An experimental study of the cylinder pressure at work of diesel engine with generator

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Abstract. In the article are presented and analyzed the obtained results of the experimental study of the cylinder pressure of a diesel engine with a generator at various external electrical loads. The system for indicating the diesel engine by measuring the cylinder pressure in its operation with an electric AC generator and the computer processing of the obtained results with the created software in MATLAB are described. The basic technical data of the diesel engine, the electric AC generator, the load system, the system for measuring the cylinder pressure at its operation are presented. The cylinder pressure measurements have been made in the operation of the diesel engine with the generator at established regimes with different electrical loads. After the computer processing of the obtained results for the cylinder pressure with the created software in MATLAB the indicator diagrams at different electrical loads were constructed and are presented in this paper. The deviations of the maximum pressure and the derivative of the cylinder pressure at established regimes with different electrical loads are calculated, presented and analyzed.

1 Introduction

Based on the measurement of the cylinder pressure during operation of internal combustion engines (ICE), a so-called indicator diagram is built. With the cylinder pressure data obtained, it is possible to calculate the main engine performance of the engine under different operating regimes and fuels [1-3], to analyze the combustion process in the engine [3, 4], to study the influence of various factors and parameters on the operation cycle of the ICE [3, 4], to check the adequacy of the created mathematical models of the processes in the ICE [4-6] and others.

2 System for Indication of diesel engine

The cylinder pressure measurement system consists of AVL QC43D pressure sensor, single channel amplifier and AVL FI PIEZO converter, NI 6343 multi-channel analogue-to-digital converter (ADC), inductive sensor for top dead centre (TDC) and MATLAB software for recording, calculations and visualization of the obtained results.

2.1 Pressure sensor AVL QC43D

The QC43D pressure sensor is manufactured by AVL and is a category of sensors for engine development. The connection of the QC43D to the cylinder head of the tested diesel engine is done in a specially designed threaded hole M14×1,25.

The AVL QC43D pressure sensor is mounted on the cylinder head of the diesel engine in a specially designed opening (Fig. 1).

The protection of the quartz element of the QC43D from overheating occurs by forced circulating coolant through the sensor. This ensures long service life and high reliability of the results. Basic data from the QC43D pressure sensor technical specification is available at [7].

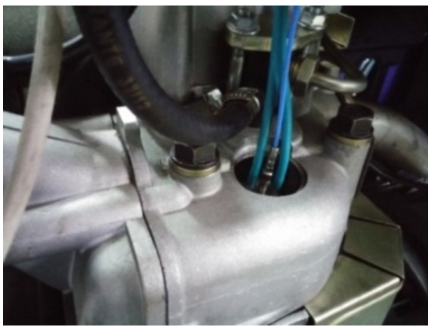

Fig. 1. Location of the AVL QC43D pressure sensor.

2.2 Single channel amplifier and converter AVL FI PIEZO 2P2E

The other element of the system – AVL FI PIEZO in the specific version 2P2E includes a single channel amplifier and an electric signal converter.

The AVL FI PIEZO 2P2E is equipped with a 120×80 LCD display showing the cylinder pressure as a function of the crankshaft rotation angle for one operating cycle or shorter interval previously defined.

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The functional diagram of AVL FI PIEZO 2P2E includes two parts, respectively, for digital and analog signal processing. To protect the measured interference signal, the analogue part is galvanically separated from the digital one.

AVL FI PIEZO 2P2E is equipped with a 16 bit analogue-to-digital and digital-to-analogue converter with a 1 MHz operating frequency. The electrical charge range is from 0 to 14000 pC, and the analog output ranges from -10 V to +10 V.

The possibility of dynamic drift compensation allows trouble-free operation of cable length from sensor to device up to 20 m. On the other hand, the robust construction of the device allows its mounting in the immediate vicinity of the engine under consideration. The device can be used for both bench measurements and road conditions.

Determination of the gain factor is done according to the formula

$$A \leq \frac{8000}{S\, p_n}, \qquad (1)$$

where S is the sensitivity of the sensor, pC/bar; p_n – maximum value of the measured signal, bar.

Formula (1) is in effect at 0V offset. When selecting 8V offset, the 8000 constant in formula (1) is replaced by 16000.

The conversion factor from the electric charge to voltage is calculated according to the formula

$$SCF \leq \frac{800}{S\,A}, \frac{\text{bar}}{\text{V}}. \qquad (2)$$

Main data from the technical specification of AVL FI PIEZO 2P2E is available at [7]. To control the signal output of the AVL FI PIEZO 2P2E, with a digital oscilloscope, a real-time visualization is performed during the measurements.

