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THE EFFECT OF FUEL INJECTION PARAMETERS ON THE COMBUSTION PROCESS IN A SELF-IGNITION ENGINE[*]

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Abstract

This paper presents the effect of the main parameters of fuel injection, such as injection angle and injector opening time, on the combustion process in a self-ignition engine. The study continues the research aimed at optimising the bi-fuel feeding of self-ignition engines with a main fuel dose of methane (CNG). The results described in the paper apply to a HATZ 1B40 one-cylinder engine, which was adapted for being powered with methane.

Examinations of the engine powered with a pilot dose of mechanically-injected diesel oil revealed the necessity to adjust the fuel injection advance angle. To this end, the mechanical system of fuel supply was replaced with a Common Rail, with controllable fuel injection pressure, fuel injection advance angle and injector opening time.

The results presented in the paper show the characteristics of the injector output depending on the fuel pressure in the Common Rail and on the duration of the electric impulse which opens the injector. Moreover, the article presents examples of pressure courses in the combustion chamber at a constant fuel dose and with a different fuel injection advance angle. An example of the combustion pressure course at a constant fuel dose and variable injection pressure and injector opening time is given.

Keywords: *injection pressure, injector opening time, fuel injection advance angle, course of combustion*

1. Introduction

The need to reduce greenhouse gases emission and the shrinking resources of crude oil make it necessary to seek new sources of energy which could be used as fuel in combustion engines.

Currently, interest has been growing in natural gas, particularly in methane – its main component being used as fuel for combustion engines. Natural gas can be used as fuel in combustion engines in two forms: compressed – as CNG (Compressed Natural Gas) and liquid – as LNG (Liquefied Natural Gas). Natural gas is also the main component of biogas (up to 55%). Powering engines with LNG is not too popular as condensed methane has to be stored at very low temperatures (*-162 °C*).

Powering engines with CNG has been gaining popularity and more and more cars are being adapted to using CNG.

Currently, using CNG as fuel in combustion engines is restricted mainly to spark-ignition engines, which is mainly due to the properties of methane, the main components of CNG?

Currently, intensive studies are under way in many scientific centres at home and abroad aimed at using methane as fuel in diesel engines. These studies are founded on the need to make use of the greatest advantage of diesel engines – its overall higher efficiency – and on the advantage of using methane – its relatively low level of toxic emissions.

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Due to the high temperature of its self-ignition (about 540ºC), methane cannot be used directly as fuel to power a diesel engine. Methane self-ignition in a diesel engine takes place after injecting a dose of liquid fuel, which initiates self-ignition, into a combustion chamber filled with methane-air mixture.

The research so far has shown that the biggest problem which has to be solved in powering diesel engines with methane is an adverse effect which may accompany combustion, i.e. explosive combustion. It is very important to eliminate this effect as it determines not only the efficiency of the entire system, but also engine durability. The main parameters which affect the explosive combustion of methane in a diesel engine include:

- the percentage share of each fuel in the total dose supplied to the engine,
- the injection advance angle for the self-ignition starting liquid fue,
- engine temperature.

In bi-fuel feeding, the engine fuel system usually supplies a small dose of diesel oil with methane accounting for the remaining part of the fuel dose; its amount is determined by the momentary conditions of the engine operation. When such a solution is applied, a diesel engine powered with methane does not need to be reconstructed, but the existing fuel supply system has to be adapted and an additional CNG system has to be built; moreover, its control system has to be interfered with. In order to achieve comparable parameters of the engine operation to those observed when the engine is powered by fuel oil alone, the following parameters should be properly selected: the angle of ignition initiating dose injection onset, pilot dose size and methane dose size. The methane feeding dose in a bi-fuel feed diesel engine can be controlled qualitatively (fuel dose control) and quantitatively (gas-air mixture control - throttle. A diagram of an example bi-fuel diesel engine feed system is shown in Fig. 1.

