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THE INFLUENCE OF THE IGNITION SYSTEM CHARACTERISTIC ON THE TWO-STROKE ENGINE OPERATING CONDITIONS

This paper presents an indicator analysis of the impact of the characteristics of an electronic ignition system on the operating conditions of a two-stroke spark ignition engine. The tests were carried out on a single-cylinder two-stroke engine equipped with a combustion pressure sensor using the apparatus for recording fast-varying signals. The influence of changes of the ignition angle of advance at constant engine speeds on the engine operating indicators was analysed. The assessment of the impact of the changes to the settings of the ignition system was analysed in terms of thermodynamic conditions: combustion pressure and average effective pressure. It was found that the ignition angle of advance has positive influence on engine operating conditions and uniformity of engine operation. As a measure of non-uniformity of engine operation were accepted the coefficient of variation of the engine speed and the mean indicated pressure. It was indicated that, along with the ignition angle of advance, the indicators of two-stroke engine operation also increase with simultaneous increase in the non-uniformity of engine operation.

Keywords: two-stroke engine, ignition system, combustion, thermodynamic analysis

1. INTRODUCTION

One of the most important and necessary phases of operation of the internal combustion piston engine is the ignition phase, indispensable in engine cyclic operation. With the development of combustion engines, the parameters of operation of these

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units increased, such as maximum engine speed, the range of engine speeds and specific power. This, in turn, generated a number of problems as far as the ignition systems are concerned. The increased engine speed meant that mechanical elements originally controlling the moment of the ignition initiation, with certain inertia, didn't behave predictably and repeatedly. With the increased unit power, the selection of the optimum ignition angle of advance became noticeably significant [Blair 1996, Nora and Zhao 2015]. The moment of ignition also affects the emission of harmful substances [Ghazikhani 2013, Pradeep, Bakshi and Ramesh 2014], fuel consumption, effective power and non-uniformity of engine operation [Galindo et al. 2011, Andwari et al. 2014]. In addition, too early moment of ignition can contribute to engine knocking, which decreases the efficiency of the system and causes excessive load of mechanical elements and increases noise. The modern control system of ignition should therefore include a feedback responsive to changing operating parameters of the engine. The most important of these parameters are: engine crankshaft speed and the quality and quantity of the air-fuel mixture in the cylinder, expressed in form of the engine load or cylinder combustion air factor [Pradeep et al. 2015].

2. THE AIM OF THE STUDY

The objective of the research was to evaluate the operating conditions of a two-stroke engine equipped with an electronic system for controlling the ignition angle of advance. This analysis was carried out using information about the combustion process in the form of characteristics of pressure in the cylinder and on the basis of this signal after processing. The quality criterion of the combustion process was the values of mean indicated pressure and its dispersion specified by the coefficient of variation.

3. MODIFICATION OF THE IGNITION SYSTEM

The standard ignition system used in the engine is characterized by a constant ignition angle of advance -15^{o} before TDC. Throughout the entire engine operating range this angle varies within the limits of $\pm 1^{o}$ as a result of the system imperfections. The system is powered by AC power directly from the generator mounted on the crankshaft. The moment of ignition is controlled by an electric pulse from so-called pulse generator; then the pulse is sent to the CDI (Capacitor Discharge Ignition). This in turn causes the discharge of the capacitor previously charged by the generator. As a result of the rapid discharge and induction in the ignition coil on spark plug electrodes, an electrical discharge is generated. The situation is repeated with each turn of the crankshaft. As an alternative, a digital ignition system with the possibility of selecting any ignition angle of advance was utilized. The change consisted in adapting an analogue system and using the microcontroller controlling the ignition (Fig. 1). The system used an ATmega2560 microprocessor (4), which by analyzing the speed of the crankshaft (3) generates a pulse that triggers ignition (replacing the pulse from the sensor (1) sent to the CDI module (5) at the moment corresponding to a specific ignition angle of advance. In addition, with the use of two potentiometers, the system makes it possible to choose any ignition angle of advance and to set the desired carburettor throttle valve position (8). The controller with the use of a cable is connected to the computer (12) that displays the values of the engine speed, the current ignition angle of advance and the throttle opening.

