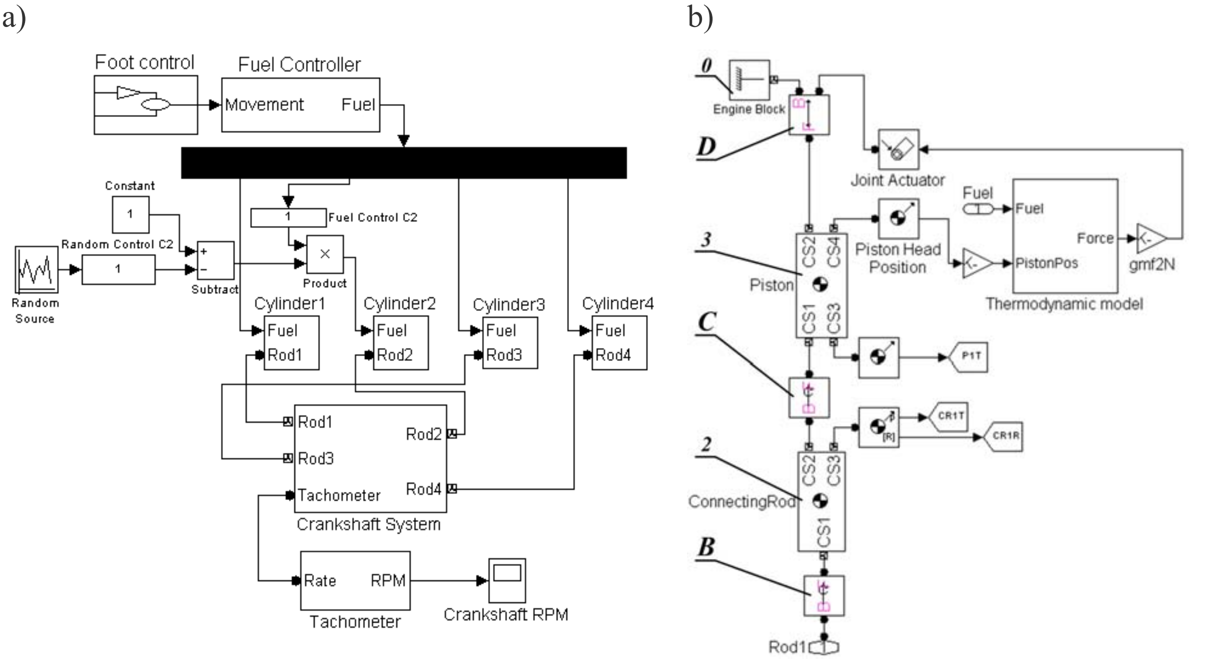
2. Dynamic simulation of the ICE operation with defects in the ignition and fuel delivery systems

Studies of the influence of defect formation in the ignition and fuel systems on the engine kinematic parameters were performed according to the principles of mathematical modeling in the package Simulink of the software environment Matlab. The dynamic model is adopted in accordance with the main features of the IEC functioning: a four-link mechanism for each of four cylinders, the four stroke operation, the procedure of engine cylinders operation according to the scheme 1-3-4-2; the account of inertial factors in kinematic links (piston mass, mass and inertia moment of connecting rods and a crankshaft) and gravity forces, the friction losses account in kinematic pairs. To simplify the dynamic model the following assumptions were made: kinematic pairs are considered to be ideal, losses in intake, compression and exhaust are not taken into account. In the block diagram of the engine link for one of the cylinders (Fig. 1) the body 0, a crankshaft 1, a connecting rod 2, a piston 3 and the kinematic pair *A*, *B*, *C*, *D* are indicated.

