AN UNREPEATABILITY OF MEAN INDICATED PRESSURE IN THE MULTICYLINDER BIOGAS ENGINE

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Abstract

Un repeatability of consecutive work cycles in individual cylinders of turbocharged biogas engine was calculated on a basis of results of simultaneous engine indication. Numerical analysis of cycles shows that distribution of values of elementary indicated work in individual cylinders can be approximated by taking advantage of normal distribution, while one common data set of values of elementary indicated work does not satisfy a condition of λ-Kolmogorov test and cannot be approximated using normal distribution.

1. Object of research

Turbocharged, eight-cylinder biogas engine was the object of investigations. Indication of all cylinders of engine (362 continuous cycles of engine work) was carried out for every 0.5 degree of crank angle for mean effective power $N_{ef} = 600$ kW, what corresponds to mean effective work 1.3 MJ/m^3. The investigation was performed with the use of 8-channels indication system. This system was composed of 5017B Kistler multichannel charge amplifier and IoTech 16-bit ADC488/8SA A/D converter. Indication was performed with the use of original cylinder's head indicator channels (242 mm in length, what correspond to 121% of cylinder diameter). As it was shown in [1] in research engine, which works with unchangeable rotational speed 1000 rpm, the length of channel has not significant influence on results of indication.

2. Results of measurements

Results of analysis of engine indication are shown as a bar chart of values of elementary indicated work and maximum pressure. Unrepeatability of values of elementary indicated work and heat release in consecutive work cycles are estimated with the use of *"return maps"* [3]. Estimation of p_i and p_{max} distribution was carried out the application of λ-Kolmogorov test [5]. This test allows to use normal distribution, in case of obtained λ value is lower than critical $λ_k$ value.

An analysis of indicator diagrams and heat release process was carried out using software „Silnik" [2], where combustion process is approximated by the zero-dimensional, two-zone model, which takes into account variable mole fractions of ten half-ideal gases. Results of analysis of an elementary indicated work are shown in Figure 1. λ values are specified in individual figures. In all cases obtained λ values are lower than critical value and all distributions can be approximated using normal distribution. The critical values $λ_k$ are dependent on level of significance $α$ and for $α = 0.05$ reach 1.358.

Distribution of p_i values for all engine cylinders are shown in Figure 2. Common data set

of values of elementary indicated work were created as a sum of parameter distributions in individual cylinders. Values of λ, calculated for this case, equals 1.392 and is higher than the critical value.