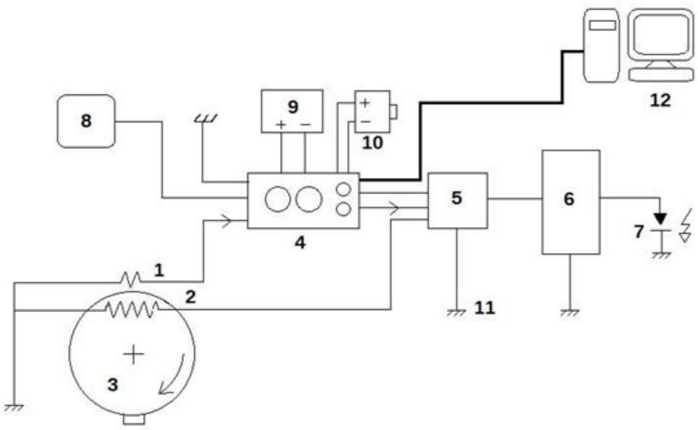

Fig. 1. Diagram of the digital ignition system utilized: 1 – pulse generator, 2 – generator coil, 3 – generator with a marker, 4 – microcontroller, 5 – CDI module, 6 – ignition coil, 7 – spark plug, 8 – throttle, 9 – battery, 10 – starter, 11 – ground, 12 – PC

The originally used analogue system without feedback and with a fixed ignition angle of advance was replaced by an electronic system that allows for selection of the optimal ignition angle of advance, with feedback in the form of information about the speed of the crankshaft and the percentage opening of the carburettor throttle valve, which indirectly specifies the amount of mixture in the cylinder.

4. RESEARCH METHODOLOGY

4.1. Data preparation and the research programme

The data was recorded using the IndiSmart Gigabit module by AVL, and processed with the use of Concerto V4.3 by AVL. The recorded test results were processed in order to eliminate the distorted characteristics. The reason for acquiring such characteristics was a strong magnetic field emitted by the ignition system and affecting the recording apparatus. For this reason the incorrect engine operating cycles were eliminated (incorrect cycles amounted even up to 20% of full recording). In addition, the data were subjected to digital filtration with the use of a low pass filter at frequency of 4000 Hz with resolution of 0.1^o of crankshaft rotation. Characteristics so processed were averaged to get representative results for specific engine settings that are listed later in this article. The conditions of tests are presented in Table 1.

Table 1

Table of the test conditions of the electronic ignition system

Impact of the ignition angle change		
Engine speed [rpm]	1900	3000
Ignition angle [bTDC]	19; 32; 40; 50	30; 40; 52; 60
Impact of the engine speed change		
Engine speed [rpm]	1900; 3000; 5000; 6500	
Ignition angle [bTDC]	~20 deg before TDC	

4.2. Test stand

The research of indicated pressure in the cylinder was made on a chassis dynamometer were two-stroke combustion engine was placed (Fig. 2), whose technical specification is shown in Table 2. The test stand was prepared according to the diagram shown in Fig. 3. In order to determine parameters of engine operation between the cycles, an analysis of the fast-varying processes with respect to crank angle was conducted.

