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ANALYSIS OF HEAT RELEASE IN COMPRESSION IGNITION ENGINE

Abstract. The main goal of this research was to analyze the heat release in a compression ignition (CI) engine. Work contains description of the combustion process in the combustion chamber of CI engine with an explanation of the combustion stages. The research was conducted for wide range of load. At full load of engine achieved the highest value of pressure rise, temperature, fuel consumption and indicated mean effective pressure. The lowest values of these parameters were obtained for the smallest load. The full load of engine was characterized by the highest value of the heat release, and the longest combustion period due to the large share of diffusion combustion phase. The lowest load was characterized by 3.5 times less in value of heat release than in case of maximum load and heat release rate course was without visible diffusion combustion phase.
Keywords: compression ignition engine, diffusion combustion, premixed combustion.

ANALIZA WYDZIELANIA CIEPŁA W SILNIKU O ZAPŁONIE SAMOCZYNNYM

Streszczenie. Głównym celem badań było przeprowadzenie analizy wydzielania ciepła w silniku o zapłonie samoczynnym. Badana jednostka to sześciocylindrowy silnik z zapłonem samoczynnym o mocy 80 kW, poddany obciążeniom w szerokim zakresie. Dla obciążenia maksymalnego uzyskano największy przyrost ciśnienia, temperatury, godzinowego zużycia paliwa oraz ciśnienia indykowanego. Najmniejsze wartości powyższych parametrów zostały uzyskane dla najmniejszego obciążenia. Obciążenie maksymalne charakteryzuje się najwyższą ilością wydzielonego ciepła, a także najdłuższym procesem spalania za sprawą dużego udziału spalania dyfuzyjnego. Przy obciążeniu minimalnym wydzielania ciepła było 3,5- krotnie mniej niż dla maksymalnego, ponadto proces spalania trwał najkrócej, bez widocznego udziału spalania dyfuzyjnego.

Słowa kluczowe: silnik o zapłonie samoczynnym, spalanie kinetyczne, spalanie dyfuzyjne.

Introduction

The study of the rate of heat release, i.e. the conversion of chemical energy to mechanical energy, allows analysis of the operation of the piston engine. The source of information on the rate of heat release in the internal combustion (IC) engine is the combustion pressure course obtained during experimental researchers [1-2, 10-13, 16]. To characterize the combustion process in the IC engine, it is important to identify its start and the end. In a spark-ignition engine, spark ignition is often considered as the beginning of combustion. In the compression ignition engine, there is also the so-called: ignition delay period and its duration depend on many physicochemical factors. The ignition delay is defined as the time between the start of fuel injection to the beginning of the combustion process. The total delay of ignition consists of: physical delay - fuel atomization, evaporation of fuel droplets, mixing with air and chemical delay - pre-flame reactions. Ignition delay is one of the most important parameters of compression ignition (CI) engines which will directly affect the performance, emission and combustion. A number of investigations have been conducted to study the ignition delay and combustion duration of diesel fuel combustion [4, 12].
Attempts to determine the rate of heat release in a piston engine have been made since the beginning of the existence of engines. One of the earliest work on this issue was Marvin's work published in 1928, in which the author evaluated the rate of heat release on the basis of an analysis of the logarithmic graph of pressure course [1, 5, 8]. The heat release process in the IC engine is used to determine the combustion rate of fuel. Particular attention is given to the position of 50% of the heat release relative to the position of the engine crankshaft. It is stated in the literature that if half of the heat release is about 8 degree after top dead center (TDC) then the engine achieves maximum efficiency. An analysis of the heat release process can be carried out as an analysis of the heat release rate (HRR) and analysis of the mass fraction burned (MFB) [2, 3, 15]. Determining the moment of 50% heat release is also important for engine control [9]. In determining the rate of combustion in the IC engine, the so-called Vibe function [17]. This is a semi-empirical relationship used to determine the course of fuel mass fraction changes during combustion process occurred in the thermal cycle of IC engine.

As part of the work, a compression ignition internal combustion engine was investigated. The collected measurement data was used to calculate the basic indicators characterizing the operation of the piston engine at various loads as well as to analyze the process of heat release. The analysis allowed characterizing the process of heat release and identification of combustion phases, the determination of the ignition delay and the combustion duration.

Test stand and measurement system

The research stand was a six-cylinder, compression ignition IC engine. The tested engine is the power component of the mobile generator set. The aggregate load was a heat pump with adjustable power, which allowed for a gradual change in the load of the tested engine. The main engine parameters are presented in Tab. 1.