It results in inability to use the normal distribution for approximation of common date set. The values of mean elementary indicated work in individual cylinders are significantly diversified: they are changing in the range of 1.3±0.123 MJ/m^3.
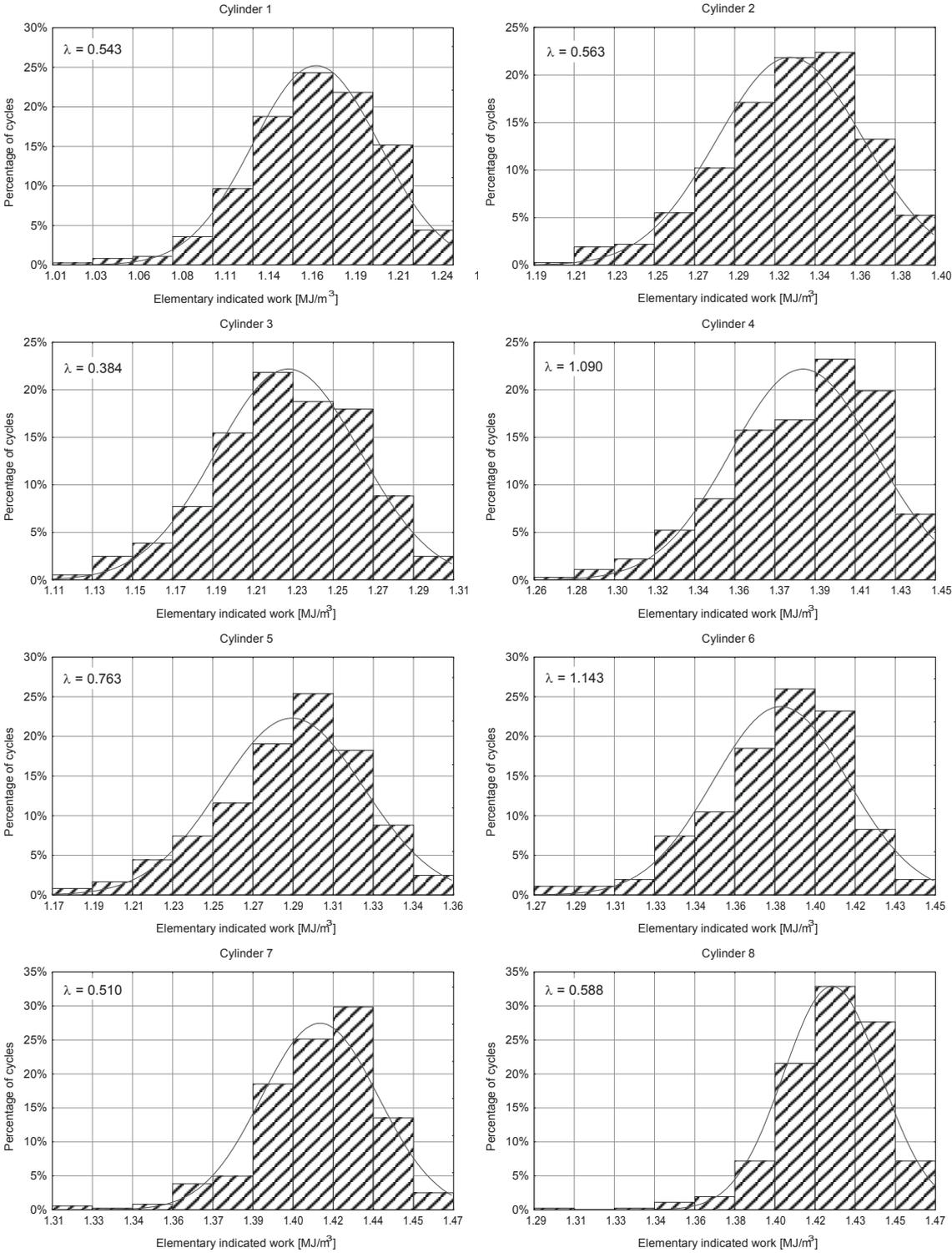

Figure 1. *Distributions of values of an elementary indicated work in all cylinders; real distributions approximated with the use normal distribution*

Approximation distribution of the values of elementary indicated work (Figure 3) shows, that those distributions are significantly different. For this reason the engine work cannot by described by using the results obtained for an individual cylinder.
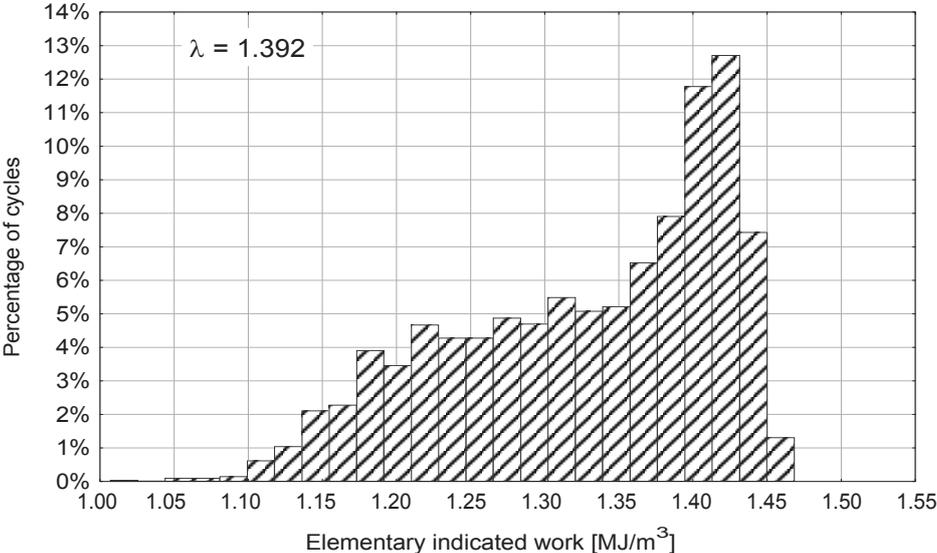