The thermodynamic model of the operation is formed taking into account the amount of fuel combustion energy in each cylinder. In this case, the change of the useful capacity during the piston movement on the value u_1 was calculated as

$$f(u) = R^2 \cdot \pi \cdot u_1 ,$$

where R - cylinder radius, m.


a) b)

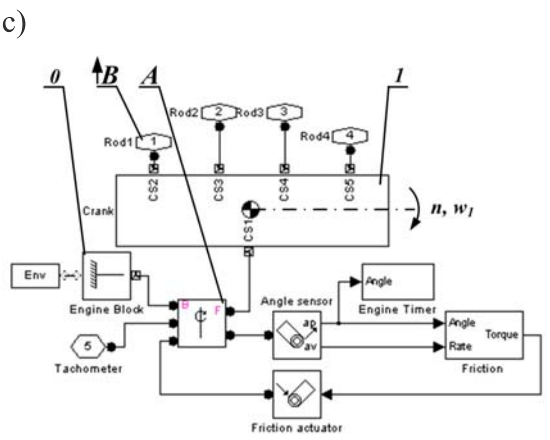

c)

Figure 1 – Dynamic engine model:
a) model of defect formation in ignition and fuel systems,
b) connecting rod and piston of a cylinder;
c) crankshaft

The temperature in the cylinder as a function of changing volume u_1

$$f(u) = T_a \left(\frac{V_0}{u_1} \right)^{G-1},$$

where T_a - initial temperature (of an atmosphere), K;
V_0 - initial volume of a cylinder, m^3;
G - exponent of the process.
The cylinder pressure is defined as

$$f(u) = P_a \left(\frac{V_0}{u_1} \right)^{G},$$

where P_a - initial pressure (of an atmosphere), Pa;
u_1 - changing volume, m^3.
The temperature in the cylinder after combustion

$$f(u) = \frac{u_1}{\rho \cdot \alpha \cdot c_v} + u_2$$

The results of the defect formation simulation in the second cylinder systems are shown in Fig. 2 as a chart of the crankshaft rotating velocity change.

a) b)

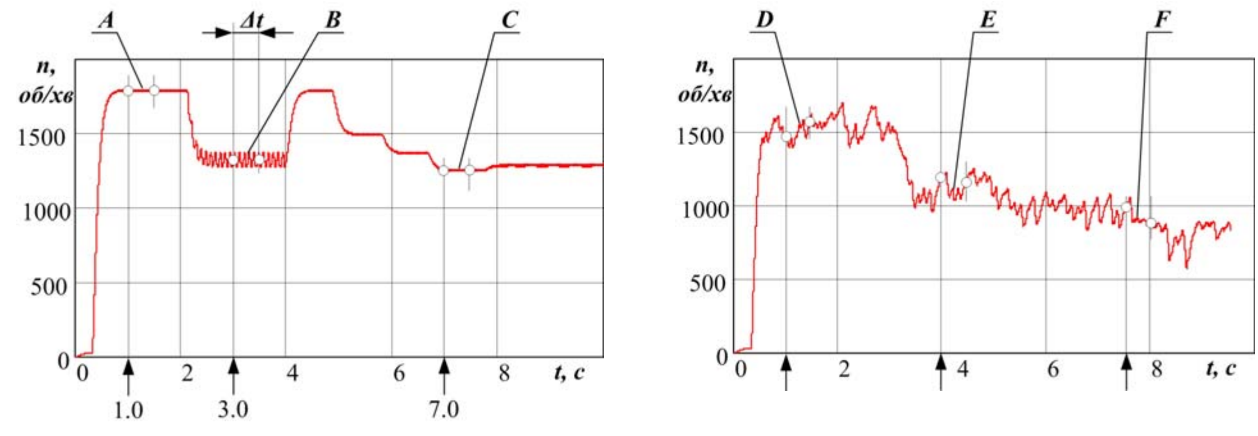


Figure 2 - Variation of crankshaft rotating velocity during the defect: a) deterministic defect, b) random defect

The comparison of the unevenness of crankshaft rotating velocity is performed with regard to Mode ***A*** of the ICE defect-free operation. For statistical calculations the selection of 1000 points was adopted, this interval is graphically displayed on the charts as ***Δt*** (see Fig. 2a).

