AN INTERACTIVE MODELLING OF WORK CYCLE OF SI GAS ENGINE

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INTRODUCTION

Zero-dimensional model of heat release is applied in many models used for an analysis of engine work cycles in macro-scale. These models are based on the predicted heat release inside a cylinder. Wiebe function is one of the commonly used functions applied for this phenomenon:

$$\Delta x_{burn}(\varphi) = 1 - \exp\left(-a \cdot \left(\frac{\varphi - \varphi_{SOB}}{\varphi_{burn}} \right)^{m+1} \right) \tag{1}$$

where:

- a – parameter of heat release duration,
- m – parameter of heat release curve shape,
- φ – current crank angle,
- φ_{SOB} – start of burning,
- φ_{burn} – combustion duration.

The logistic function [4], which is an empirical function with no physical basis, is applied apart from Wiebe function. This function has a form:

$$\Delta x_{burn}(\varphi) = \frac{1}{1 + \exp(-B \cdot (\varphi - [M + \varphi_{burn}]))} \tag{2}$$

where:

- M – inflexion point on the pressure curve (the so-called ignition delay),
- B – measure of the speed of burn.

An analysis of a possibility to achieve accuracy of model, which is based on the description of heat release with the use of Wiebe function, was carried out in the paper.

RESULTS OF MODELLING

The supercharged biogas engine 8A20G ($S/D = 240/200$ mm and l_e = 12.6 MJ/m^3) was the object of investigations. An indication of engine (1100 continuous cycles of engine work and pressure courses in the inlet and in the outlet channels) was done for every 1°CA, for the mean indicated work 1.7 MJ/m^3.

A registration and analysis of indicator diagrams were carried out using “LCTXR” [3] and “SILNIK” [1] programs.

The modelling of the high-pressure part of engine work cycle (without charge exchange) was carried out with a program [1], where heat release was described by Wiebe functions. These functions have parameters which can be interactively selected until the best consistency of the two pressure traces: the real and the modelled one, is obtained. An interactive selection of parameters was realised in two stages:

– iteration of conformity of two compression polytropic curves: real and modelled,

– iterative selection of: start of burning, angle of $(dQ/dt)_{\max}$, combustion duration and heating value (modelling of high-pressure part of indicator diagram).

The following criteria were used to estimate the conformity of the real and the modelled work cycles:

DIW – Difference of Indicated Works

$$DIW = \frac{l_{i\,real} - l_{i\,\mathrm{mod}el}}{l_{i\,real}} \tag{3}$$

ADIW – Absolute Difference of Indicated Works

$$ADIW = \frac{1}{l_i} \cdot \int \left| p_A - p_B \right| dV \approx \frac{\dfrac{\sum_{180}^{540} \left| \left(\dfrac{p_{A1} - p_{A2}}{2} - \dfrac{p_{B1} - p_{B2}}{2} \right) \cdot \left(V_2 - V_1 \right) \right|}{V_S}}{l_{i\,cycle}} \tag{4}$$

QDIW – Quadratic Mean Difference of Indicated Works

$$QDIW = \frac{1}{l_i} \cdot \int \left(p_A - p_B \right)^2 dV \approx \frac{\dfrac{\sqrt{\sum_{180}^{540} \left[\left(\dfrac{p_{A1} - p_{A2}}{2} - \dfrac{p_{B1} - p_{B2}}{2} \right) \cdot \left(V_2 - V_1 \right) \right]^2}}{V_S}}{l_{i\,cycle}} \tag{5}$$

where:

p_{A1}, p_{B1}, p_{B2} – in-cylinder pressure,
l_i – indicated work of the cycle,
V – cylinder capacity.

Interactive modelling of pressure traces was carried out for four real cycles selected from a series of 1100 continuous cycles.

cycle with maximum value of indicated work – l_i = 1.793 MJ/m^3
cycle with minimum value of indicated work – l_i = 1.573 MJ/m^3
cycle with mean value of indicated work – l_i = 1.699 MJ/m^3
randomly chosen cycle – l_i = 1.719 MJ/m^3

The best conformity of modelling results with measuremen results was obtained after 3-4 repetitions of two stages of iterative calculations. Other repetitions do not increase model accuracy.