Figure 2. Distribution of common data set of values of elementary indicated work for all cylinders
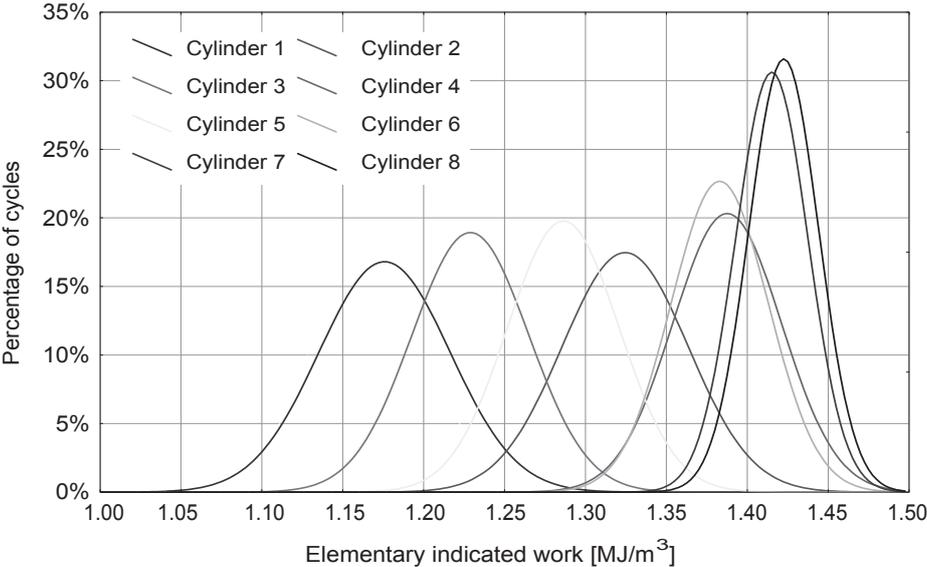

Figure 3. Comparison of values of elementary indicated work for individual cylinders; simultaneous measurement with the use of long channels

On basis of observation of figures presented the distributions of elementary indicated work in individual cylinders, one can conclude, that differences of individual cylinders can results from symmetrical location of cylinders in relation to the symmetrical suction manifold, and can be caused by the wave phenomena in asymmetric exhaust manifold. In this engine cylinder no 1 in situated near turbocharger. The diversification of the average values of elementary indicated work of individual cylinders is significant in the above case (Figure 4), particularly situated at the opposite sides of engine, cylinder No. 1 and 8. Mean values of elementary indicated work are significantly different in spite of the same distance from the centre of symmetrical suction manifold: 1.176 MJ/m^3 - cylinder No. 1 and 1.423 MJ/m^3 - cylinder No. 8.

It is noticeable, that with the growth in mean values of p_i, the limits of scatter of values is narrowed, but in this case the number of observation is too small to conclude about dependence of limits of scatter on mean value of elementary indicated work.
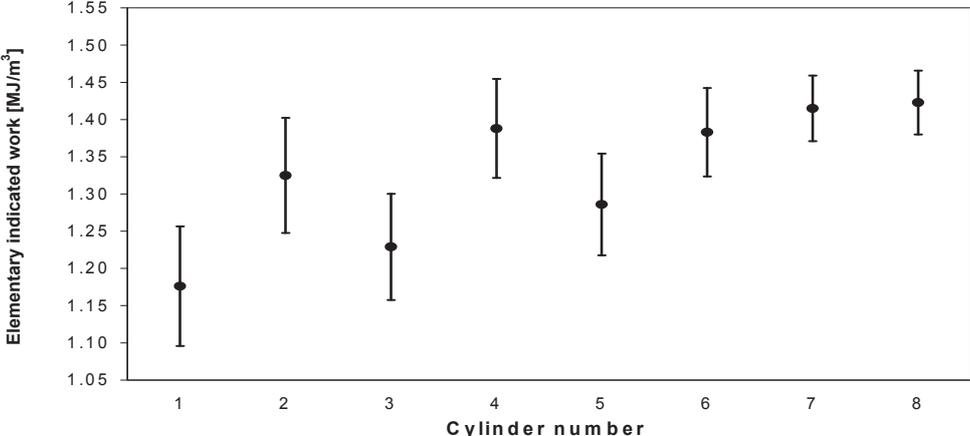

