TEST BED STUDIES OF AN ENGINE WITH COMBUSTION INITIATION FROM IGNITION DOSE OF FUEL

Bronisław Sendyka, Marcin Noga

Cracow University of Technology
Institute of Automobiles and Internal Combustion Engines
Jana Pawła II Av. 37, 31-864 Krakow, Poland
tel.:+48 12 6283688, fax: +48 12 6283690
e-mail: bsendyka@pk.edu.pl, noga@pk.edu.pl

Abstract

Results of test bed studies of combustion engine with work possibility with application of spark ignition and combustion from ignition dose injected directly into the combustion chamber were described in this article. In engine working according to the patent solution of Prof. B. Sendyka, during start and work at low rotational speed and low load a system realizing spark ignition of homogenous mixture formed in classical way in the intake manifold is active. For higher rotational speeds and heavy load the ignition system is switched off whereas, injectors of ignition dose injecting fuel by the end of the compression stroke directly into the working space of the engine are activated. The fuel dose injected into the combustion chamber undergoes auto-ignition and in this way the combustion process in the whole volume of the homogenous combustion charge accumulated in the cylinder is initiated. The mass of ignition dose of fuel constitutes about 5 – 10% of the whole fuel mass per working cycle what differs decisively the presented solution from other known engines working according to similar principles. Application of two combustion system in four stroke combustion engine aims at combining the advantages of spark ignition a compression ignition engines. The engine is characterized by easy starting and during work at higher rotational speed and higher load in the mode of ignition from pilot dose exploitation efficiency of energy contained in fuel is higher than for spark ignition engine, this finds direct reflection in increase in total efficiency by over 9% as related to the base value.

Keywords: *Two-cycle engine, compression ignition, spark ignition, total efficiency of engine*

1. Introduction

Nowadays, new solutions of combustion systems for a four stroke piston engine which could combine advantages of a classic engine with spark ignition and advantages of compression ignition are looked for. In many scientific and research & development centres works on engine working with homogenous charge compression ignition – HCCI are performed. A driving unit working according to this principle is characterized by low fuel consumption as it is in case of engine with auto-ignition and its exhaust gases are cleanliness degree encountered in spark ignition engine. However up till now one did not succeed in implementing such a combustion system in mass-produced engine [2]. The basic problem which is barrier on the way of mass-application of such engine lies in difficulties concerning control of the moment of auto-ignition of the homogenous charge at larger range of rotational speed and load.

Referring to the above mentioned problems attempt at elaboration of engine which would combine the advantages of both engine with spark ignition and with compression ignition was undertaken in the Chair of Internal Combustion Engines of Cracow University of Technology. With this aim in view a four stroke combustion engine with spark ignition was reconstructed in such a way as to create an alternative possibility of work with combustion initiation from an ignition dose of fuel injected directly into the cylinder. This solution aims at increase in the obtained total efficiency of engine at maintenance of exhaust gases toxicity known from engine with spark ignition.

2. Test bed

Investigations which are subject of this elaboration were performed on test bed whose basic element were a naturally aspirated combustion engine Toyota 2SZ-FE and electronically controlled eddy current brake dynamometer with a gravimetric system of fuel consumption measurement. The engine chosen for the object of study is a four-stroke, four cylinder unit of displacement 1.298 dm^3 of spark ignition with multipoint injection fuelling system. For the needs of investigations the engine cylinder head was subjected to complex modernisation consisting in mounting in ignition dose injectors. The view of combustion chamber of one of the cylinders of the studied engine with the mounted in injector of ignition dose was presented in Fig. 1.