Table 1. Comparative indicators of crankshaft rotation unevenness

Plot analysis	Speed of the motor shaft, rpm	SD, rpm	Height standard deviation relative plot A, %
A	1792,82	3,204	–
B	1319,55	33,91	958,25
C	1255,58	4,069	27,01
D	1502,03	58,32	1720,3
E	1117,09	56,43	1661,3
F	946,39	62,35	1846,1

The defect simulation in ignition and fuel systems is created by decreasing the amount of fuel in the second cylinder (mode ***B***). The mode ***C*** corresponds to a defect-free engine operation at the low shaft rotating velocity.

According to the adopted model, the effect of random manifestation of defects at different rotating velocities was calculated for the modes ***D***, ***C*** and ***F***. The comparison of the results (Table 1) shows that the random appearance of defects leads to the greater fluctuations of shaft rotating velocity. The standard quadratic deviation (QD) is 1600-1800% versus 900% for the deterministic defect.

In this case, a deterministic defect manifestation in the ICE systems at low rotating velocities is more significant, while the random nature of defects can lead to significant fluctuations of the crankshaft rotating velocity in the whole velocity range.

3. Experimental studies of the dynamics in the engine case

On the basis of the numerical simulations the technique of ICE systems and mechanisms assessment by the amount of the case parts oscillation unevenness is proposed. For experimental studies the apparatus for fixing and analysis of vibro-acoustic emission signals (Fig. 3), consisting of piezoelectric converters, a charge converter LE-41, a signal level normalizer, a module of the analog-digital converter ADA-1406 and a PC, was designed.

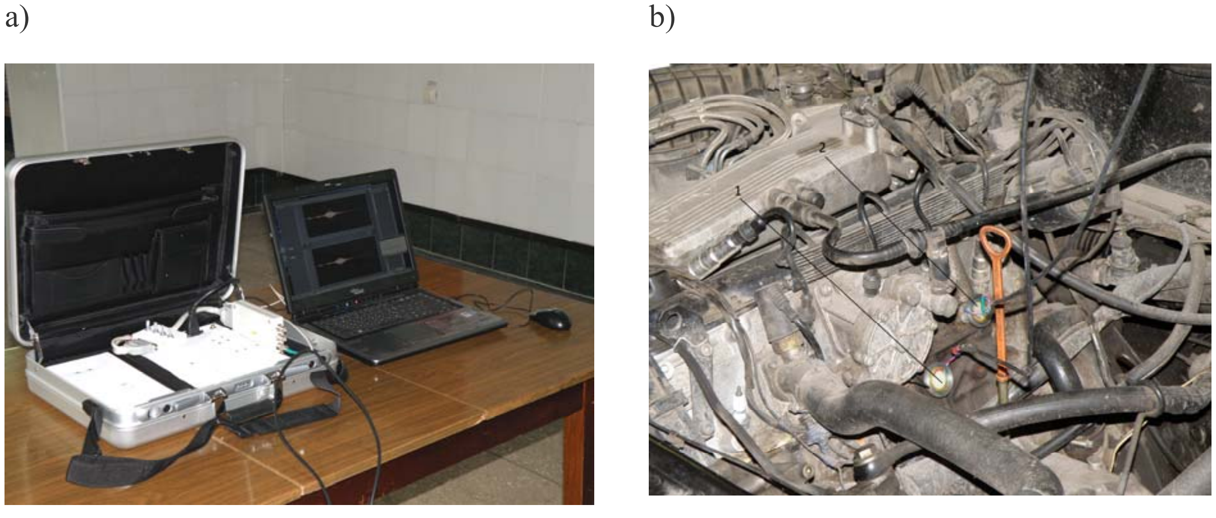


Figure 3 – Diagnosing engine apparatus: a) apparatus for fixing and analysis of a signal, and b) placement of sensors on the ICE case

The acoustic emission signals measurement was performed with specially designed piezoacoustic converters based on PZT ceramics with one or two active elements (Fig. 4).