Example results for the 1st approximation are shown in Fig. 1-4. These figures show the changes of four parameters for randomly chosen cycle.

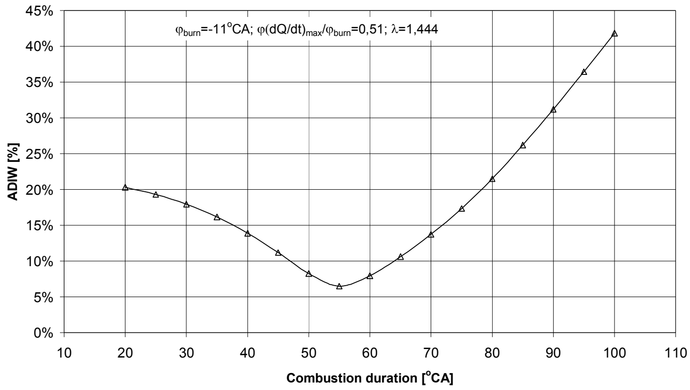

Fig. 1. An influence of changing of combustion duration on ADIW criterion, 1st approximation – 1st step

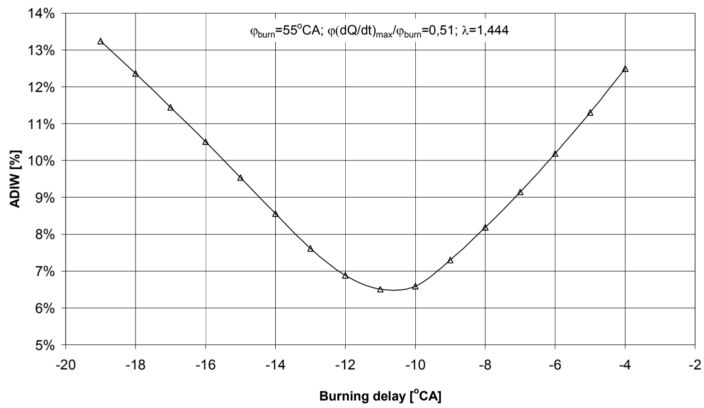

Fig. 2. An influence of changing of burning delay on ADIW criterion, 1st approximation – 2nd step

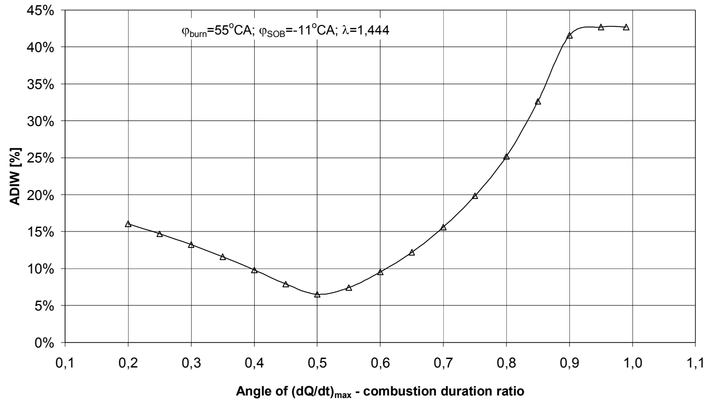

Fig. 3. An influence of ratio changing of angle of $(dQ/dt)_{max}$ to combustion duration on ADIW criterion; 1st approximation – 3rd step

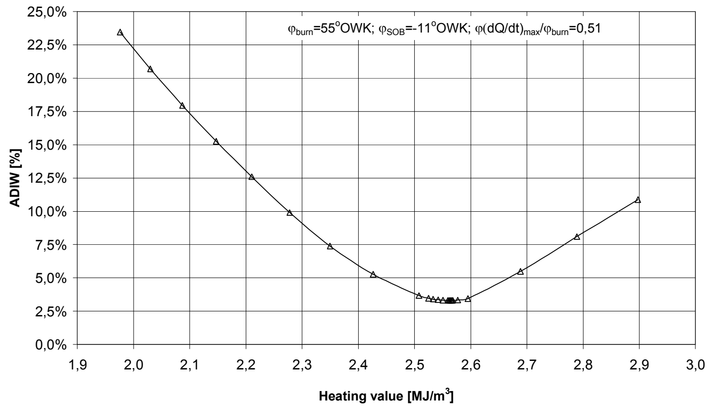

Fig. 4. An influence of changing of heating value on ADIW criterion, 1st approximation – 4th step