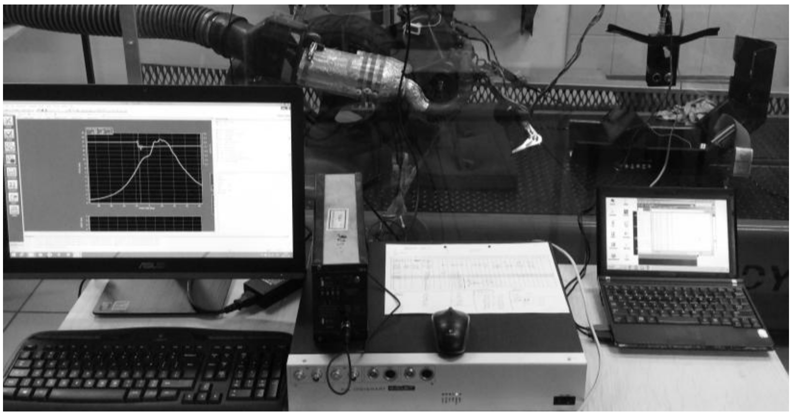

Fig. 2. Chassis dynamometer with a test two-stroke engine

Table 2

Technical parameters of a two-stroke test engine

Parameter	Unit	Value
No. of cylinder	–	1
Displacement	V	99 cm^3
Stroke	S	49.7 mm
Diameter	D	50.6 mm
Compression ratio	ε	11
Maximum power	Ne	6.4 kW/7000 rpm

The test engine (4) placed on a motorcycle chassis dynamometer (9) was controlled by a microcontroller (1) allowing the engine to start, stop, to select any ignition angle of advance and the desired setting of throttle opening given in percentage (0–100%). This controller is connected via a USB cable to the computer (8) to control the settings. The test stand was equipped with an exhaust system (5), the fuel tank (6) and digital thermometer (7) acting as a control. The operating parameters of the engine were measured with the use of a GH12D sensor by AVL (measuring range of 0 to 25 MPa and a sensitivity of 15 pC/bar) mounted on the spark plug W7BC by Bosch. The crankshaft position sensor allowed to determine the characteristics of the pressure in relation to the piston position with a resolution of $\alpha = 1^{o}$ of a crankshaft rotation. In addition, with the use of the sensor of the secondary voltage of the ignition system was determined the actual ignition angle of advance. The load from the piezoelectric pressure sensor required amplification with the help of the 3057-A01 amplifier by AVL (3) (measuring range 0.1 to 100 mV/pC, sensitivity 1.0 to 99.99 pC/bar). All signals were sent to the IndiSmart Gigabit module by AVL (2), which was connected to the recording computer (8) equipped with Concerto V4.3 software by AVL.

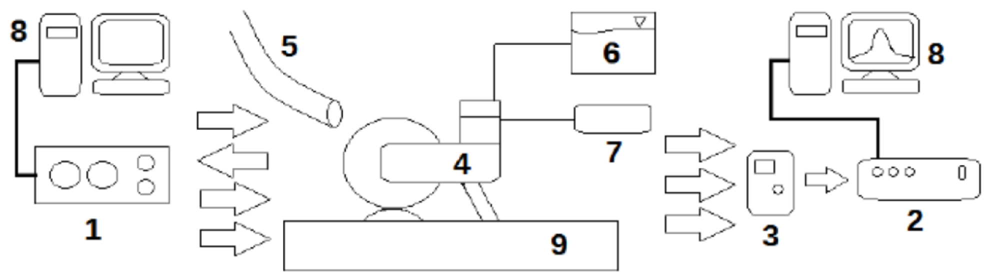

Fig. 3. Diagram of a measuring stand

5. TEST RESULTS

5.1. Assessment of the conditions of engine operation for steady-state engine speed

The analysis of the steady-state engine operation conditions was conducted for two engine speeds: 1900 rpm (idling) and 3000 rpm (average load). Figure 4a shows the relationship between the ignition angle of advance, the value of the pressure and the position of its maximum during idling. Ignition angle of advance (up to about 50^o before TDC), results in an increase in the maximum cylinder pressure (up to 18%). Dispersion of values is similar to the settings for other ignition angles of advance ($\Delta\alpha_{Pmax}$ – 3.5^o of crankshaft rotation). For the engine running at average load (Fig. 4b) at engine speed of n = 3000 rpm, the situation is repeated. Acceleration of ignition up to 60^o before TDC causes an increases in the indicated pressure and the dispersion of values around TDC. During idling and average loads, an increase in the ignition angle of advance (ignition advance) reduces the dispersion of the maximum values of pressure (reduction of coefficient of variation CoV(P_{max})). The minimum value of CoV(IMEP) is determined using ignition advance = 19^o for idling and ignition advance = 40^o for the average load (Fig. 5). The ignition advance in both cases reduces the angle at which the centre of combustion occurs (the angle indicates 50% of the total heat released during the whole process) (Fig. 6). Increasing the value of the ignition advance increases the amount of heat released and the rate of heat release, which helps to improve the thermal efficiency of the engine at a selected engine speed.

