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The Determination of Increase in Charge Combustion Velocity in a Two – cycle Otto – Diesel Engine

Abstract: Investigations and analysis of charge combustion velocity in a two – cycle Otto – Diesel engine were undertaken for the following cases: work of engine with spark ignition and switch to a Diesel cycle by direct injection of ignition dose. During engine work at switch from Otto cycle - i.e. switching off ignition and application of ignition dose - increase in combustion pressure is obtained. Analysis of mass fraction burned (MFB) in the case of work of engine with spark ignition and auto - ignition was carried out. A considerable increase in charge combustion velocity is noticeable. Moreover, during investigations a comparative determination of exhaust gases temperatures was made for an engine with spark ignition as well as for ignition by means of a dose initiating ignition. This was done for two cases of dose injection angle 28º and 30º CA before TDC. Decrease in exhaust gases temperature was found for the case of ignition from the initiating dose.

Key words: *analysis of combustion velocity in two-cycle engine, spark ignition, compression ignition, increase in total efficiency of internal combustion engine*

Określenie zwiększenia szybkości spalania ładunku w silniku dwuobiegowym Otto - Diesel

Streszczenie: W pracy podjęto badania i analizę zwiększenia szybkości spalania w silniku dwuobiegowym Otto – Diesel dla następujących przypadków: praca silnika z zapłonem iskrowym i przejście na obieg Diesla przez bezpośredni wtrysk dawki zapłonowej. W trakcie pracy silnika przy przejściu z obiegu Otto, tzn. wyłączenie zapłonu i zastosowanie dawki zapłonowej uzyskano zwiększenie ciśnienia spalania. Przeprowadzono analizę udziału masowego ładunku spalonego dla przypadku pracy silnika z zapłonem iskrowym i zapłonem samoczynnym. Wyraźnie widoczne jest zwiększenie szybkości spalania ładunku. Ponadto w trakcie prowadzonych badań dokonano porównawczego określenia temperatur spalin dla silnika o zapłonie iskrowym oraz dla zapłonu za pomocą dawki inicjującej zapłon dla dwóch przypadków kąta wtrysku tej dawki 28 i 30 º OWK przed GMP. Stwierdzono obniżenie temperatury spalin dla zapłonu od dawki inicjującej. W związku z obniżeniem temperatury spalin w przypadku zapłonu od dawki inicjującej wystąpiło również zmniejszenie ilości tlenku azotu w spalinach.

Słowa kluczowe: *analiza szybkości spalania w silniku dwuobiegowym, zapłon iskrowy, zapłon samoczynny, zwiększenie sprawności ogólnej silnika spalinowego*

1. Introduction

Investigations on determination of increased charge combustion velocity in a two – cycle engine were carried out in the Laboratory of the Chair of Internal Combustion Engines of the Cracow University of Technology. A redesigned four – stroke engine was used for investigations. Redesigning of the engine consisted in it that, apart from multipoint supply, direct injection of fuel was applied for injection of an ignition dose it means at the moment of engine switch from Otto cycle to auto-ignition which starts from injection of a very small ignition dose at maintenance of the basic supply system in the multipoint injection system. Moreover, an electronic system of change control from spark ignition to ignition from the initiating dose was designed and executed. General view of the test bed was presented in the Fig. 1.

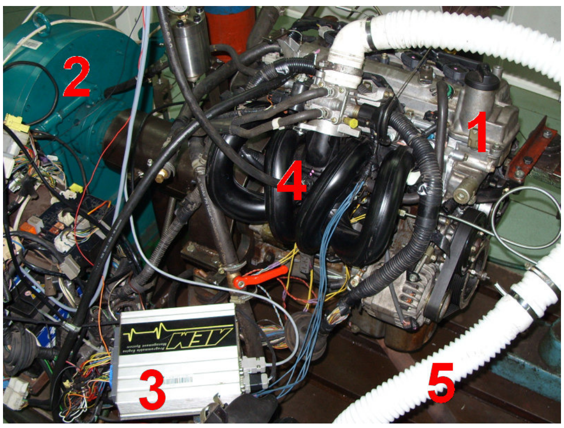

Fig. 1. General view of the engine installed on the test bed; 1 – Engine , 2 – Eddy – current brake, 3 – Engine controller, 4 – Intake manifold, 5 – Elastic intake pipe

Rys. 1. Widok silnika badawczego zainstalowanego na stanowisku hamownianym; 1 – Silnik, 2 – Hamulec elektrowirowy, 3 – Sterownik silnika, 4 – Kolektor dolotowy, 5 – Elastyczny przewód dolotowy

The test bench equipped in this way permitted to carry out investigations of combustion pressure increase as well as increase in mass fraction burned. Differentiating the traces of mass fraction burned, traces of combustion velocity dMFB/dα were obtained.