Figure 4. Un repeatability of values of elementary indicated work in individual cylinders of biogas engine

Significant differences in individual cylinders in reference to maximum pressures (Figure 5) occur similarly, as in case of elementary indicated work. The sequence of cylinders on graph of maximum pressure distributions is analogous as in case of distributions of elementary indicated work.
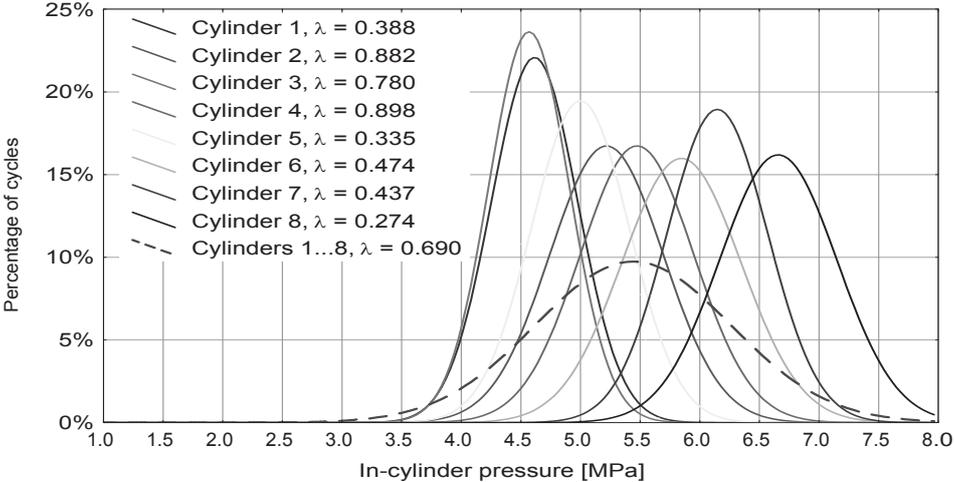
Figure 5. Distribution of values of maximum pressure in individual cylinders of biogas engine; simultaneous measurement with the use of long channels

Correctness of approximation with the use of normal distribution was confirmed by the results of test λ-Kolmogorov [5]. Received λ values (specified in Figure 5), for all eight cylinders are lower than critical λ_k value equal to 1.358 [5]. λ value for distribution of maximum pressures of common data set for whole engine is also below critical value of λ_k=1.358.