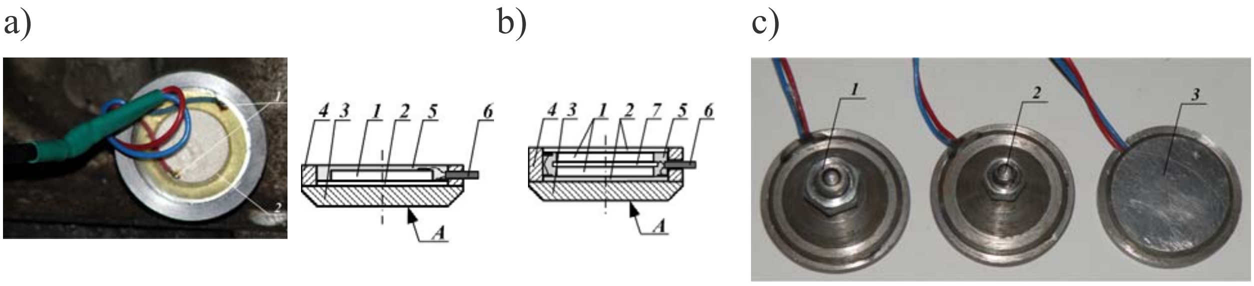
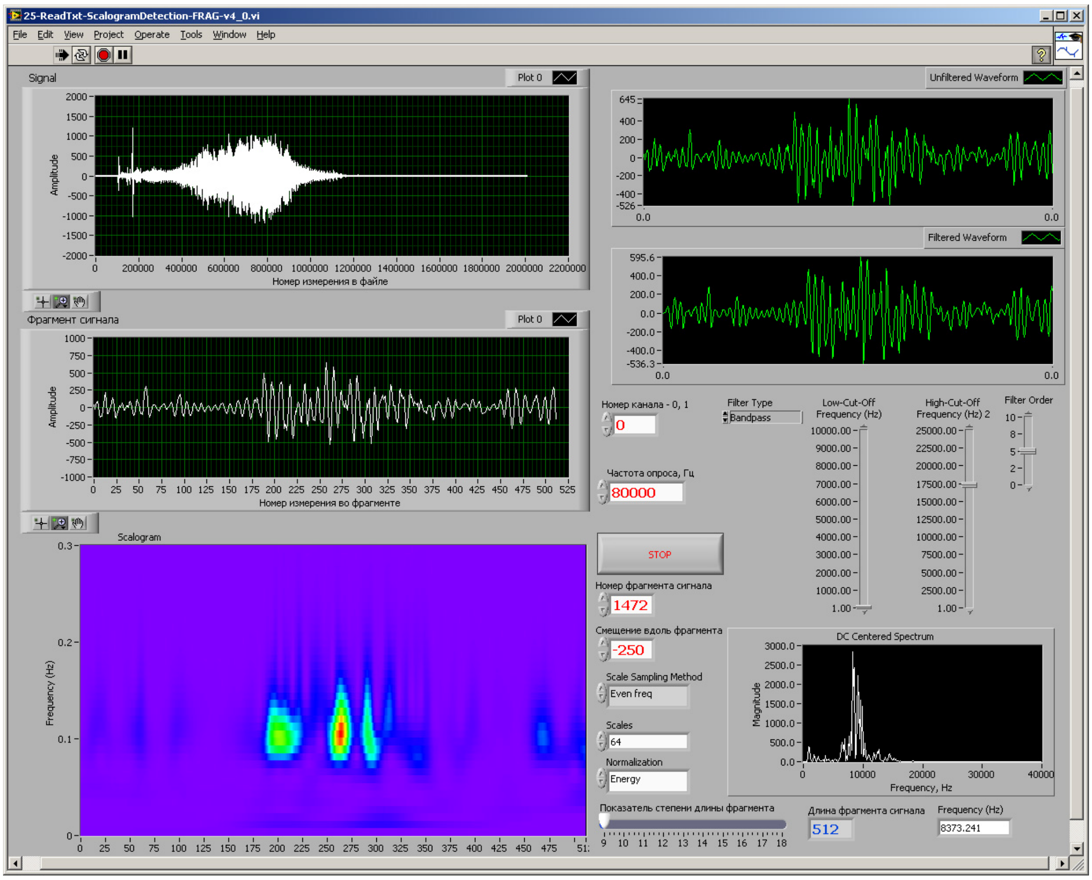