AVL FI PIEZO 2P2E settings are made by a computer connected via a USB interface and an installed application IndiSignal or via the buttons and the display on the front panel of the device.

2.3 Multi-channel AD and DA converter NI 6343

The analog output signal from the AVL FI PIEZO 2P2E is fed to one of the sixteen differential analogue inputs of the ADC of the NI 6343 multi-functional device manufactured by National Instruments.

The connection between the NI 6343 and the computer is via a USB interface.

2.4 Inductive sensor for TDC

An element of the system is also the fixed to the end of the crankshaft of the diesel engine disk with a tooth, which during the operation of the engine generates impulses in the nearby to the disk inductive sensor.

These synchronizing pulses are fed to the other of the analogue inputs of the NI 6343 and serve to synchronize the measurements relative to TDC.

Inductive sensor Autopribor 191.3847 is connected to the NI 6343 via a high-frequency shielded conductor - type RG58U (with 50 Ω impedance), which guarantees minimal loss of HF signal transmission as well as minimal interference in the measured signal. The technical data for the inductive sensor is available at [7].

2.5 Program in MATLAB with Simulink

The built-in program in the Simulink application in the MATLAB environment allows real-time visualization and storage of measurement data in files with a “mat” extension. Through the created script in MATLAB it is possible to process and visualize the measurement results at a later stage.

3 Object of research and methods

The indicating system is mounted on an experimental system, consisting of a diesel engine and a AC generator. The experimental system was developed on the basis of an diesel generator, manufactured by KIPOR, model KDE 6500T.

3.1 Object of research

The object of research is a single-cylinder, air cooled diesel engine KIPOR KM 186F, having the following parameters and indicators: cylinder diameter D = 86 mm; stroke of the piston S = 72 mm; displacement volume V_h = 0,418 dm^3; compression ratio ε = 19; rated power N_e = 5,7 kW at a rotational speed n = 3000 min^{-1} [7].

An external electrical load is used for loading the electric generator and the diesel engine connected to it. The electric load consists of seven heaters, connected in parallel to two power controllers in two circuits.

3.2 Research method

The diesel engine operating pressure is measured at a stabilized rotation speed of n = 3000 min^{-1} as the motor drives an AC generator with a generator frequency f = 50 Hz.

The programs created in MATLAB allow the selection of the number of operating cycles during the operation of the engine in the established mode for which the pressure values in the working space are measured and recorded, and the indicator diagrams are constructed.

To ensure the comparability of the results obtained at the different value of electrical load is necessary to obtain indicator diagrams at:

- equal adjustment (according to the manufacturer's prescriptions) of: the gas distribution mechanism (kinematic circuit loop) and the engine fuel system (starting angle of injection and injection pressure);
- the same thermal state (engine oil temperature in the crankcase T_m) of the engine;

- identical atmospheric conditions (measuring and recording the pressure values at the different external loads sequentially in one day).

4 Test results

The test consist of a measurements of the cylinder pressure during operation of the diesel engine, building its indicator diagrams in different load and idle regimes at 3000 min^{-1} as the motor drives an AC generator with frequency f = 50 Hz and U = 230 V.

4.1 Indicator diagrams

The engine load is achieved by plugging resistors into the generator's electrical circuit. A series of indicator diagrams are produced for established operating modes where the magnitude of the electric current I = 0, 5, 10, 15, 20 A.

The results of the cylinder pressure measurements are visualized for forty consecutive working cycles at a selected power of the electric current and the obtained 40 indicator diagrams are presented, one over another in green colour in Figures from 2 to 6, the crankshaft angle range being from 180 to 540 degrees.

Calculations were made of the current average pressure values with which the indicator diagrams were constructed at the corresponding external loads presented in black color in Figures form 2 to 6.

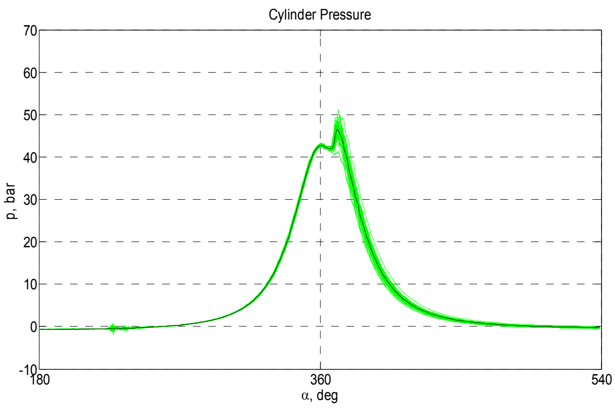

Fig. 2. Indicator diagrams with magnitude of current I = 0 A when idling.