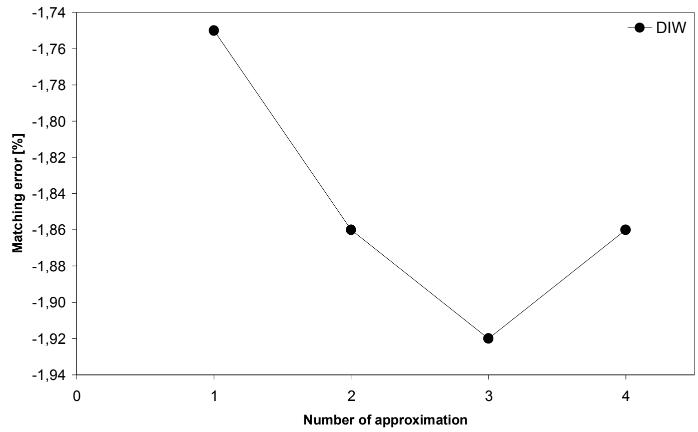

Fig. 5. Minimal values of ADIW criterion in consecutive approximations

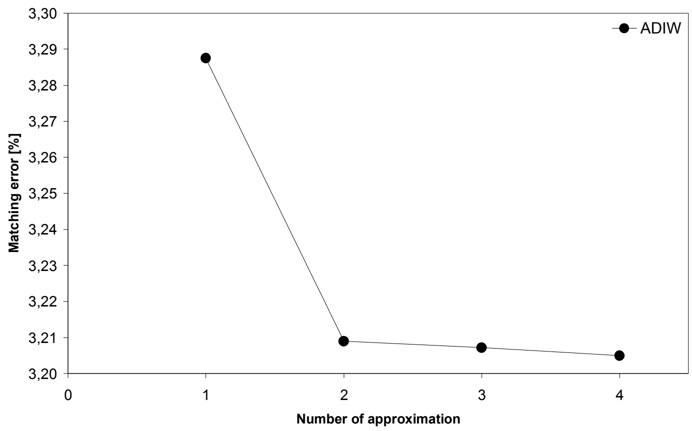

Fig. 6. Minimal values of DIW criterion in consecutive approximations

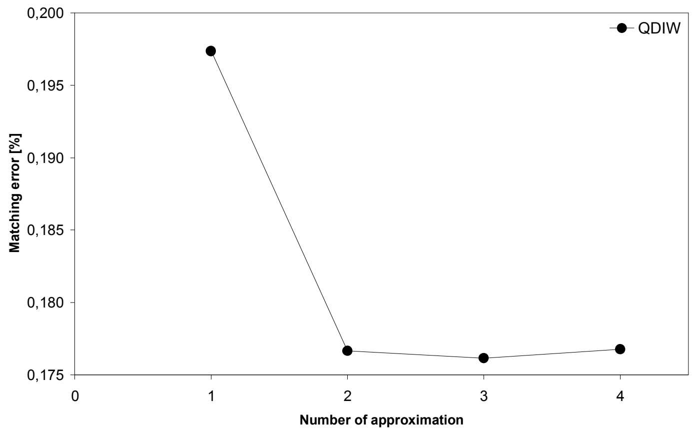

Fig. 7. Minimal values of QDIW criterion in consecutive approximations

Minimal values of ADIW and QDIW criterions, shown in Fig. 5-7, are qualitatively similar, but QDIW values are about 15 times smaller than values of ADIW. This similarity can be the reason of incorrect interpretation of modelling results – modelling is not so perfect as it is pointed by small numerical values. DIW value is minimal (–1.75%) in case of 1st approximation, although values of two others criterions are relatively large. These values stabilize at the minimal level only after the 4th approximation. In this approximation DIW achieve value insignificantly larger than at the beginning of the optimization (–1.86%)

Four series of calculations were carried out for each of the analysed cycles. An exception is a cycle with the mean value of the indicated work (l_i = 1.699 MJ/m^3). For this cycle the minimal values were achieved after three approximations.