Figure 4 – Measuring piezoelectric converters:
a) - general view, b) design circuits with one or two active elements, and c) variants of fastening;
1 – piezo element; 2 - brass padding; 3 – wave guide; 4 – case; 5 – compound;
6 - signal cable; 7 - contact element

The software is developed in the logic of LabVIEW (license № 5018512E-01) [5] and it includes the tools of:
- recording in a file;
- an analysis of signals in the window mode (Fig. 5);
- a calculation of the engine case oscillation frequency.



Номер канала - 0, 1: 0

Частота опроса, Гц: 80000

Filter Type: Bandpass

Номер фрагмента сигнала: 1472

Смещение вдоль фрагмента: -250

Scale Sampling Method: Even freq

Scales: 64

Normalization: Energy

Длина фрагмента сигнала: 512

Frequency (Hz): 8373.241

Figure 5 – The program interface signal analysis

The quantitative and qualitative analysis of the information received is made with the help of the Fourier and wavelet analysis. In this case (see Fig. 5) for the fixed process (the diagram in the upper left corner of the panel) the amplitude-frequency (the diagram at the bottom right corner) and time amplitude-frequency characteristics (the diagram in the lower left corner of the panel) of signal's window fragments are calculated. For the adopted mode for filtering and the fixed length of fragment the program provides a harmonic value definition, in which the maximal energy of engine case oscillations is concentrated according to the following algorithm.

1. The signal analysis in the window mode with the window length ***m*** signal multiple of 2.
2. Defining the average signal value for each window as

$$\overline{S} = \frac{\sum_{i=0}^{m-1} S_i}{m},$$

where S_i - current value of a signal, V.

3. The alignment of a signal relative to the average $\overline{S}$

$$S_i' = S_i - \overline{S} \ .$$

4. The identifying of the most significant energy component of the ICE case oscillations as $\left\{P_k\right\}_{\max}$, so that the frequency of these oscillations is

$$\nu_{\max} = \frac{k_{\max}}{T \cdot N} \ \text{, Hz,}$$

where $k_{\max}$ - a serial number of the oscillation harmonic, which corresponds to the maximum energy value; T - ADC channel polling period, c; N - the length of the signal's vector, in accordance with which the amplitude-frequency characteristics are calculated .

5. The calculation of the engine case oscillation frequency in revolutions per minute

$$n = \frac{30 \cdot \nu_{\max} \cdot N_{np}}{\pi \cdot N_{ц}},$$

where $N_{ц}$ - a number of ICE cylinders; N_{np} - a number of operation strokes.

For the ICE state assessment the idling test mode for loading and unloading is adopted (see Fig. 5).The experiment includes the following stages:

1. turning on the equipment for the measured parameters recording in a file;
2. engine starting;
3. gradual rotating velocity increase ;
4. gradual rotating velocity decrease;
5. engine turning off;
6. turning off the measuring equipment.

The adopted procedure allows estimating the effect of defects in ICE systems and mechanisms on the case oscillation unevenness by constructing a generalized characteristic $P_{\max} = f\left(n_{\max}\right)$.