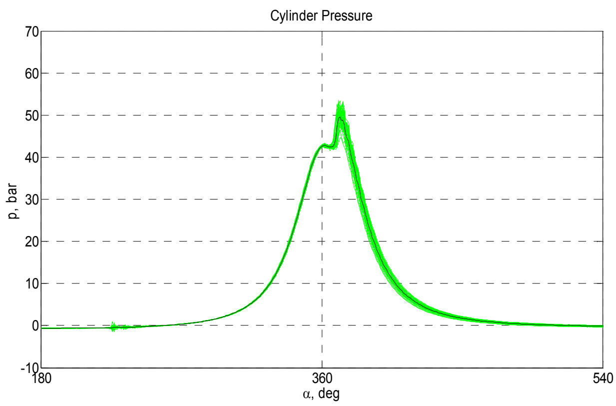

Fig. 3. Indicator diagrams with magnitude of current I = 5 A.

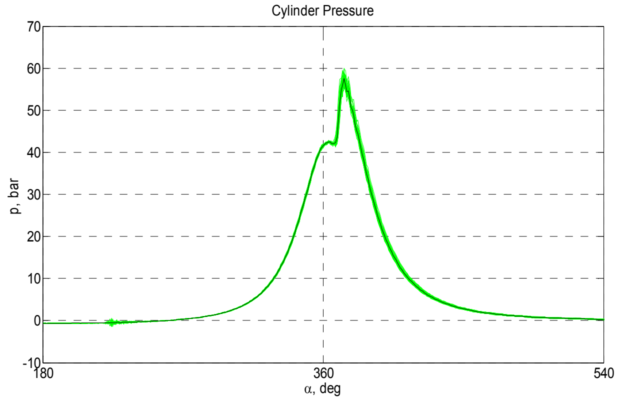

Fig. 4. Indicator diagrams with magnitude of current I = 10 A.

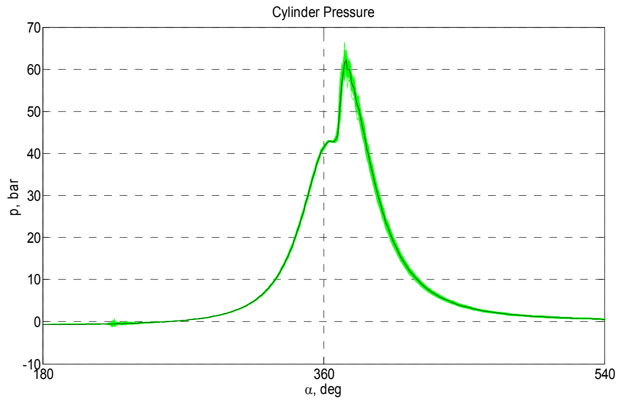

Fig. 5. Indicator diagrams with magnitude of current I = 15 A.

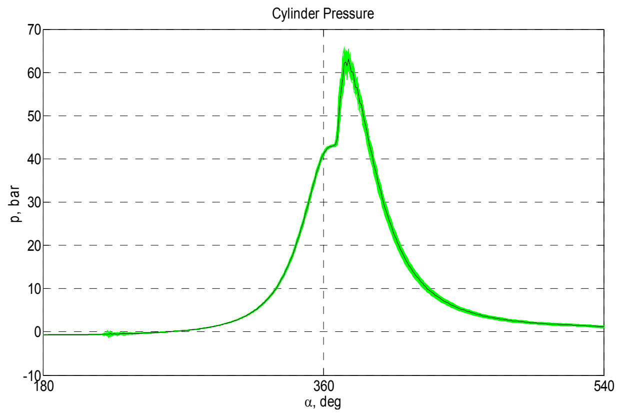

Fig. 6. Indicator diagrams with magnitude of current I = 20 A.

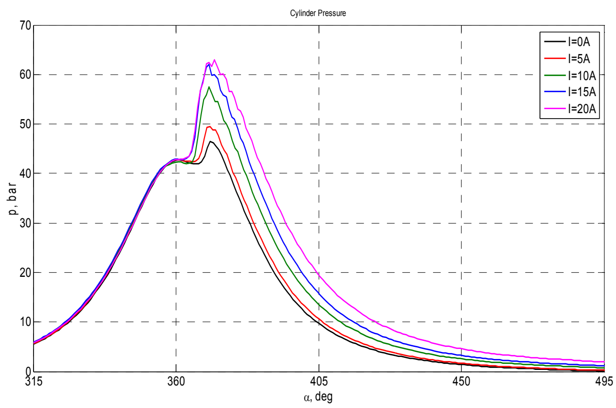

Fig. 7. Indicator diagrams with the mean cylinder pressure values at magnitude of current I = 0, 5, 10, 15, 20 A.

