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SELECTION OF MODEL PARAMETERS OF BIOGAS IC ENGINE

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Summary. The statistical methods of selection of four chosen engine model's value parameters are presented in this paper. The aim of this paper is to create a model taking into consideration non-repeatability of consecutive engine work cycles. Modelling of consecutive engine work cycles was carried out with using zero-dimension, two-zone engine model. In this model heat release was described with Vibe function and heat exchange was described with Woschni equation. Values of four characteristic parameters obtained by applying the presented methods allows for a comparatively precise modelling of individual cycles as well as series of engine work cycles.

Key words: value parameters, engine work cycles, methods of selection

NON-STATIONARY MODEL OF ENGINE WORK

The aim of non-repeatability consecutive engine work cycles modelling is taking this non-repeatability into consideration, for instance during an analysis of an assembly of crankshaft, pistons and connecting-rod or during an analysis of thermo-chemical processes in a cylinder during individual engine work cycles. These phenomena are very important for an application to generating sets driven by biogas engine, which have a higher level of non-repeatability of engine work cycles than generating sets driven by a CI engine fuelled by liquid fuels. The model utilized in this paper permits to reach a satisfactory agreement of value of elementary indicated work, maximum pressure and maximum pressure rise in individual cycles.

Modelling was carried out using a zero-dimension, two-zone engine model [Cupiał 2003], which takes into account variable mole fractions of ten half-ideal gases: N_2, O_2, CO_2, CO, H_2, CH_4, C_2H_6, C_3H_8, C_4H_{10} and H_2O. In this model heat release was described with Vibe function [Vibe 1957] and heat exchange was described with Woschni [2001] equation.

The groups as follows were distinguished in this model (Fig. 1):

– parameters with constant values determined by engine settings;
– parameters with values definite by well-known functional dependences;
– parameters with quasi-random variable values.

Selection of model parameters for each individual cycle was realized as long as obtains the best consistent two pressure traces: real and modelled. Values of these parameters are changed in each engine work cycle. These parameters are:

– dispersion of temporary values of elementary energy ΔE_j (caused by variable values of a filling factor in consecutive cycles); energy supplied into cylinder expressed as a product of two factors: calorific value of flammable mixture (at 1 bar, 273 K) and a filling factor;

– flame development angle φ_{rp} – the crank angle interval between the spark and the time at which 2% of heat is released;

– burning duration angle φ_{spal} – the crank angle interval between the end of the flame development stage and the time at which the 99.89% (≈ 100%) of heat is released;

– relative angle peak φ_{piku} - the angle of maximum heat flux and burning duration angle ratio.

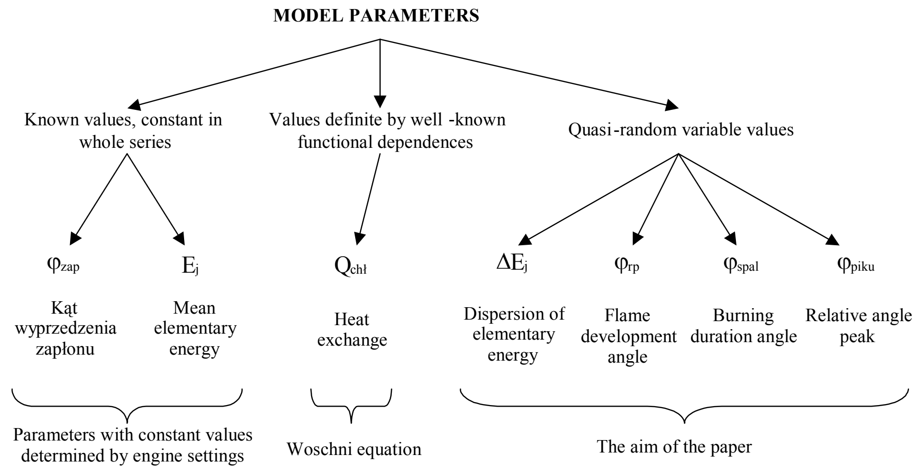

Fig. 1. Division of model parameters

During modelling were considered, in indirect way, non-repeatability of heat exchange process by introducing into Woschni equation course of pressure and temperature in individual engine work cycles. Modelling was carried out for mean values of elementary indicated work, which was calculated for mean fuel consumption and fuel's calorific value.