The exponential function $P_{\max}'\left(n\right) = c_1 \cdot e^{c_2 \cdot n}$ was adopted as the basic dependence for the correlation of characteristic $P_{\max}$. Its coefficients are determined by the square difference minimizing of current values.

As the criterion of evenness of the crankshaft rotation we assumed the correlation coefficient of experimental data $P_{\max}$ and functions $P_{\max}'$, calculated as

$$C_{corr} = \frac{\frac{1}{m}\cdot\sum_{i=0}^{m-1}\left(\left(S_i - mean(S)\right)\cdot\left(S'_i - mean(S')\right)\right)}{CKB(S)\cdot CKB(S')},$$

where $mean(S)$, $mean(S')$ - average energy dependence value; $CKB(S)$, $CKB(S')$ - average quadratic deviation of energy dependence.

The results of applying this techniques for diagnosing of the four- stroke engine of the passenger car Audi in the diagnostic laboratory of the Automobile and Road Institute of the State institution of higher education "Donetsk National Technical University” are shown in Fig. 6. The experiment was conducted for the engine in good order (Fig. 6a) and in the mode of simulation of the defect created by turning off the spark plug on one of the cylinders (Fig. 6b).

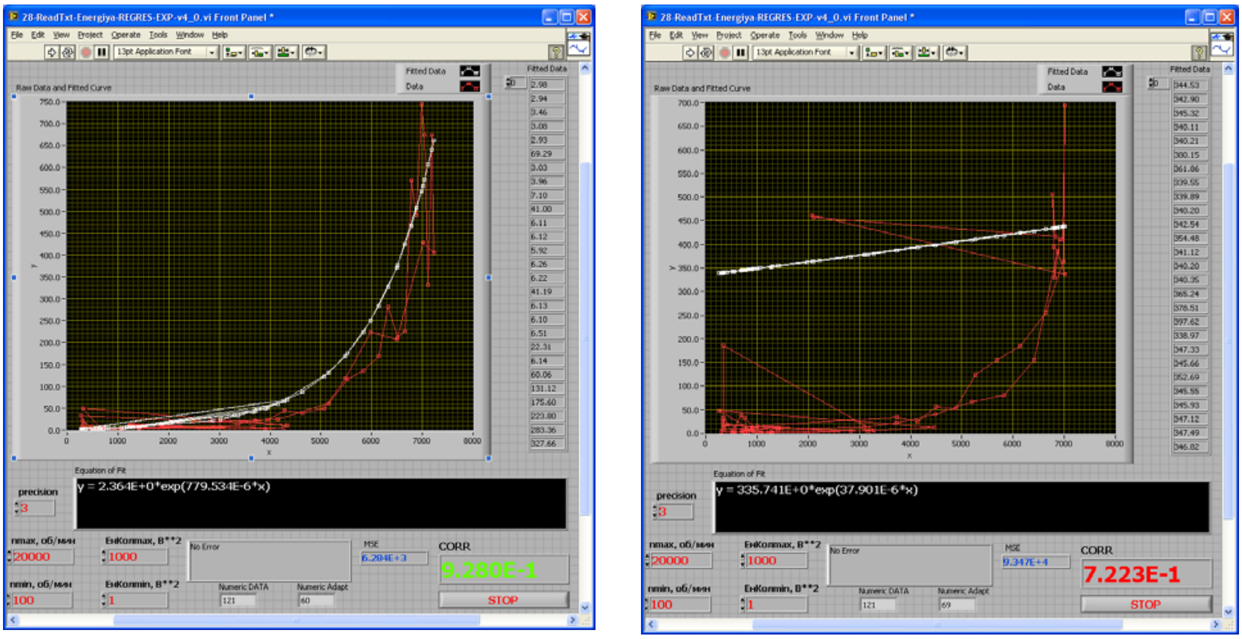
The measurements showed that for the ICE in good condition the generalized characteristic $P_{\max} = f(n_{\max})$ is well described by an exponential dependence. In this case, the correlation coefficient has values above 0.9.