Final modelling results are shows in Table 1.

Table 1. Final values of parameters and inaccuracy of the model received as results of interactive optimization for selected SI engine work cycles

Indicated work	Combustion duration	Burning delay	Angle of $(dQ/dt)_{max}$/ combustion duration ratio	Heating value	DIW	ADIW	QDIW
MJ/m^3	°CA	°CA	-	MJ/m^3	%	%	%
1.573	78.1	–13.0	0.498	2.4712	–0.13	3.42	0.256
1.699	62.2	–11.0	0.501	2.5753	–0.88	3.33	0.178
1.719	53.6	–10.5	0.515	2.5647	–1.86	3.21	0.177
1.793	52.9	–12.3	0.510	2.6466	–0.95	4.16	0.033

Comparison of different criterions of conformity of modelling results with measurement results shows that the absolute difference of the indicated works (the real and modelled one) ADIW is more sensitive than standard deviation QDIW. Small values of QDIW criterion are not objective, these values are much smaller than the difference of indicated works DIW for high-pressure part of the indicated diagram. Finally, the absolute difference of indicated works ADIW was chosen as a conformity criterion in an iteration of calculation.

Unobtrusive differences between real and modelled values of indicated works were obtained as a result of modelling. This was described by the DIW criterion, whose values are contained in the range from –0.13% to –1.86%. ADIW value takes into consideration only the indicated work of the high-pressure part of the indicated diagram, apart from charge exchange.

ASDIW criterion was chosen as a main criterion to estimate the precision of modelling. This criterion calculates in a correct way the difference between the real and the modelling pressure courses. ADIW value is contained in the 3.21-4.16% range.

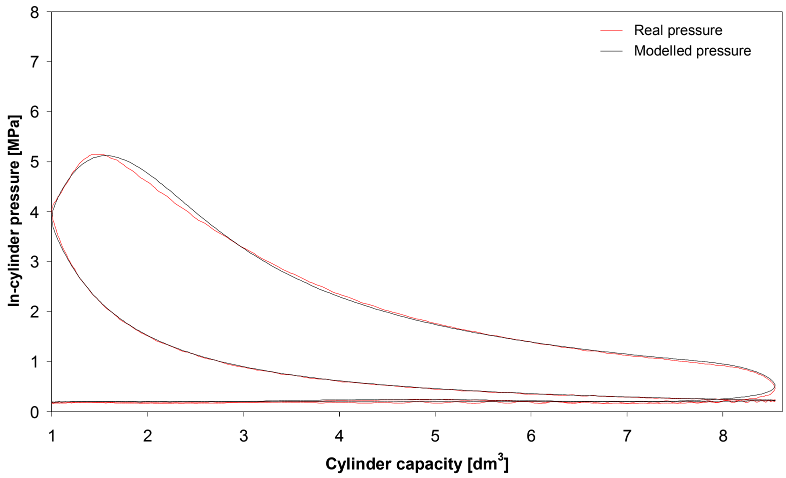

Fig. 8. Example of modelling of SI engine work cycle; $l_i = 1.573$ MJ/m^3 (min indicated work)

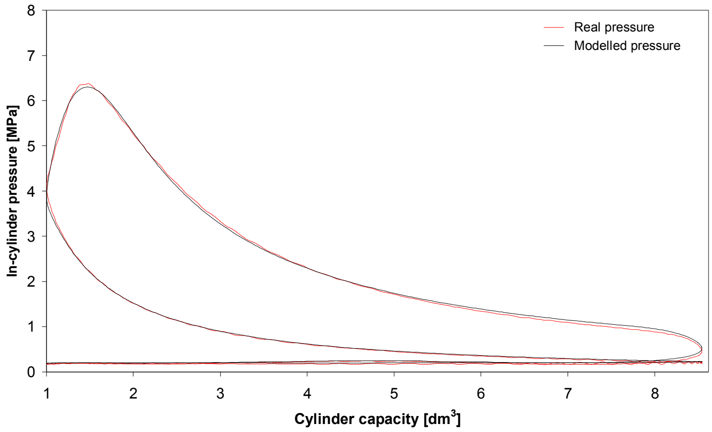

Fig. 9. Example of modelling of SI engine work cycle; $l_i = 1.699$ MJ/m^3 (mean indicated work)