Modelling of non-repeatability of consecutive cycles was based on the results of supercharged biogas engine indications. The indications of an engine (1100 continuous cycles of engine work and pressure courses in the inlet and in the outlet channels) were carried out for every 0.5°CA for mean effective power N_{ef} = 630 kW, which corresponds to mean indicated work 1.7 MJ/m^3.

ITERATIVE SELECTION OF MODEL PARAMETERS VALUES FOR INDIVIDUAL CYCLES

The aim of the work was checking a possibility to achieve the best consistence of the high-pressure part of engine work cycle (without charge exchange) of two pressure traces: a real and a modelled one. It was carried out by using iterative selection of values for four characteristic model parameters for individual cycles within a series of 100 continuous engine work cycles. Iterative selection of values for four chosen, characteristic parameters of an engine work cycle depended on change values of individual parameters as well as on observation of an influence of this change on the value of the chosen criterion of modelling quality.

An agreement of results of modelling with real pressure course was estimated by using the absolute values of elementary differences of indicated works counted for real and modelled cycles divided by value of real indicated work. It was expressed by numerical criterion ADIW (Equation 1). This criterion is most sensitive on local non-adjustment of pressure courses among the other analysed criterions [Katolik 2005]. The value of COV of elementary indicated work was used to estimate the precision of modelling, too (Equation 2).

ADIW criterion was used to estimate the precision of modelling of individual cycles. Values of COV_{pi} were used to estimate the precision of modelling of a cycle's series without taking into consideration features of individual cycles entering into the series.

$$\mathrm{ADIW} = \frac{\sum_{i(\varphi=180^{o}\,CA)}^{i(\varphi=540^{o}\,CA)} \left|\Delta l_{real} - \Delta l_{mod}\right|}{\sum_{i(\varphi=180^{o}\,CA)}^{i(\varphi=540^{o}\,CA)} \Delta l_{real}} \tag{1}$$

where:

l_{real} – real elementary indicated work;

l_{mod} – modelled elementary indicated work.

Modelling with iterative selection values of four characteristic model parameters (dispersion of elementary energy ΔE_j, early flame development angle φ_{rp}, burning duration angle φ_{spal} and relative angle peak φ_{piku}) permits to exact modelling of high-pressure part of engine work cycle. Maximal error of modelling of individual cycles, expressed by ADIW criterion is lower than 4.46%, mean values of ADIW criterion reach 3.21% (Fig. 2).

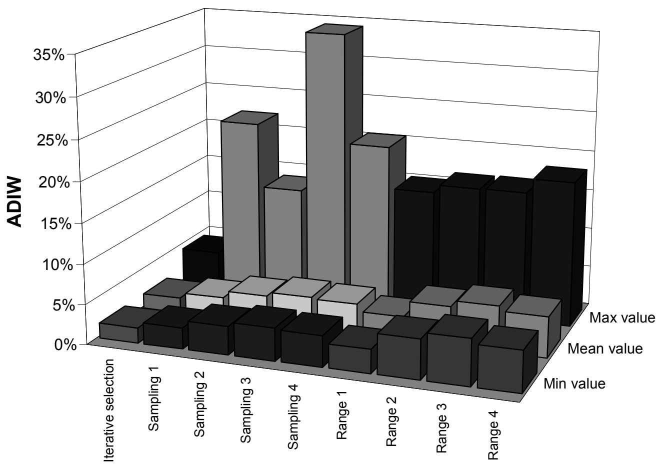

Fig. 2. Comparison of accuracy of engine work cycle modelling

Obtained values of COV_{pi} reach 2.55% and are very approximate to COV_{pi} values obtained for series of real engine wok cycles reach 2.34% (Fig. 4).

Comparisons of real and modelled pressure courses obtained during iterative modelling (ADIW = 3.21%) are shown in Fig. 3.