The presence of defects in the ICE mechanisms and systems leads to the significant scatter of experimental values with regard to the generalized dependence and to lowering of the correlation coefficient (see Figure 6).

Conclusion

1. The detection of defects in the ICE systems and mechanisms can be exercised on the basis of assessment of the unevenness degree of the case oscillations by the vibro-acoustic emission signals. A criterion of the ICE state may be a correlation coefficient of experimental data with the generalized exponential dependence.

2. The developed methodology for diagnosing the state of engine systems and mechanisms by the degree of the case oscillation evenness may be recommended for the practical use in the internal combustion engines diagnosis.


a)

28-ReadTxt-Energiya-REGRES-EXP-v4_0.vi Front Panel *

Equation of Fit: y = 2.364E+0*exp(779.534E-6*x)

precision: 3

nmax, об/мин: 20000

ЕнКоnmax, B**2: 1000

nmin, об/мин: 100

ЕнКоnmin, B**2: 1

No Error

MSE: 6.284E+3

Numeric DATA: 121

Numeric Adapt: 60

CORR: 9.280E-1

Fitted Data: 2.98, 2.94, 3.46, 3.08, 2.93, 69.29, 3.03, 3.96, 7.10, 41.00, 6.11, 6.12, 5.92, 6.26, 6.22, 41.19, 6.13, 6.10, 6.51, 22.31, 6.14, 60.06, 131.12, 175.60, 223.80, 283.36, 327.66

б)

28-ReadTxt-Energiya-REGRES-EXP-v4_0.vi Front Panel *

Equation of Fit: y = 335.741E+0*exp(37.901E-6*x)

precision: 3

nmax, об/мин: 20000

ЕнКоnmax, B**2: 1000

nmin, об/мин: 100

ЕнКоnmin, B**2: 1

No Error

MSE: 9.347E+4

Numeric DATA: 121

Numeric Adapt: 69

CORR: 7.223E-1

Fitted Data: 344.53, 342.90, 345.32, 340.11, 340.21, 380.15, 361.06, 339.55, 339.89, 340.20, 342.54, 354.48, 341.12, 340.20, 340.35, 365.24, 378.51, 397.62, 338.97, 347.33, 345.66, 352.69, 345.55, 345.93, 347.12, 347.49, 346.82

Figure 6 – Comparison of case oscillation unevenness for a engine in good order and a defective engine

References:

1. Оксень Е.И. Особенности акустических параметров двигателя 2103 / Е.И. Оксень, А.В. Гарачук, В.В. Быков // Вісті Автомобільно-дорожнього інституту. – 2006. – № 1(2). – С. 43-49.
2. Оксень Е.И. Метод акустического диагностирования системы зажигания двигателей внутреннего сгорания / Е.И. Оксень, А.В. Гарачук, В.В. Быков, Д.Е. Оксень // Восточно-Европейский журнал передовых технологий. – 2006. – № 3/2(21). – С. 141-147.
3. Оксень Е.И. Метод вибрационного диагностирования системы зажигания двигателей внутреннего сгорания / Е.И. Оксень, Д.Е. Оксень // Двигатели внутреннего сгорания. – 2006. – № 1. – С. 136-140.
4. Оксень Е.И. Исследование особенностей сигналов акустической эмиссии, возникающих в кинематических парах двигателя при работе со знакопеременными нагрузками / Е.И. Оксень, В.Г. Цокур, Д.Е. Оксень // Двигатели внутреннего сгорания. – 2007. – № 1. – С. 141-146.
5. NI LabVIEW 8.6. Platform DVD – [Програмное обеспечение]. – National Instruments, 2008. – 6 електрон. опт. диск (DVD-ROM); 12 см. Систем. треб: Pentium; 32 Mb RAM Windows Vista/XP/2000.

Received on 05.04.2011