2. Influence of applied mode of mixture ignition on charge combustion velocity

Analysis of the diagrams of pressure in the work space of the cylinder obtained for both combustion systems aimed at determination of the process of charge combustion. A method permitting determination of mass fraction burned (MFB) in the cylinder in function of crank angle was applied. This method was described more extensively, among others, in [6].

After initiation of the combustion process from an electric spark or auto-ignition of the fuel, the increment of pressure Δp_c in the cylinder during crankshaft revolution by angle Δα is composed of two components (1):

$$\Delta p_c = \Delta p_{comb} + \Delta p_V \qquad (1)$$

In Fig. 2 the pressure p_{comb} change in the cylinder was presented in function of crank angle, which is the result of mixture combustion during work with spark ignition as well as in case when combustion is initiated by the pilot dose injection

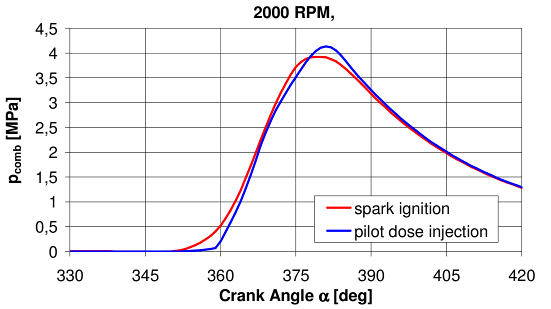

Fig. 2. Pressure increment in the cylinder work space as result of the combustion process in function of crank angle

Rys. 2. Wzrost ciśnienia w przestrzeni roboczej cylindra będący wynikiem procesu spalania w funkcji kąta obrotu wału korbowego

The change of the cylinder work volume from V_i to V_{i+1} is connected with change of crank angle from α_i to α_{i+1}, what is reflected in the pressure change from p_{ci} to p_{ci+1}. It was assumed that pressure change resulting from the change of the cylinder volume proceeds according to polytrophic relation with a previously calculated exponent k. The above assumptions make it possible to bring equation (1) to the form defined by the formula (2):

$$p_{ci+1} - p_{ci} = \Delta p_{comb} + p_{ci} \cdot \left[\left(\frac{V_i}{V_{i+1}} \right)^k - 1 \right] \qquad (2)$$

After appropriate transformation aiming at calculation of pressure increment Δp_{comb} connected with the combustion process it takes the form (3):

$$\Delta p_{comb} = p_{ci+1} - p_{ci} \cdot \left(\frac{V_i}{V_{i+1}} \right)^k \qquad (3)$$

It should be remembered that pressure increment as a result of combustion process cannot be directly proportional to mass of the combusted fuel with regard to the fact that combustion in a real piston engine does not proceed at constant volume. With regard to this fact it is necessary to refer the obtained pressure increment to a certain volume which may constitute the volume of the combustion chamber V_{cc}. This operation is presented by the formula (4):

$$\Delta p_{comb}' = \Delta p_{comb} \cdot \frac{V_i}{V_{cc}} \qquad (4)$$

After N increments of the crank angle the pressure increment resulting from combustion tends to zero. This means the end of the combustion process. Making assumption that corrected pressure increment in consequence of combustion Δp_{comb}' is proportional to mass fraction burned MFB of the mixture equation (5) is obtained:

$$MFB = \frac{\sum_0^i \Delta p_{comb}'}{\sum_0^N \Delta p_{comb}'} \qquad (5)$$

Fig. 3 shows the traces of changes of mass fraction burned in function of crank angle obtained for the both combustion systems.

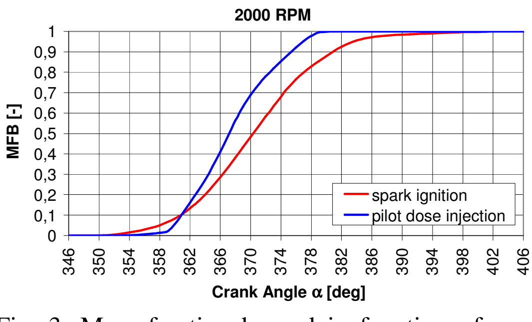

Fig. 3. Mass fraction burned in function of crank angle in both of engine work modes

Rys. 3. Udział masowy spalin w funkcji kąta obrotu wału korbowego w obu trybach pracy