The use of *"return maps"* [4] to estimate the quality of work of cylinders (Figure 6) shows the largest repeatability of the work in case of cylinders No. 6 and 7, where the largest concentrating of points in graph occurs. The largest dispersion of points in graphs occurs in case of cylinders No. 1 and 8. For all cylinders Q_{netto} dispersion creates figure with the shape similar to wheel, what is characteristic for the normal distribution [4]. Figure 6 shows unrepeatability of p_i values in the individual cylinders.
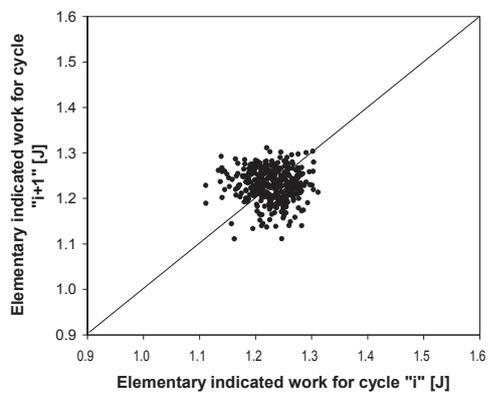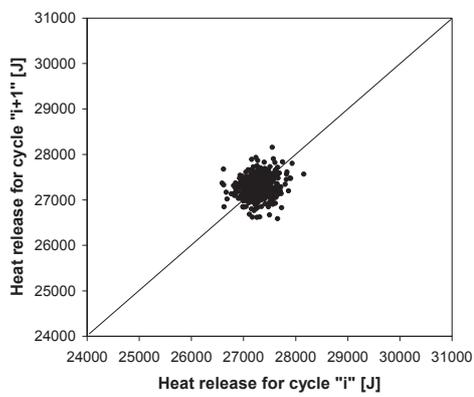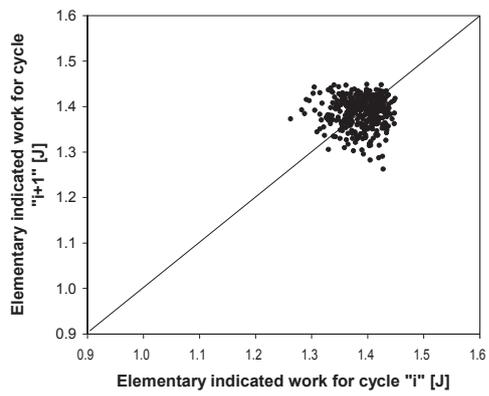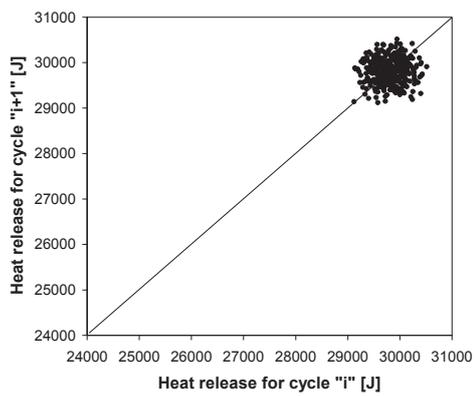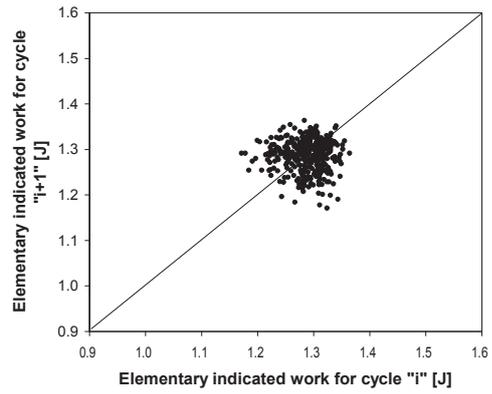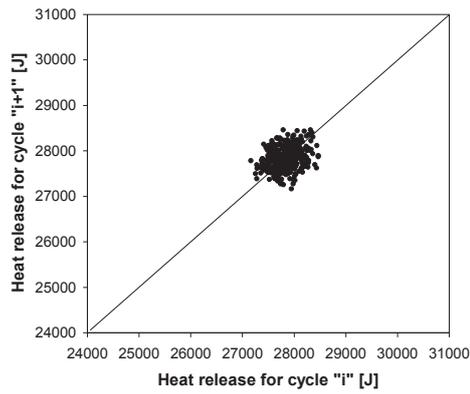
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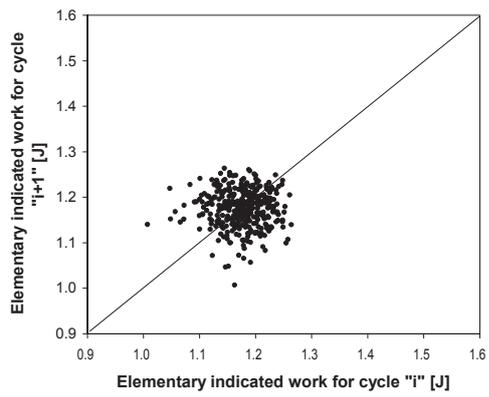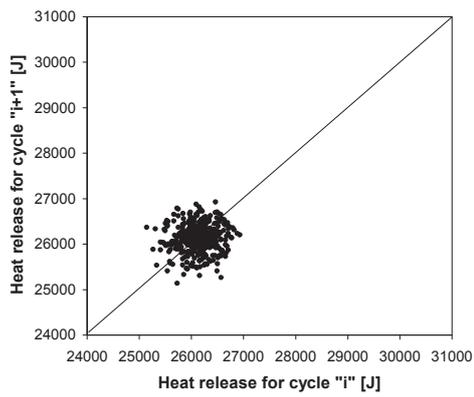
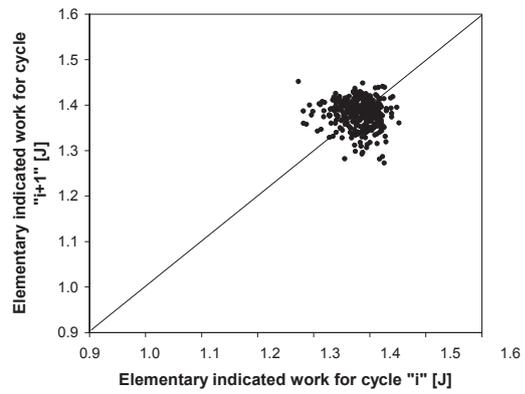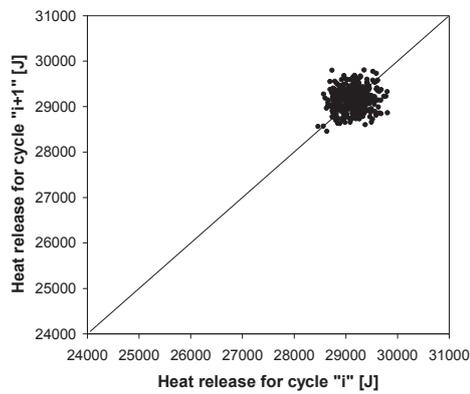Cylinder no. 1