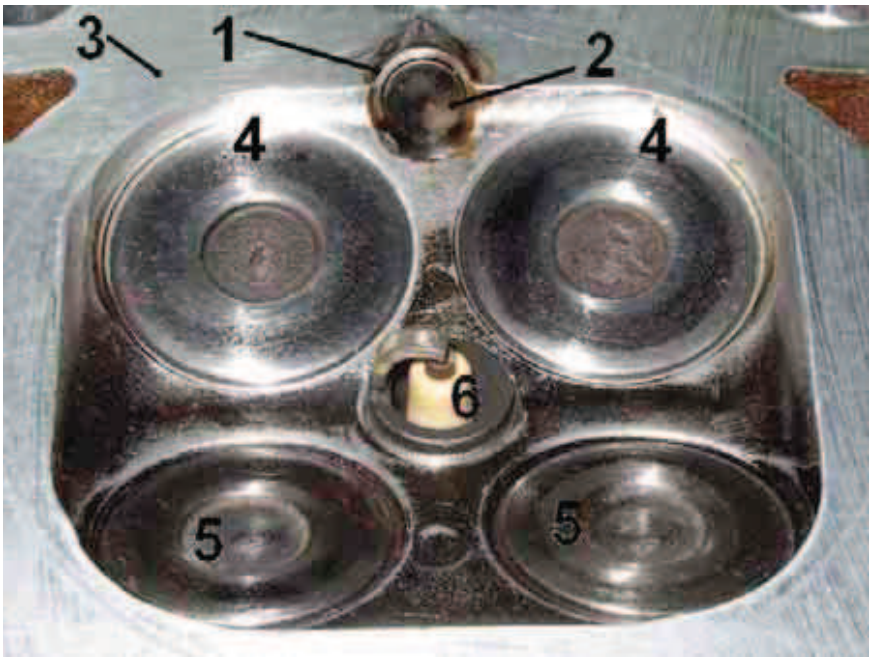

Fig. 1. Combustion chamber of the studied engine; 1 – Injector sleeve, 2 – Injector nozzle, 3 – Cylinder head surface, 4 – Intake valves, 5 – Exhaust valves, 6 – Spark plug

3. Experimental studies

Experimental studies of engine working with combustion initiation from ignition fuel dose were performed in following stages:

1. Determination of curves of torque, instantaneous fuel consumption, specific fuel consumption, exhaust gases temperature and engine total efficiency in dependence of angle of start of ignition dose injection for constant values of fuel doses.
2. Determination of curves of torque, instantaneous fuel consumption, specific fuel consumption, exhaust gases temperature and engine total efficiency in a function of engine load at constant rotational speed with ignition dose injection,
3. Elaboration of above mentioned curves in dependence of rotational speed for engine working with ignition dose injection.

First of all such quantities as: engine rotational speed, torque, fuel consumption were measured during test bed investigations. During experimental investigations ambient pressure and temperature was measured so as to bring the obtained results to standard conditions.

During test bed studies the variable intake valve timing system was inactivate. This was done in order to make the obtained results independent from the influence of setting of the valve timing. The angle of the start of fuel injection into intake pipes was constant. The start of opening of the basic-dose injectors occurred at 10º CA before TDC i.e. just before the start of intake valves opening.

During preliminary investigations of the engine the maximal constant value of the ignition dose injection pressure was determined. It equalled 15 MPa. This restriction was forced by application in the ignition dose injection system of injectors applied in systems of gasoline direct injection in which the working pressure of fuel did not exceed 12 MPa.

4. Influence of the angle of start of ignition dose injection on engine working parameters

Investigations aiming at determination of influence of the angle of start of ignition dose injection on engine working parameters were carried out for engine rotational speed 2000 RPM and absolute pressure in the intake manifold 0.132 MPa. Injection time was regulated so as to bring the mass of the fuel injected into intake manifold equalled 13.65 mg per cycle, whereas, the mass of the ignition dose was established on the level 6.74 mg per cycle. The angle of the start of ignition-injection was regulated in the range from 14 to 31º CA before TDC. The pressure of the ignition dose injection was 15 MPa.

Figure 2 presents the traces of engine torque and the temperature of exhaust gases in function of the angle of start of ignition dose injection.