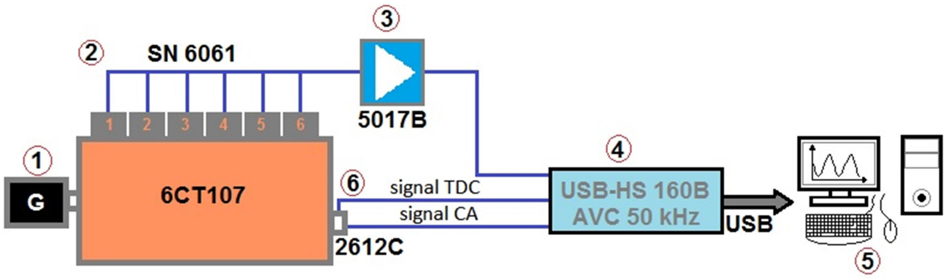

Fig. 1 Diagram of the system for engine's indication 1 - 6-cylinder internal combustion engine, 2 - pressure sensors, 3 - signal amplifier, 4 - measurement card, 5 - computer, 6 - crankshaft position sensor.

Table 1. Engine specification

Parameters	value	
displacement	6.54	dm^3
rotational speed	1500	rpm
crank throw	60.325	mm
cylinder bore	107.19	mm
connecting-rod length	245	mm
compression ratio	16.5	-
intake valve opening	10 ± 4^o BTDC	deg
intake valve closure (IVC)	50 ± 4^o ABDC	deg
exhaust valve opening	46 ± 4^o BBDC	deg
exhaust valve closure (EVC)	14 ± 4^o ATDC	deg
injection angle	$9^o\pm1.5^o$	deg

During the engine's indication, the pressure in all 6 cylinders was indicted with the resolution of 1 deg. The compression pressure was also measured to determine the thermodynamic top dead center (TDC). Kistler's pressure sensors 6061 SN 298131 were used during the study (sensitivity: ±0.5%) and charge amplifier Kistler 5011B of linearity of FS <±0,05%. The test engine operated with constant rotational speed 1500 rpm. The measured data were collected using data acquisition module, Measurement Computing USB-1608HS – 16 bits resolution, sampling frequency 20 kHz. The error of piezoelectric pressure transducer is $\delta_{tr}=0.5\%$ and the amplifier $\delta_a=3\%$. The measurement error of *IMEP* is $\delta_{IMEP}=\delta_{ITE}=3.1\%$.
Analysis of combustion process in the internal combustion engine usually is carried out with the rate of heat release [14]. Heat release rate (dQ/dφ) is calculated on the basis of the measured in-cylinder pressure data and crank angle readings. The basis for determining the heat release rate is the first law of thermodynamics and the equation of state. After rearranging and simplifications, the heat release rate vs. crank angle is obtained in well-known form as follows:

$$\frac{dQ}{d\varphi}=\frac{1}{\kappa-1}\left[\kappa p\frac{dV}{d\varphi}+V\frac{dp}{d\varphi}\right] \tag{1}$$

where: κ- the ratio of specific heats, V – cylinder volume, p – in cylinder pressure.

Instantaneous cylinder volume V is precisely described by engine geometry. Due to omitting as follows: heat transfer to walls, crevice volume, blow-by and the fuel injection effect, the resulted heat release rate is termed as the net heat release rate. The cumulative net heat released is obtained by integrating Eq. 1 over the crank angle φ.

Results

On the bench, the engine was investigated for 6 loads. The obtained results were used for analysis of heat release. Among other things, the indication mean effective pressure, the engine's performance and the hourly and specific fuel consumption were determined as well. The engine was indicated in all cylinders and the arbitrarily first cylinder was selected for the purpose of the analysis. For the maximum test load that was 55 kW for this engine, a heat release analysis was also carried out using the (Rassweiler–Withrow) R&W concept of pressure distribution [6-7, 9].