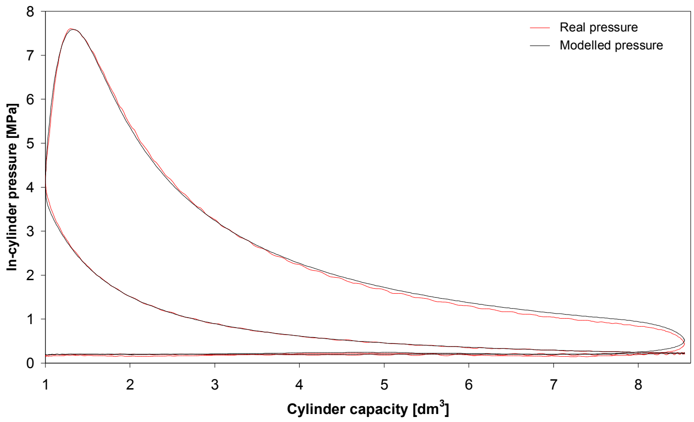

Fig. 10. Example of modelling of SI engine work cycle; $l_i = 1.713$ MJ/m^3 (max indicated work)

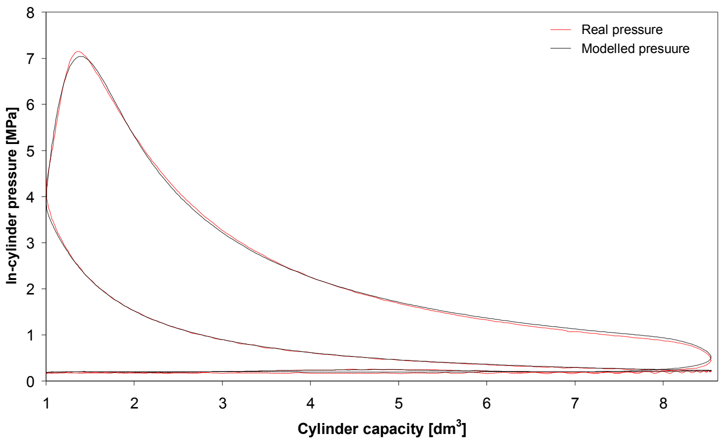

Fig. 11. Example of modelling of SI engine work cycle; $l_i = 1.793$ MJ/m^3 (randomly chosen cycle)

An analysis of 1100 consecutive work cycles of SI gas engine shows that the indicated work reaches 1.699 MJ/m^3 ±4.47%. Uncertainty of the high-pressure part of the indicated diagram representation in four selected cycles, among other things extreme cycles, reached –1.86% and was about 5 times smaller than 95% of the indicated work dispersion limits caused by unrepeatability of engine work cycles. It means that the models which use Wiebe function can be helpful in the modelling of unrepeatable engine work cycles. In spite of the conformity of the indicated work values (the real and the modelled one) for the whole cycle, a local unconformity can appear. ADIW criterion was chosen as a main criterion of estimation, because it is less sensitive to fluctuations of pressure courses.

CONCLUSION

A minimization of the absolute difference in the indicated work values (ADIW) is a good method to estimate the conformity of real and modelled pressure courses.

This criterion allows to estimate an uncertainty of the high-pressure part of the indicated diagram modelling (with the use of Wiebe function) at the range 4-5 times lower than 95% dispersion limits of the indicated work caused by the unrepeatability of engine work cycles.

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SUMMARY

An interactive modelling of SI gas engine work cycle using Wiebe function is presented in this paper. This method includes interactive selection of model parameters to accomplish the best conformity of modelling pressure course with real pressure course.

The aim of this paper is to estimate the accomplishment of possibilities of pressure course transformation in SI gas engine work cycle applying the model, which uses Wiebe function.