Cylinder no. 2
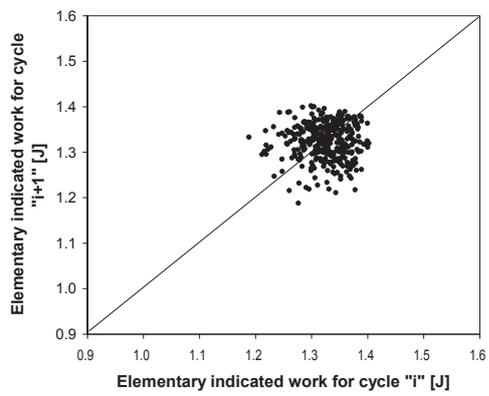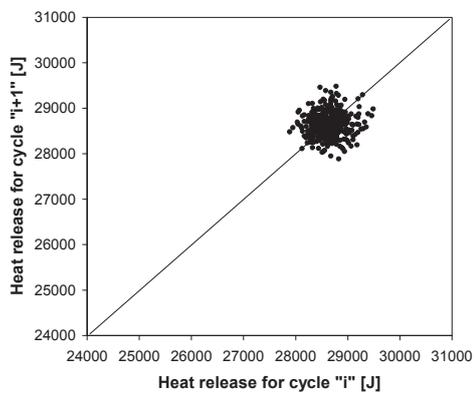
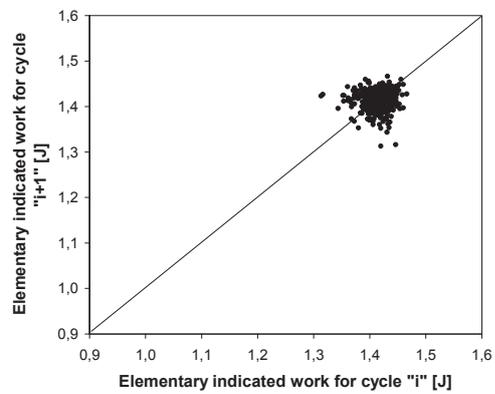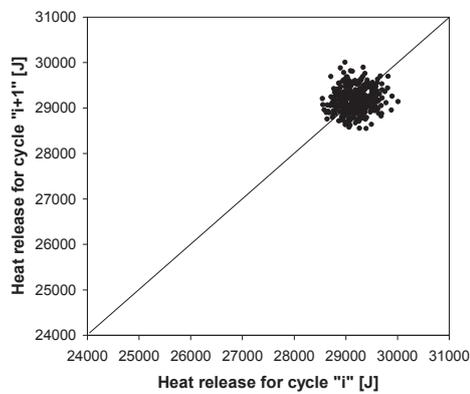
Cylinder no. 3