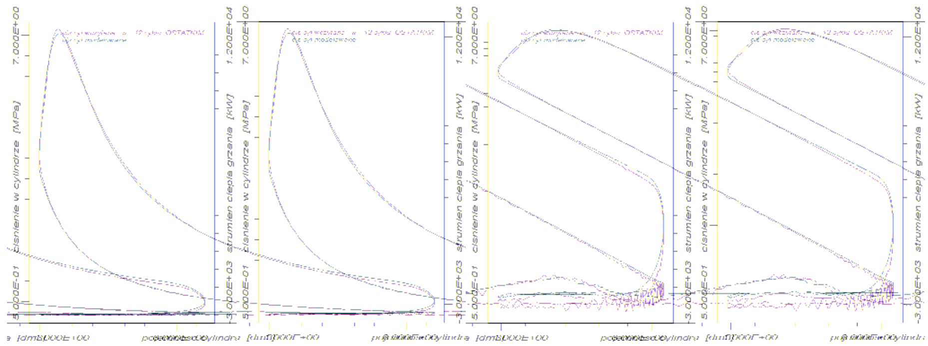

Fig. 3. Example of SI engine work cycle modelling (ADIW 3.21%) [Cupiał 2003]

The iterative method requires multiple repetitions of calculations of for each cycle and allows to obtain the enough large precision of modelling. However this method requires considerable amounts of job, which makes difficult applying of this method in practice.

The random selection of values of four parameters from their range of changeability does not allow obtain the reliable modelling of individual cycle, because the error of modelling expressed by the value ADIW that can reach very large values.

SELECTION OF MODEL PARAMETERS VALUES FOR CYCLE SERIES

Goodness-of-fits of real and modelled parameters without taking consideration conformity of individual cycles is analysed in this part of paper.

Analysis of conformity of real and modelled series of engine work cycles was based on COV_{pi} value (Equation 2), which is statistical measure of deviation of elementary indicated work in series:

$$COV_{p_i} = \frac{\sigma_{p_i}}{\overline{p_i}} = \frac{\sqrt{\frac{\sum_{i=1}^{n}\left(p_i - \overline{p_i}\right)}{n-1}}}{\overline{p_i}} \tag{2}$$

were:

σ_{Pi} – standard deviation of p_i;

$\overline{p_i}$ – mean elementary indicated work;

n – number of measurements.

Values of four selected, characteristics models parameters were selected with using the pseudorandom numbers generator (distribution can be approximated with using normal distribution). These values were generated from empirical determined ranges of parameters values, which are described by standard deviations. The ranges were defined on basis of real cycles analysis and iterative modelling results. Sampling values of parameters were done four times for complete series of engine work cycles. Obtained values weren't connected by empirical equations. Precision of modelling was estimated with using the COVpi values.

COVpi values obtained during random modelling (Fig. 4), in all cases, are higher than COVpi value calculated for series of real engine work cycles reach 2.34%. It shows, that using random factor in process of model parameters values selection can cause the larger dispersion limits of pi in comparison with series of real cycles. This enlargement was expressed by higher values of COVpi about 0.5…2.5% in reference to the analogous value counted for real cycles series.