The value of flame development angle $\Delta\alpha_r$ is determined by the moment in which the mass fraction burned is 0.1 according to formula (6):

$$\Delta\alpha_r = \alpha_{0.1} - \alpha_{ign} \quad (6)$$

The fast burn angle $\Delta\alpha_s$ [3] is defined with equation (7) as difference between the value of crank angle at which mass fraction burned equals 0.9 and the angle at which the mass fraction burned constitutes 0.1 the whole charge mass of the cylinder.

$$\Delta\alpha_s = \alpha_{90\%} - \alpha_{10\%} \quad (7)$$

The sum of the flame development angle $\Delta\alpha_r$ and fast burn angle $\Delta\alpha_s$ was defined by the name of burn duration angle $\Delta\alpha_o$ – formula (8):

$$\Delta\alpha_o = \Delta\alpha_r + \Delta\alpha_s \quad (8)$$

Values of angles characterizing the course of the combustion process are presented in Table 1 respectively for the case of work of engine with spark ignition and combustion initiation by means of direct injection of the ignition dose.

Tab. 1. Values of crank angles describing the course of the combustion process in both considered modes of engine operation

Tab. 1. Wartości kątów CA opisujących przebieg procesu spalania w obu rozpatrywanych trybach pracy silnika

No.	Angle,	Symbol	SI [°CA]	CI [°CA]
1	Ignition/pilot dose injection	α_{ign}	346	330
2	Reaching 0.1 MFB	$\alpha_{0.1}$	361	361
3	Reaching 0.9 MFB	$\alpha_{0.9}$	381	375,5
4	Flame development	$\Delta\alpha_r$	15	31
5	Fast burn	$\Delta\alpha_s$	20	14,5
6	Burn duration	$\Delta\alpha_o$	35	45,5

In the case of engine work with use of two injectors the value of the angle of flame development increased from 15 to 31 °CA. A remarkable decrease in the value of the fast burn angle $\Delta\alpha_s$ from 20 to 14.5 °CA is a more important fact. So, the most essential part of combustion process is shortened by 5.5 °CA at work of the engine with ignition initiated from a pilot dose i.e. about 28%. This is, beyond doubt, the cause of the increase in the indicated mean effective pressure and in caloric efficiency. Combustion of mixture in a shorter time causes smaller heat losses through the cylinder sleeve, since, in this situation the surface area of its part contacting the cylinder charge of high temperature is smaller.

Curves of combustion velocity dMFB/dα in function of crank angle for both injection systems is presented in Fig. 4. The charge combustion velocity was obtained by means of differentiation of traces of mass fraction burned presented in Fig. 3 with respect to the crank angle.

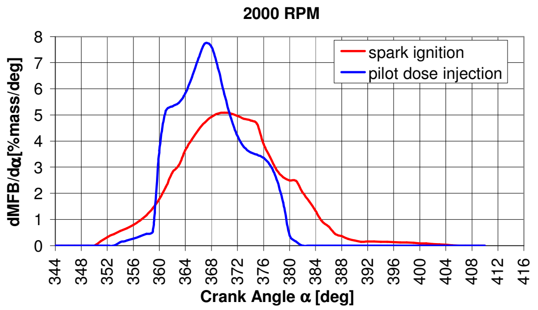

Fig. 4. Velocity of charge combustion in the cylinder dMFB/dα in function of crank angle for both combustion systems

Rys. 4. Szybkość spalania ładunku w cylindrze dMFB/dα w funkcji kąta obrotu wału korbowego dla obu systemów spalania

The velocity of charge combustion reaches in the major part of the period of fast burn higher values in the case of engine work with combustion initiated by injection of a fuel ignition dose. In the case of work of engine with spark ignition higher charge combustion velocities shifted towards the afterburning period are observed, this being not a positive phenomenon. Biggest influence on improvement of the engine caloric efficiency is exerted by increase in charge combustion velocity in the first stage of the process i.e. up to combustion of 50% of mass of the mixture [3].

3. Presentation of decrease in exhaust gases temperature at engine work changed from spark ignition to combustion from an ignition dose

During investigations decrease in temperature of exhaust gases was found in the case of ignition from the initiating dose. A diagram in form of columns illustrating comparison of exhaust gases temperatures in the case of spark ignition and ignition from a initiating dose was presented in Fig. 5 for two cases of injection angle of the ignition dose.

Fig. 5. Mean temperature of exhaust gases in the manifold of engine working with spark ignition (SI), with advance angle of pilot dose injection 28 °CA (CI 28 deg) and with advance angle of pilot dose injection 30 °CA (CI 30 deg)

Rys. 5. Średnia temperatura spalin w kolektorze wylotowym silnika pracującego z zapłonem iskrowym mieszanki (SI), z wyprzedzeniem wtrysku dawki pilotującej 28 ºOWK (CI 28 deg) oraz dla wyprzedzenia wtrysku dawki pilotującej 30 ºOWK (CI 30 deg)

In the case of work of engine with mixture ignition from the pilot dose decrease in mean temperature of exhaust gases in the exhaust manifold was recorded. When injection of the pilot dose started at 28 ºCA before TDC the exhaust gases temperature dropped by 9 ºC in comparison to the value recorded during work with spark ignition. For advance injection of ignition dose equaling to 30 ºCA the temperature of exhaust gases underwent a decrease by 6 ºC.