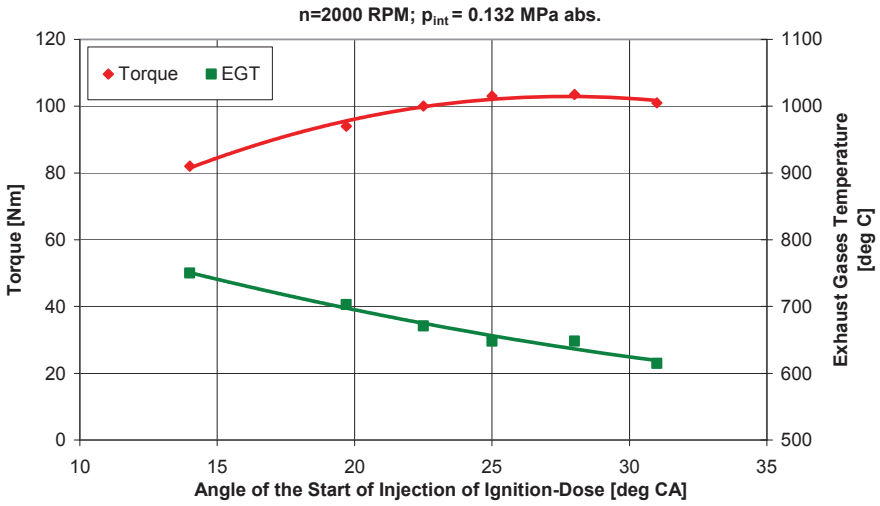

Fig. 2. Traces of torque and temperature of exhaust gases (EGT) in function of angle of the start of ignition dose injection for constant values of mass of fuel injected into the intake manifold and directly into the cylinder

It is noticeable that the torque maximum takes place in the analysed point of engine operation map for the angle of the start of ignition dose injection equal 28º CA before TDC. For the angle 31º CA a drop of torque was recorded at simultaneous audible noises of engine work characteristic for knock combustion. The exhaust gases temperature recorded during tests shows a decreasing tendency at increase in the advance angle of ignition dose injection.

Figure 3 shows the traces of brake specific fuel consumption and associated diagram of engine total efficiency obtained during investigation in the above described conditions.

The minimal value of brake specific fuel consumption recorded in the considered point of the engine operation map equalled 226 g/kWh what corresponds with total efficiency of the engine equalling 0.37.

5. Impact of engine load on specific fuel consumption and total efficiency

The influence of engine load on specific fuel consumption was determined for rotational speed equal 2000 RPM. Similarly as in the former case, the absolute pressure in the intake manifold was fixed on the level 0.132 MPa. The start of the ignition dose injection took place at 28º CA before TDC. The injection pressure was 15 MPa. The quantities of both of the ignition and basic dose

were variable. Fig. 3 shows the diagram of changes of the fuel dose in consequent measurement points in fractions of mass of the basic and ignition dose.

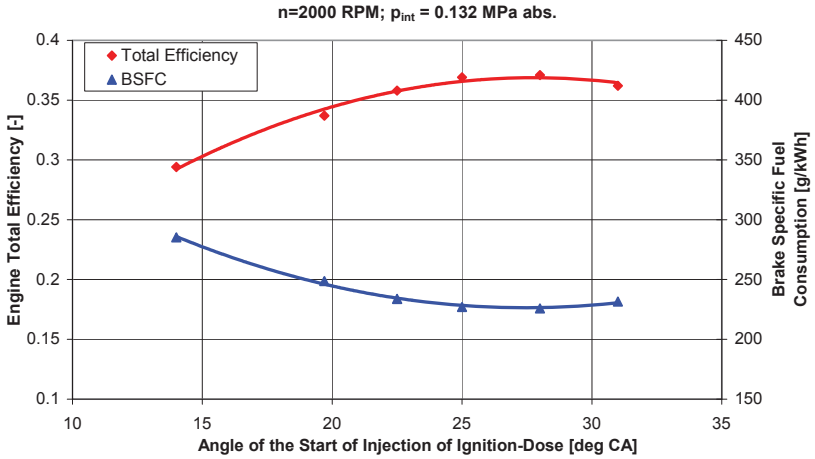

Fig. 3. Traces of brake specific fuel consumption (BSFC) and total efficiency in function of the angle of start of ignition dose injection obtained at rotational speed 2000 RPM