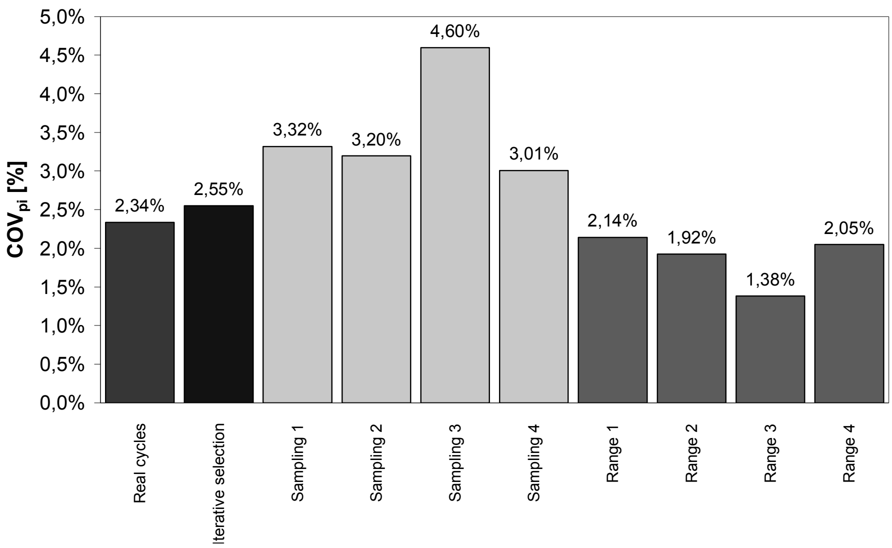

Fig. 4. Comparison of COV_{pi} values of engine work cycle modelling for simplified methods of values parameters model selection

Using random selection of model parameters values require definition of changeability parameters limits. Determination of these limits required a statistical analysis of four characteristic model parameters. Calculation of standard deviations of parameters is required too. One of the methods of determination of limits is simplified „range" method (known as „rozstęp") [Volk 1973]. The calculation of *R* value (Equation 3) depends on calculation of minimal and maximal value in data series.

$$R = x_{max} - x_{min} \tag{3}$$

There are requires only two values, maximum and minimum in series, to make a „rozstęp" calculation. In case of engine work cycle, values of elementary indicated work were chosen. Next step was standard deviation calculation with using mean value of elementary indicated work in whole series. Standard deviation values obtained with „rozstęp" method are 40% lower than standard deviation values calculated on basis of results of iterative modelling. Random selection of model parameters values was done four times. Comparison of modelling results obtained with using three methods of model parameters values selection are shown in Figure 2 and 4.

The last method appears to be the fastest and the easiest method of values selection. Values of COV_{pi} obtained in this case were about 0.20…0.96% lower than value obtained for real engine work cycles series reach 2.34%.

Methods presented above concerns modelling of engine work cycles for individual cylinders. Values of elementary indicated work obtained for all cylinders of test engine are shown in Table 1.

Table 1. Elementary indicated work of cylinders of gas engine

Cylinder no.	Mean value p_i MJ/m^3	Standard deviation σ_{pi} MJ/m^3	COV_{pi} MJ/m^3	λ
1	1.176	0.0406	0.0345	0.543
2	1.325	0.0391	0.0295	0.563
3	1.229	0.0360	0.0293	0.384
4	1.388	0.0336	0.0242	1.090
5	1.286	0.0345	0.0268	0.763
6	1.383	0.0301	0.0218	1.143
7	1.415	0.0223	0.0158	0.510
8	1.423	0.0216	0.0152	0.588

Statistical analysis of indication results shows, that mean values of elementary indicated work in individual cylinders are significantly diversified: they are changing in the range between 1.176…1.423 MJ/m^3, values of standard deviations are changing in the range between 0.0216…0.0406 MJ/m^3. Values λ [PN-83/N-01052.07], obtained for individual cylinders, are presented in the Table 3. In all cases obtained λ values are lower than critical value. The critical values λ_k are dependent on level of significance α and for $\alpha = 0.05$ reach 1.358 [PN-83/N-01052.07].

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.

CONCLUSIONS

Modelling with iterative selection of model parameters values for individual cycles permits to obtain the maximal error of modelling, expressed as a ADIW value, reach 4.46%; mean values of ADIW criterion reach 3.12%. These results were calculated for engine, which worked without knock. Value of COV_{pi} calculated for the same series of cycle's reach 2.55% and is only about 0.21% higher than value obtained in case of real cycles analysis.

Method of random selection of model parameters, introduced in this paper, requires real cycles series analysis. The aim of this analysis was to fix the range of variation of selected model parameters. COV_{pi} values obtained for this method are higher than values obtained for real cycles series and they are changing in the range between 3.01…4.60%.

Estimation of standard deviation values for four selected, characteristic model parameters carried out with using „range" method allows to reduce the time of calculations and allows to obtain COV_{pi} values lower about 0.20…0.96% than COV_{pi} value calculated for series of real cycles.

Random modelling, based on „range" method of standard deviation calculation, is most suitable for practise use. This model requires comparatively small number of data and can by applied to quick modelling of the series of cycles with taking into consideration their non-repeatability.

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.

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