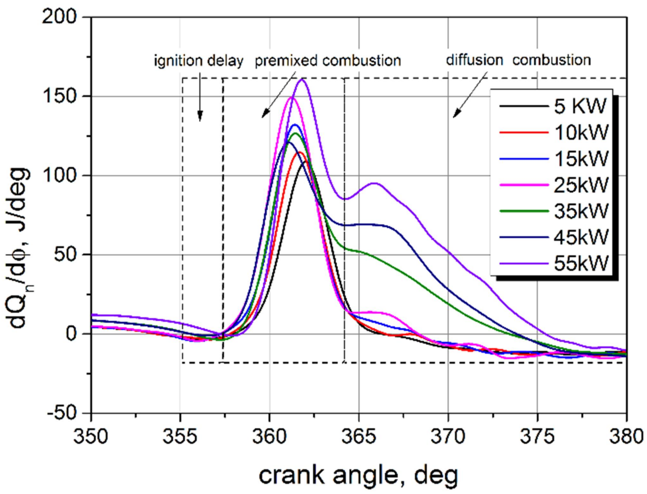

Fig. 2 The heat release rates for the test engine for all analyzed loads

Figure 2 shows the combination of the heat release rates for the test engine for all analyzed loads. Traces for loads of 5-25 kW have similar waveforms, without a clear contribution to diffusion combustion. Between 35 and 55 kW the share of diffusion combustion increases. Runs of 5-25 kW do not exceed 150 J/deg. The smallest heat release rate is for 5 and 10 kW loads and is 123 J/deg, the highest for 55 kW equals 162 J/deg. After exceeding the 25 kW load, the diffusion phase is clearly visible during the course of the heat release, thus reducing the contribution of premixed combustion to diffusion. The figure shows the start point of the diesel injection and the distribution of heat to the four combustion phases (Fig. 3). The first phase is called the ignition delay, which for this engine was about 8 deg. Of course, this value was different for each of the loads, as shown in the previous analysis. The second stage of combustion, called premixed combustion phase in this engine, started after the ignition delay period and lasted about 5 deg after TDC, which was comparable to the ignition delay time. The third stage of heat release is diffusion combustion phase, controlled primarily by the evaporation process and the fuel-air mixture was the longest and occupied nearly 15 deg. This third stage of combustion was noticeable, as already mentioned, for the three highest loads. In addition, it is evident here that with the increase in engine load, the share of heat release rate at this stage increases. For a 35 kW load, the maximum value of the heat release rate in the diffusion combustion phase was 53 J/deg, for a 45 kW load it was 69 J/deg a for a maximum load of 92 J/deg. The last step was post-combustion.

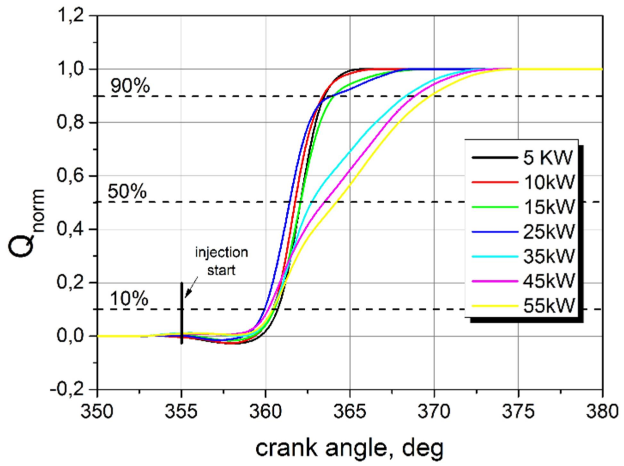

Fig. 3 The normalized heat release in the test engine

Figure 3 shows the normalized heat release traces for the tested engine. As shown, the 5, 10 kW loads are close to each other and their course is more violent than for 35, 45 and 55 kW, because with small loads, premixed combustion phases takes place. For smaller loads, the total heat output ends at about 368 deg while for the higher at about 374 deg.

Based on the analysis of Q_{norm} traces, it is possible to evaluate the combustion process by determining the ignition delay time and the combustion duration time. The ignition delay time is defined as the time from the beginning of the injection until the 10% heat is released. Combustion duration time is defined as the period from the time of 10% heat release up to 90% release.

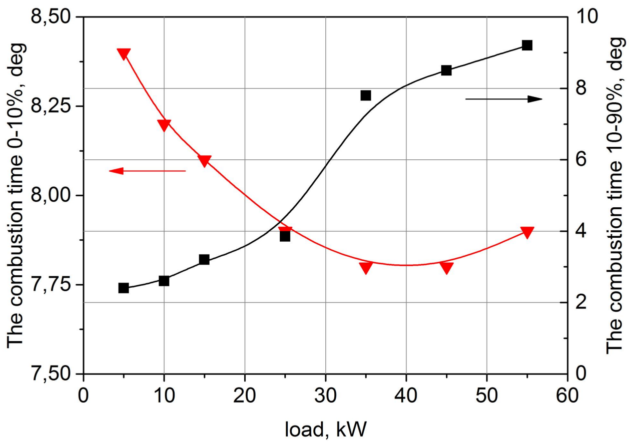

Fig. 4 The delay time of ignition and the duration of combustion

On the basis of the data presented in Figure 4, it can be assumed that as the engine load increases, the ignition delay time decreases, while the differences in values are small in the range of 1 deg. The visible difference is in combustion duration. For loads up to 25 kW there was a relatively small increase in combustion time, while for loads exceeding 25kW there was a noticeable increase in combustion duration. As Fig. 4 shows, the shortest duration of fuel burnout was recorded at 5 kW and reached 2.4 deg, while the longest time was 55 kW at 9.3 deg. The upward trend is due to the absence of diffusion combustion phase at the first four loads and its growing share in the case of loads 35, 45 and 55 kW.

Summary

The paper presents an analysis of the heat release in the combustion process in a compression ignition internal combustion engine. Based on the conducted research it was stated:

- With the increase in engine load, the nature of the heat release rate in the engine under test was changed. The increasing load on the engine caused the diffusion rate to increase relative to the premixed phase of the combustion rate curve. The 25 kW load was dominated by premixed combustion. After exceeding this load, ie 35 kW load, the diffusion rate is shown on the heat rate curve.
- With the increase in load, the ignition delay time decreased slightly.
- With increasing load, the duration of combustion increased. Exceeding 50% of engine load it is a noticeable increase in combustion time due to the increasing share of the diffusion phase during the combustion process in the engine.

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