4. Presentation of nitric oxide at change of engine work from spark ignition to combustion from ignition dose

In consequence of decrease in exhaust gases temperature a concomitant decrease in the amount of nitric oxides in exhaust gases took place. Fig. 6 shows a comparison of volumetric fractions of nitric oxide in exhaust gases of engine working with spark ignition and auto-ignition, of two before mentioned values of the advance angle of beginning of pilot dose injection.

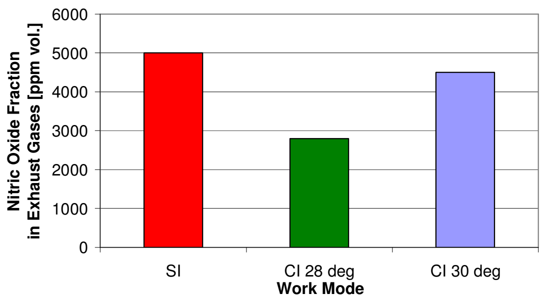

Fig. 6. Volumetric concentration of nitric oxide in exhaust gases of engine working with spark ignition (SI), with advance angle of pilot dose injection 28 ºCA (CI 28 deg) and with advance angle of pilot dose injection 30 ºCA (CI 30 deg)

Rys. 6. Stężenie objętościowe tlenku azotu w spalinach silnika pracującego z zapłonem iskrowym (SI), z wyprzedzeniem wtrysku dawki pilotującej 28 ºOWK (CI 28 deg) oraz dla wyprzedzenia wtrysku dawki pilotującej 30 ºOWK (CI 30 deg)

The measurement results presented in the above given illustration indicate at decrease in volumetric nitric oxide concentration in exhaust gases during work of engine with charge combustion initiation from the ignition dose in comparison with the result obtained when the engine worked with spark ignition.

5. Conclusions

Basing upon the carried out analysis the following conclusions can be presented:

1) The result of the above considerations are a confirmation of a positive influence of replacing spark ignition with injection of an injection dose on the charge combustion process in a chosen point of the engine operation map. This influence results in improvement of work indices, such as indicated mean effective pressure or caloric efficiency whose values exert direct influence on the achieved total efficiency of the engine,
2) During work of engine with combustion initiated by ignition dose injection a decrease in exhaust gases temperature was stated and this results in decrease in quantity of nitric oxide in exhaust gases.

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Nomenclature/*Skróty i oznaczenia*

‘ corrected/*skorygowany*

α Crank Angle [°]/*kąt obrotu wału korbowego*

Δ change, increment/*zmiana, przyrost*

$\alpha_{0.1}$ angle of reaching 0.1 mass fraction burned [ºCA]/*kąt OWK uzyskania 0.1 udziału masowego spalin*

$\alpha_{0.9}$ angle of reaching 0.9 mass fraction burned [ºCA]/*kąt OWK uzyskania 0.9 udziału masowego spalin*
α_{ign} angle of ignition/injection of pilot dose [ºCA]/*kąt OWK zapłonu/wtrysku zapłonowego*
$\Delta\alpha_r$ flame development angle [º CA]/*kąt rozwoju płomienia*
$\Delta\alpha_s$ fast burn angle [º CA]/*kąt szybkiego spalania*
$\Delta\alpha_o$ burn duration angle [º CA]/*kąt całkowitego spalania*
Δp_{comb} pressure increment resulting from combustion process [MPa]/*przyrost ciśnienia wynikający z procesu spalania*
Δp_V change of pressure caused by change of work space volume [MPa]/*zmiana ciśnienia od zmiany objętości przestrzeni roboczej*
CA Crank Angle/*kąt obrotu wału korbowego - OWK,*
CI Compression Ignition/*zapłon samoczynny*
k polytrophic index [-]/*wykładnik politropy*
MFB Mass Fraction Burned [-]/*udział ładunku spalonego*
p_c cylinder pressure [MPa]/*ciśnienie w cylindrze*
SI Spark Ignition/*zapłon iskrowy*
TDC Top Dead Center/*górne martwe położenie - GMP*
V cylinder work space volume [cm^3]/*objętość przestrzeni roboczej cylindra*
V_{cc} combustion chamber volume [cm^3]/*objętość komory spalania*

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