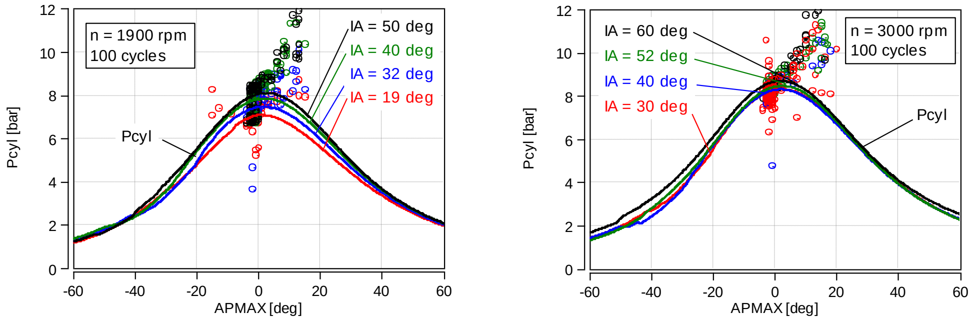

Fig. 4. The impact of changes in the ignition angle of advance on the characteristics of combustion pressure and dispersion of P_{max} in the cylinder: a) at n = 1900 rpm, b) at n = 3000 rpm

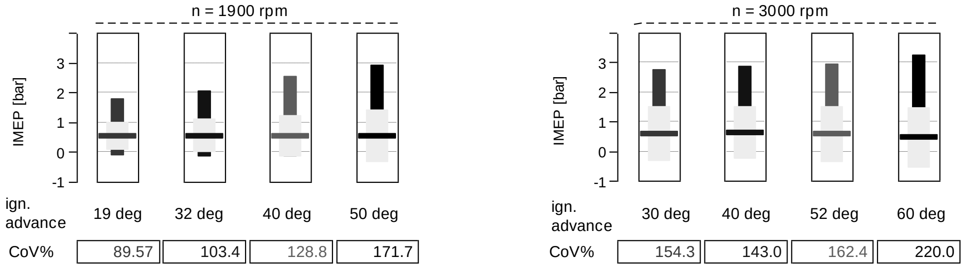

Fig. 5. Dispersion and values of the coefficient of variation of the mean indicated pressure: a) at n = 1900 rpm, b) at n = 3000 rpm

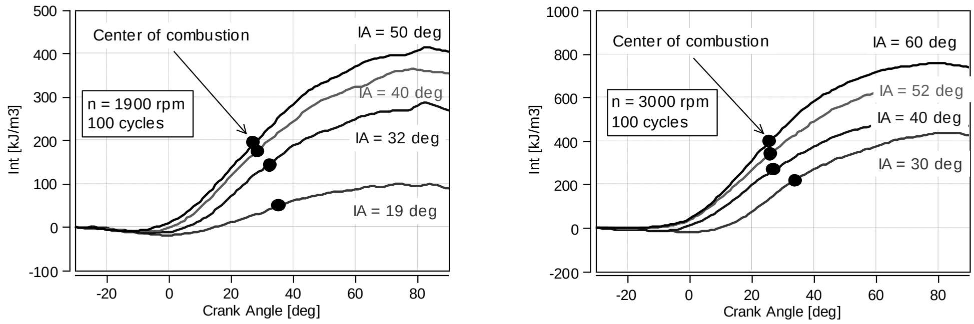

Fig. 6. Changes in the heat generation and determination of the centre of combustion: a) at n = 1900 rpm, b) at n = 3000 rpm for variable ignition angle of advance