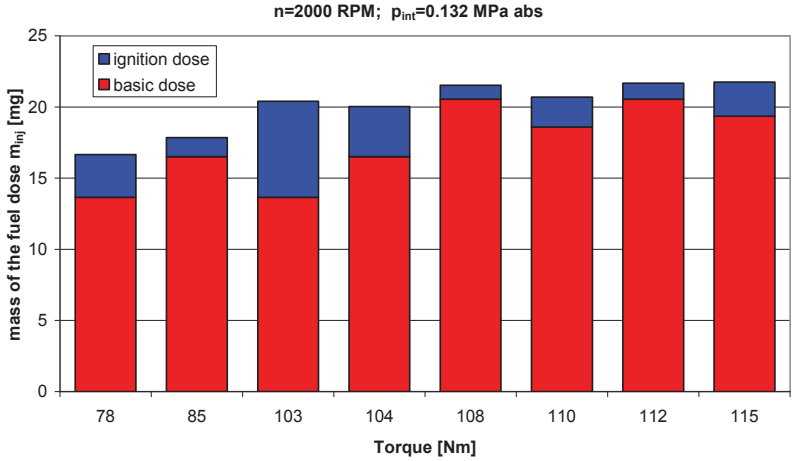

Fig. 4. Quantity of fuel doses in consequent measurement points

Diagrams of fuel consumption and brake specific fuel consumption were illustrated in Fig. 5 in function of torque generated by the engine working with direct injection of the ignition dose.

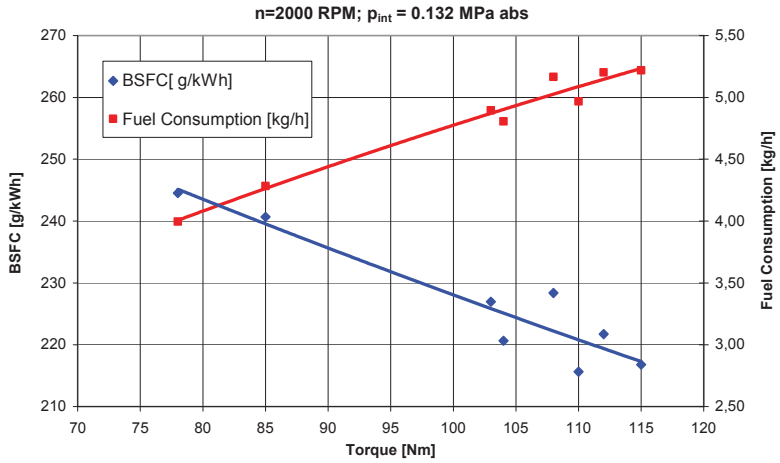

Fig. 5. The dependence of fuel consumption and brake specific fuel consumption in function of engine load obtained at constant rotational speed 2000 RPM

Decrease in brake specific fuel consumption with concomitant increase in engine load is noticeable. Work at load equal 115 Nm was characterized by occurrence of characteristic acoustic effects of knock combustion, hence, this was the last measurement point at this stage of tests.

Figure 6 presents the diagram of total efficiency obtained on the basis of the results of calculations of brake specific fuel consumption.