The indicator diagrams constructed with the calculated mean cylinder pressure values at magnitude of current $I = 0, 5, 10, 15, 20$ A are shown in Fig. 7.

4.2 Deviations of the maximum pressure

In Fig. 8 are presented the maximum, minimum and mean values of p_{max} at different external electrical loads and idling with magnitude of current $I = 0, 5, 10, 15, 20$ A.

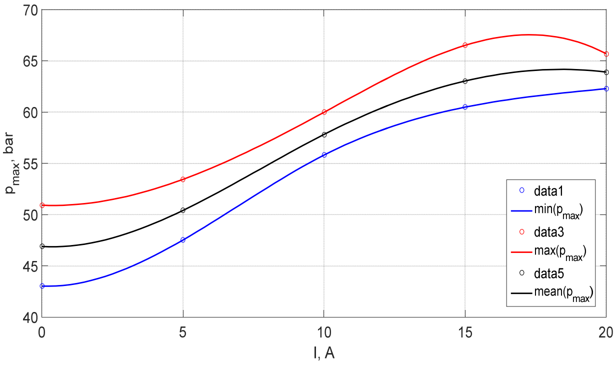

Fig. 8. Maximum, minimum and mean values of p_{max} at magnitude of current $I = 0, 5, 10, 15, 20$ A.

In Table 1 are presented deviations of the maximum and minimum values from means values of p_{max} at different external electrical loads and idling.

Table 1. Deviations of p_{max} at magnitude of current $I = 0, 5, 10, 15, 20$ A.

I, A	min Δp_{max}, %	max Δp_{max}, %	mean p_{max}, bar
0	8,2	8,6	46,896
5	5,7	6,0	50,409
10	3,5	3,7	57,822
15	4,0	5,5	63,030
20	2,5	2,8	63,910

4.3 Derivative of the cylinder pressure

The indicator diagrams in Figures from 9 to 13 are graphically presented with the derivatives of the cylinder pressure $dp/d\alpha$, [bar/deg] at different external electrical loads with magnitude of current $I = 0, 5, 10, 15, 20$ A.

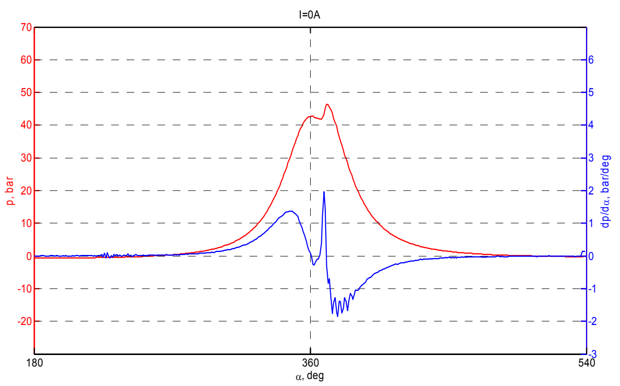

Fig. 9. Derivative of the cylinder pressure $dp/d\alpha$ at magnitude of current $I = 0$ A.

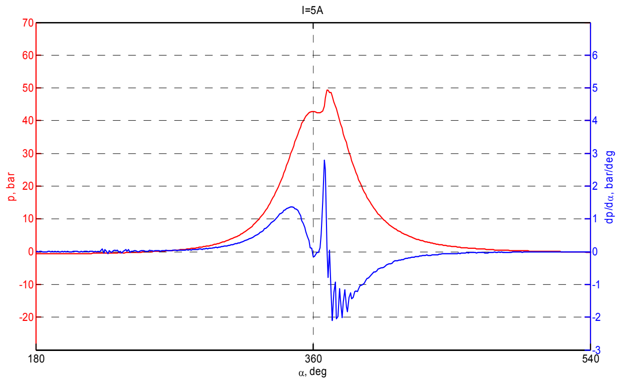

Fig. 10. Derivative of the cylinder pressure $dp/d\alpha$ at magnitude of current $I = 5$ A.