5.2. Assessment of the conditions of engine operation for variable engine speed

The analysis of the impact of changes in the engine speed was conducted at a constant ignition angle of advance of 20 deg before GMP. 100 cycles of engine operation were submitted to interpretation, for the four fixed engine speeds amounting up to, respectively, 1900, 3000, 5000 and 6500 rpm. In Figure 7a is presented characteristics of pressure changes in the cylinder. For a steady-state engine speed of 1900 rpm, the pressure in the cylinder was 8 bar. Increase in the engine speed to 6500 rpm with a constant ignition angle of advance resulted in almost two-fold increase in the pressure in the cylinder, which amounted to 15.6 bar. Analysis of Figs 7a and 8a shows lack of steady-state parameters of engine operation in the form of indicated mean effective pressure. Only for the highest engine speed of 6500 rpm, the coefficient of variation CoV (IMEP), defined as the mean deviation from the value of the variable from 100 measurement cycles amounted to 7.72. This value, due to the type of test object, is acceptable. Lower values of the engine speed for the test object resulted in stronger dispersion of the mean indicated pressure. The largest dispersion from the average value was observed at a speed equal to 5000 rpm. The highest coefficient of variation was obtained for the lowest engine speed of 1900 rpm. Figure 8b shows, despite the non-uniformity of combustion process in the engine presented above, that acceptable coefficients of variation CoV(n) were achieved. The increase in the engine speed associated with other parameters of the air-fuel mixture caused a change in the angle of incidence of the centre of combustion (Fig. 9) towards the lower angles of crankshaft rotation (from 33 deg to 30 deg), and the increase in the amount of heat released and the heat release rate.

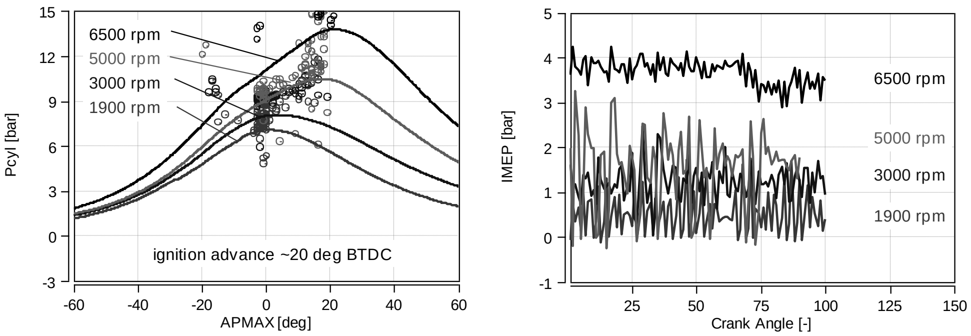

Fig. 7. Characteristics of engine speed at a constant ignition angle of advance: a) changes of the cylinder pressure, b) changes of IMEP in successive cycles of engine operation

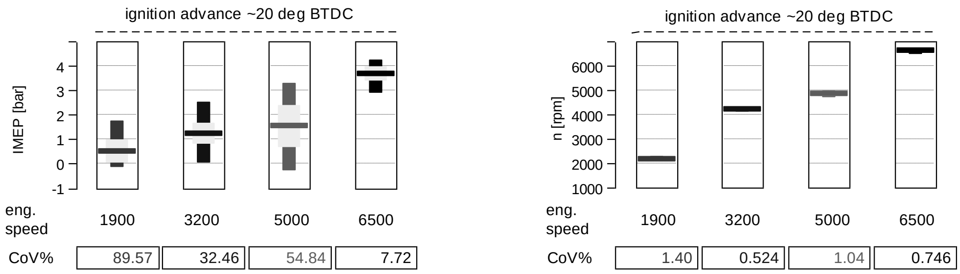

Fig. 8. Dispersion and values of the coefficient of variation: a) indicated mean effective pressure for variable engine speed, b) coefficient of variation of engine speed

The analysis of heat release changes with the determination of the angle at which the 50% of mass burn fuel takes place is shown in Figure 9. Variable engine speed during the test at constant ignition angle of advance does not have a large impact on the achieved centre of combustion, which for all speeds occurred in the vicinity of 30 deg aTDC. An increase in the value of the engine speed also causes an increase in the heat release; for the speed of 6500 rpm, about 9 times greater heat release was observed compared to the heat release for engine speed of 1900 rpm.