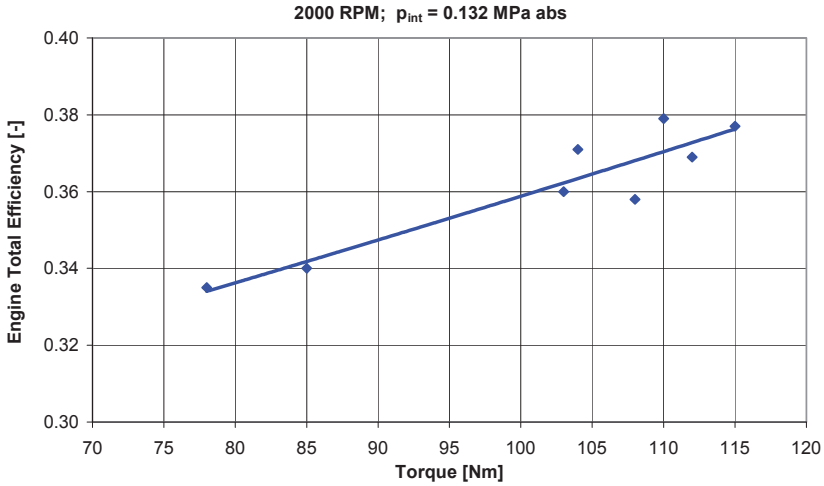

Fig. 6. The dependence of engine total efficiency in function of engine load obtained at constant rotational speed 2000 RPM

Highest value of engine total efficiency equalling about 38% was recorded during work under load of 110 Nm, at that time fraction of the ignition dose mass was about 10% of the mass of the whole fuel consumed by the engine per one work-cycle (Fig. 4).

6. The influence of engine rotational speed on torque and fuel consumption obtained for engine working with injection of ignition dose

Investigations aiming at elaboration of torque/speed and BSFC/speed characteristics of the engine were carried out within the rotational speed range from 2000 to 3500 RPM. The absolute pressure in the intake manifold equalled 0.132 MPa. The advance angle of the ignition dose injection was regulated so as to obtain engine work without characteristic acoustic effects of knock combustion [1].

Figure 7 presents the traces of torque and power during engine work with injection from ignition fuel dose.

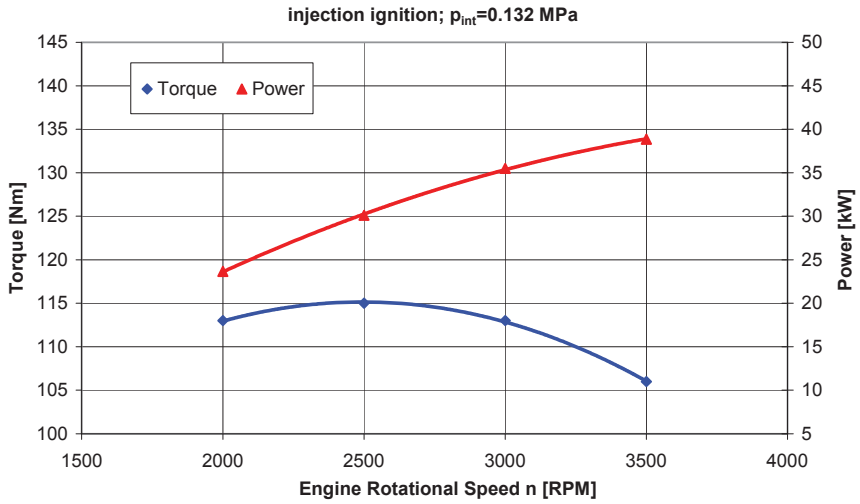

Fig. 7. Curves of torque and power in function of rotational speed of engine working with ignition dose injection

For constant pressure in the intake manifold the maximum of torque was got at rotational speed 2500 RPM. At rotational speed above 3000 RPM intensification of the tendency to decrease in torque was observed in spite of increase in the advance angle of ignition dose injection.

Figure 8 presents the traces of fuel consumption and brake specific fuel consumption in function of rotational speed determined during studies of the engine working with combustion initiation from the ignition dose of fuel. Fuel consumption was given as the sum mass flow rate of fuel injected into the manifold and as ignition dose.