Cylinder no. 4

Cylinder no. 5

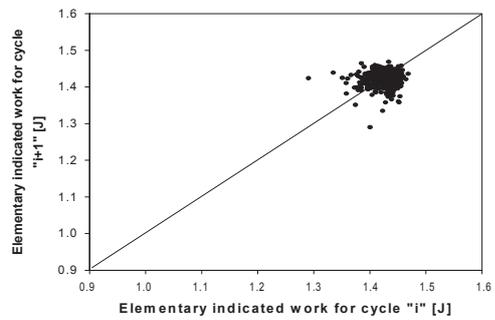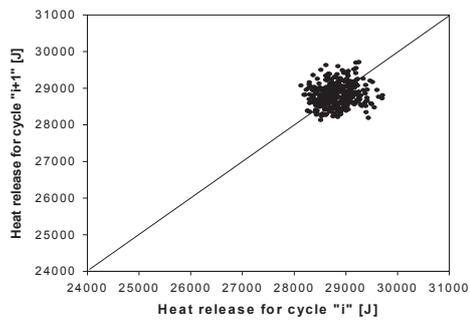Cylinder no. 6

Cylinder no. 7

Cylinder no. 8

Figure 6. „Return maps" of heat release and unrepeatability of values of elementary indicated work in individual cylinders of 8A20G engine

Diversification of work quality in individual cylinders is well visible in Figure 7, on where superposition of "*return maps*" and elementary indicated work for all cylinders were made.
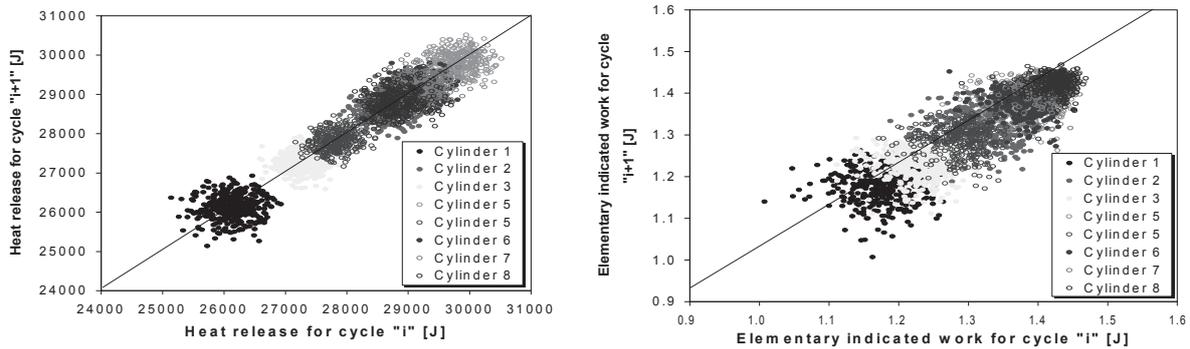

Figure 7. Superposition of „return maps" and unrepeatability of values of elementary indicated work in individual cylinders of 8A20G engine; simultaneous measurement with the use of long channels

Figure 7 presents the differences of Q_{netto} and p_i in all cylinders. It confirms conclusions, that whole engine cannot be estimated on basis of an analysis of individual cylinder.