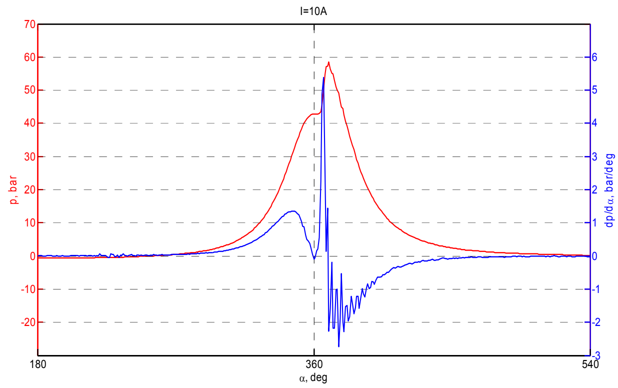

Fig. 11. Derivative of the cylinder pressure $dp/d\alpha$ at magnitude of current $I = 10$ A.

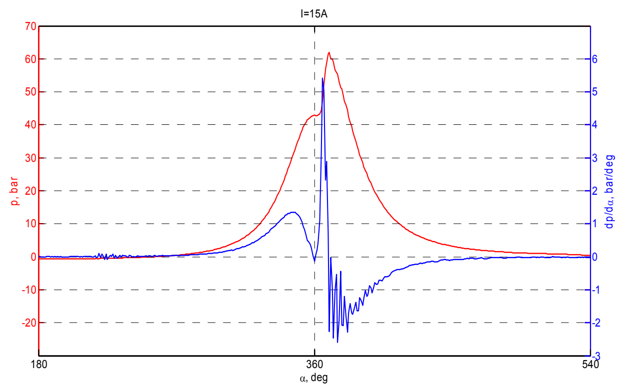

Fig. 12. Derivative of the cylinder pressure $dp/d\alpha$ at magnitude of current $I = 15$ A.

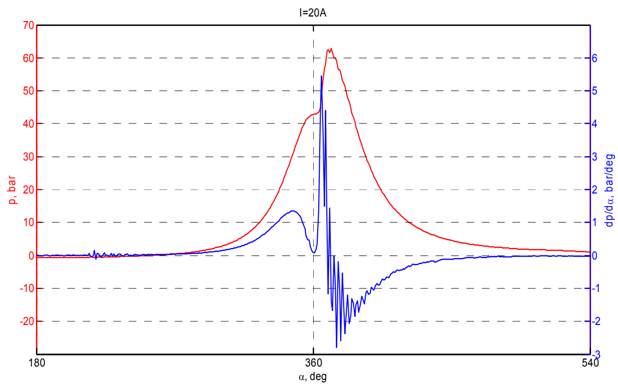

Fig. 13. Derivative of the cylinder pressure $dp/d\alpha$ at magnitude of current $I = 20$ A.

In Table 2 are presented the maximum and minimum calculated values of the derivative of the cylinder pressure $dp/d\alpha$ at different external electrical loads and idling.

Table 2. Maximum and minimum values of the derivative of the cylinder pressure $dp/d\alpha$ at magnitude of current I = 0, 5, 10, 15, 20 A.

I, A	$(dp/d\alpha)_{max}$, bar/deg	$(dp/d\alpha)_{min}$, bar/deg
0	1,97	–1,85
5	2,87	–2,09
10	5,23	–2,53
15	5,38	–2,67
20	5,38	–2,67

The research was conducted in the laboratory of the Department of Transport and Aircraft Equipment and Technologies at the Technical University – Sofia, Plovdiv Branch.

5 Conclusion

From the results, obtained with measurements of the cylinder pressure and its calculated derivatives at work of diesel engine with generator at established regimes with various external electrical loads the following conclusions can be drawn:

1. The highest average value of p_{max} = 63,91 bar is obtained at value of the current through the electrical load with I = 20 A.
2. By reducing the electrical load respectively is reduced the average value of p_{max} of the operating cycle and the lowest value of p_{max} = 46,90 bar is at idle mode of the engine.
3. The biggest deviations of the maximum and minimum values of p_{max} from its mean value are obtained at idle regime.
4. The relative deviations of p_{max} are the smallest when the diesel engine works at an external load with magnitude of current I = 20 A.
5. The maximum and minimum values of the pressure derivative in the cylinder increase as the current increases.
6. The maximum value of the derivative of the pressure in the cylinder is obtained with a smaller angle of rotation of the crankshaft with the rise of the external electrical load.

On the basis of the experimental and calculated values of the cylinder pressure and its derivative on the operation of the diesel engine with an AC generator at established regimes with different electrical loads, the following general conclusion can be made:

To increase the performance of the diesel engine when operating with an electric generator when changing the external electric load it is necessary to apply an automatic control of the start of the injection process to achieve the optimum flow and location of the combustion heat process.

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