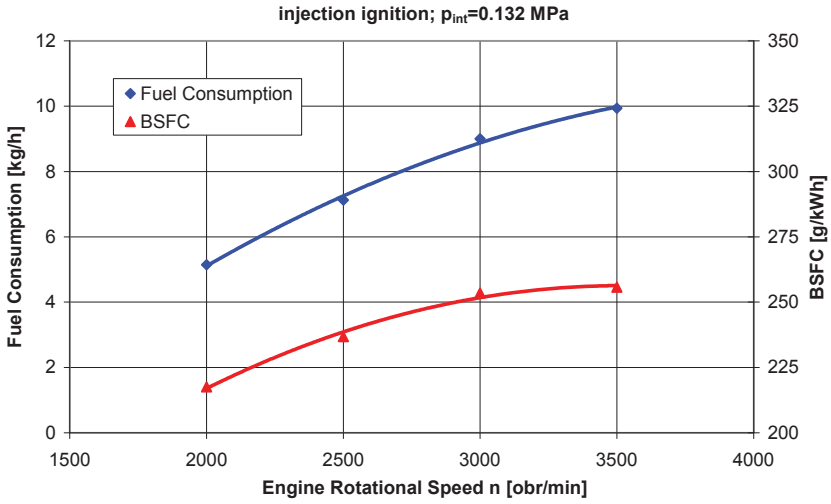

Fig. 8. Traces of fuel consumption and BSFC in function of rotational speed recorded during engine working with ignition dose injection

On the basis of analysis of Fig. 7 and 8 it may be noticed that increase in effective engine power with increment of rotational speed does not compensate the increased instantaneous fuel consumption in these conditions, so specific fuel consumption shows a growing tendency [5] .

Regulation of the quantity of fuel doses and proportion of their division between both injection systems was performed for every measurement point in such a way as to obtain possibly the lowest value of specific fuel consumption, and consequently the highest value of engine total efficiency which describes in complex form the engine energy affectivity.

4. Conclusions

Basing on analysis of results of carried out test bed investigations the following conclusions can be drawn:

1. There exist a possibility of engine work improvement where combustion is initiated by injection of ignition dose of fuel of a relatively small mass constituting about 5-10 of the whole fuel mass per working cycle, whereas, in a classic dual-fuel engine working on a similar principle the quantity of the piloting dose may be about 40% of the whole fuel mass [4],
2. In chosen points of the engine operating map transition to the mode of combustion initiation by means of ignition-injection is characterized by a much higher total efficiency at concomitant improvement of engine performance,
3. Improvement of operating parameters of engine working with ignition-injection results from intensification of the process of charge combustion, nevertheless, without entering into the domain of knock combustion. A shorter course of the combustion process of mixture influences positively on reduction of engine heat losses what is reflected directly in increase in total efficiency [3].

Acknowledgments

The scientific work financed from financial means for science and education in the years 2009-2011 as a research project No. N N509 405036.

References

[1] Eriksson, L., Andersson, I., *An Analytic Model for Cylinder Pressure in a Four Stroke SI Engine*, Proceedings of SAE 2002 World Congress, SAE Paper 2002-01-0371, Detroit 2002.
[2] Jankowski, A., *Studium wpływu ciśnienia, prędkości i rodzaju strugi gazów na przebieg procesu spalania*, Wydawnictwo Instytutu Technicznego Wojsk Lotniczych, Warszawa 2010.
[3] Kowalewicz, A., *Wybrane zagadnienia samochodowych silników spalinowych*, Wydanie 2, poprawione i uzupełnione, Wydawnictwo Politechniki Radomskiej, Radom 2002.
[4] Luft, S., *Dwupaliwowy silnik o zapłonie samoczynnym z wtryskiem ciekłego LPG do kolektora dolotowego*, Monografia Nr 10, Wydawnictwo Politechniki Radomskiej, Radom 2007.
[5] Sendyka, B., Noga, M., *Analysis of Combustion Pressure in a Two-Cycle Engine, Otto and Diesel,* Combustion Engines 3/2011 (146), PTNSS–2011–SC–209, Bielsko-Biała 2011.