Unrepeatability of work in individual cylinders can be described using the maximum pressure increase in $(dp/d\varphi)_{max}$ values. Figure 8 shows $(dp/d\varphi)_{max}$ mean value, limit of scatter of this value in individual cylinders and $(dp/d\varphi)_{max}$ mean value for all cylinders. Minimum values, in case of all cylinders, are almost the same, they are changing in the range of 0.0691…0.0771 MPa/°OWK. More noticeable differences occur in case of the mean values: 0.0824…0.2300 MPa/°OWK, the highest differences occur for the maximum values of increase in maximum pressure - 0.1527… 0.3543 MPa/°OWK.
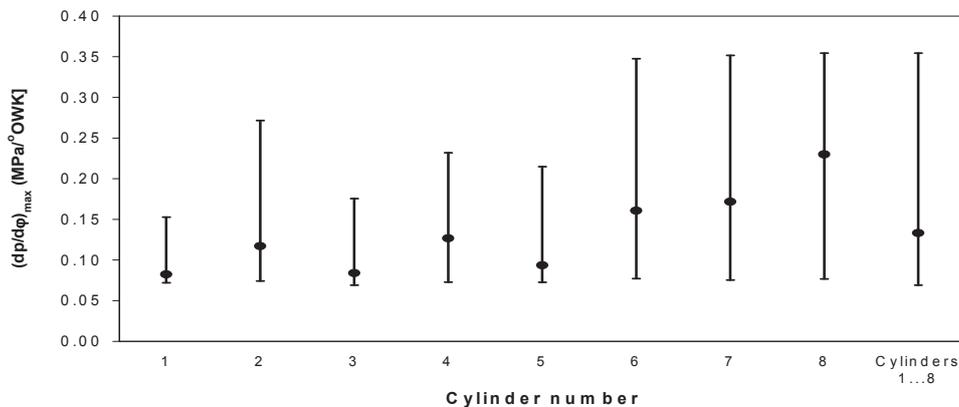

Figure 8. Unrepeatability of increase in pressure in individual cylinders and $(dp/d\varphi)_{max}$ mean values for all cylinders; simultaneous measurement with the use of long channels

3. Conclusions

Unrepeatability of individual cylinders work of turbocharged, biogas engine were evaluated comparing mean values of the following parameters: elementary indicated work p_i, maximum pressure p_{max} and increase in pressure $(dp/d\varphi)_{max}$. Comparative analysis shows an occurrence of the essential differences of mean values and dispersion limits of above parameters.

The distribution of elementary indicated work and maximum pressure can be approximated using the normal distribution. It was confirmed by results of λ-Kolmogorov test provided by PN-83/N-01052.07. Common data set of elementary indicated work for all cylinders cannot be approximated using the normal distribution, because calculated λ values is higher than critical λ_k values equal to 1.358, in spite of the fact that the common data set of

maximum pressure for all cylinders fulfils λ-Kolmogorov criterion for normal distribution ($\lambda = 0.690$).

An analysis of results of simultaneous registration of pressure courses in eight cylinders of engine shows a lack of possibility to state an opinion about quality of whole engine work on basis of analysis of measurement results from one cylinder. Particularly, it is inadmissible to generalize the scatter of elementary indicated work values, determined on the basis of measurement of only one cylinder, on the whole engine.

4. Literature

[1] Cupiał K., Dużyński A., Grzelka J., *The Effect of Sensor Positioning on the Variation of Indicated Pressure*, 28th International Scientific Conference on Internal Combustion Engines KONES 2002, "JOURNAL OF KONES - Internal Combustion Engines" 8-11.09.2002 Jurata, Vol. 9, No. 3-4 str. 21-33.

[2] Cupiał K., „*Silnik*" wersja 2003.06; program do analizy obiegu silnika spalinowego, Instytut Maszyn Tłokowych i Techniki Sterowania Politechniki Częstochowskiej, Częstochowa 2003.

[3] Finney C. E. A., Green J. B. Jr., Daw S. C., *Symbolic time-series analysis of engine combustion measurements*, SAE Paper No. 980624.

[4] Green J. B. Jr., Daw S. C., Armfield J. S., Finney C. E. A., Wagner R. M., Drallmeier J. A., Kennel M. B., Durbetaki P., *Time irreversibility and comparison of cyclic-variability models*, SAE International Congress & Exposition, Detroit, Michigan USA; 1998 March 01-04.

[5] Polska Norma PN-83/N-01052.07: *Statystyka matematyczna. Badania statystyczne. Badanie zgodności rozkładu właściwości w populacji z rozkładem teoretycznym*

[6] Volk W., *Statystyka stosowana dla inżynierów*, WNT, Warszawa 1973.