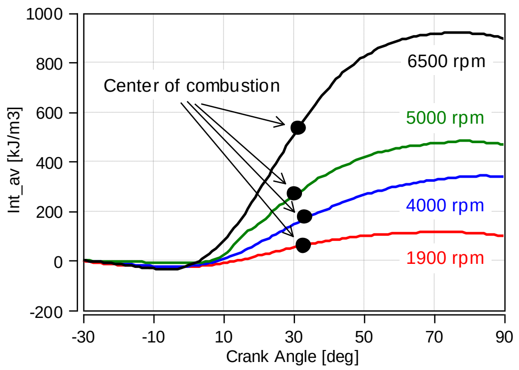

Fig. 9. Changes in the heat release and determination of the centre of combustion at variable engine speed and constant ignition advance (IA ~20 deg bTDC)

CONCLUSIONS

Significant variability of the engine operation creates unfavourable conditions in terms of fuel consumption and comfort of driving. For those reasons, it is important to optimize the combustion process. Implementation of the electronic ignition system controlling the ignition angle of advance returned a positive effect on the conditions and uniformity of engine operation, which contributed to an increase in the thermal efficiency of the system and therefore to the reduction of fuel consumption for a particular engine speed. The practice also showed a high rate of change of engine speed (as a function of IMEP) depending on the ignition advance, which suggests the use of an electronic ignition system as a controller of engine speed. The use of such control is possible during the reaction to a rapid change of load resulting e.g. from turning on the power receivers in the vehicle while idling. In addition, the values of changes of ignition advance are much higher than the changes in the centre of the combustion resulting from the analysis of heat release. This means that high changes IA (ignition advance) correspond to small changes in the angle of CoC (centre of combustion). Such interdependence of these values makes it possible to control the presence of the centre of the combustion in a very precise way.

NOMENCLATURE

APMAX	Ignition angle of advance
BDC	Bottom Dead Center
CoV	Coefficient of Variation
CDI	Capacitor Discharge Ignition

dQ	Heat Release Rate	Int	Cumulated heat release
IMEP	Indicated Mean Effective Pressure	n	Engine speed
		Ne	Maximum power
IA	Ignition Advance	TDC	Top Dead Center

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WPŁYW CHARAKTERYSTYKI UKŁADU ZAPŁONOWEGO NA WARUNKI PRACY SILNIKA DWUSUWOWEGO

Summary

W artykule przedstawiono analizę indykatorową wpływu charakterystyki elektronicznego układu zapłonowego na warunki pracy silnika dwusuwowego o zapłonie iskrowym. Badania prowadzono na jednocylindrowym silniku dwusuwowym wyposażonym w czujnik ciśnienia spalania z wykorzystaniem aparatury do rejestracji sygnałów szybkozmiennych. Analizie poddano wpływ zmiany kąta wyprzedzenia zapłonu przy ustalonych prędkościach obrotowych silnika na wskaźniki jego pracy. Ocenę wpływu zmian nastaw układu zapłonowego analizowano w aspekcie warunków termodynamicznych: ciśnienia spalania oraz średniego ciśnienia użytecznego. Stwierdzono pozytywny wpływ wyprzedzenia zapłonu na warunki pracy silnika oraz na jego równomierność pracy. Jako miarę nierównomierności jego pracy przyjęto współczynnik zmienności prędkości obrotowej i średniego ciśnienia indykowanego. Wykazano, że wraz z wyprzedzeniem zapłonu zwiększają się wskaźniki pracy silnika dwusuwowego z jednoczesnym zwiększeniem nierównomierności jego pracy.

Słowa kluczowe: silnik dwusuwowy, system zapłonowy, spalania, analiza termodynamiczna