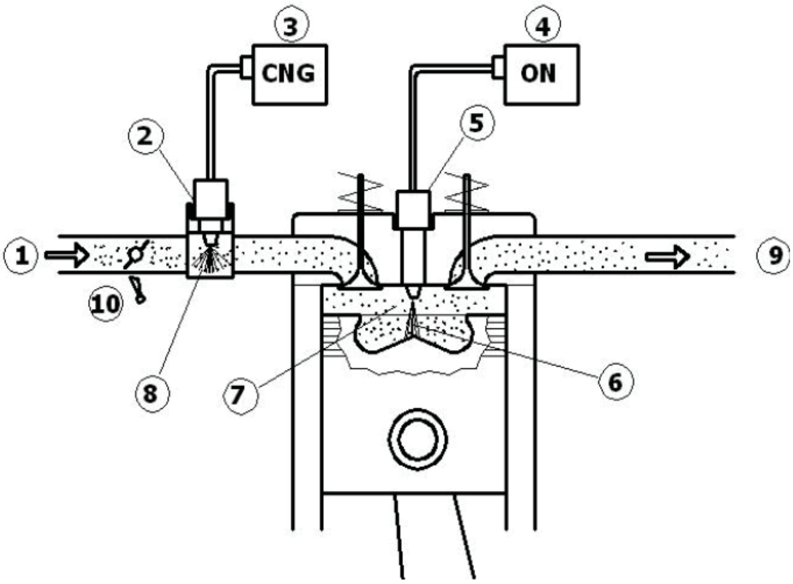

Fig. 1. Diagram of the dual-fuel feed system for the diesel engine: 1 – air inlet duct, 2 – CNG injector, 3 – CNG feed system, 4 – diesel oil feed system, 5 – diesel oil injector, 6 – ignition diesel oil dose, 7 – compressed mixture of CNG with air, 8 – main CNG dose injected into the mixing chamber, 9 – exhaust gas outlet, 10 – throttling valve

2. The test stand and the scope of research

Results of previous studies, for example [2, 3], have shown that in order to ensure the optimum operating conditions for a diesel engine powered with methane it is necessary to adjust the injection advance angle of ignition-initiating oil. To this end, the test stand based on a one-cylinder HATZ 1B40 engine has been modified. The original mechanical system of fuel injection was replaced with a Common Rail system with a specially designed control system. It allows control of fuel injection pressure (p_w), fuel injection advance angle (α_w) and the duration of the injector opening electric impulse (t_w). Moreover, the system makes it possible to divide the fuel dose into four separate parts.

The basic technical characteristics of the HATZ 1B40 engine are shown in the following Tab. 1.

Tab. 1. Technical characteristics of the Hatz 1B40 engine

Engine type	HATZ, 1B 40, 4-stroke, air-cooled
Rated power	6.8 kW at 3000 rpm
Number of cylinders	1
Engine displacement	462 cm^3
Cylinder diameter	88 mm
Piston stroke	76 mm
Compression ratio	21
Mixture making system	direct injection

The study results presented below were obtained in a study of a HATZ 1B40 engine, powered with a Common Rail type system (Fig. 2). The rapidly changing pressures in the engine combustion chamber were recorded with an AVL Indimodul 621 engine indicator, owned by the Department of Mechatronics of the University of Warmia and Mazury in Olsztyn. The set comprises: a FlexIFEM Piezo 2P2E AVL charge amplifier, a crankshaft rotation angle marker – 365C AVL, a piezoelectric sensor for measuring rapid pressure changes in a cylinder – GM 12D AVL. The IndiModul was controlled by an IndiCom computer software pack. The test stand enabled data registration depending on the crankshaft rotation angle with real-time indication analysis. The crankshaft rotation angle marker 365C was mounted on the crankshaft free end. Combustion chamber pressure within 60° of the crankshaft rotation angle (CA) (before and after TDC) was recorded every *0.5°CA;* it was recorded every *1°CA* in the remaining interval. 50 successive engine cycles were recorded during the measurement.

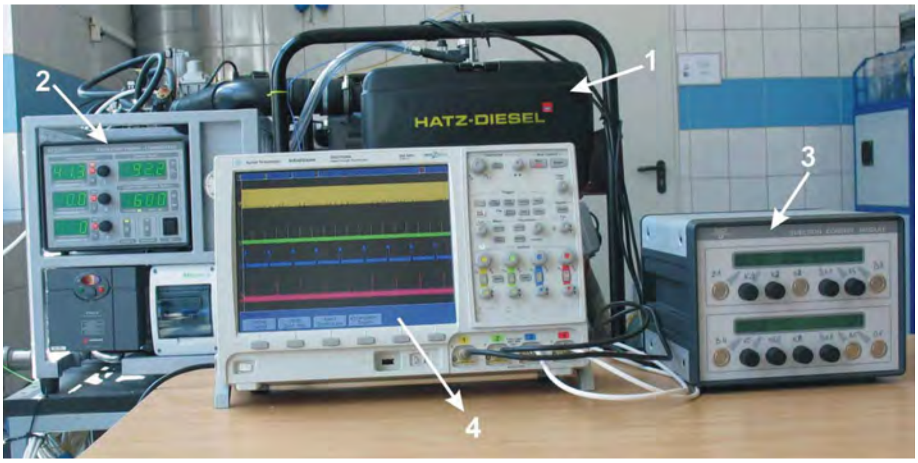

Fig. 2. A view of the HATZ 1B40 engine with the Common Rail control system: 1 – HATZ 1B40 engine, 2 – fuel injection pressure control system, 3 – injector opening time and angle control system, 4 – oscilloscope

3. Test results

In order to ensure the correct engine operation, the proper electromagnetic injector was selected for the working parameters corresponding to the engine operation conditions. The selection criteria included the injector size and shape and the combustion chamber size.

Before recording the combustion chamber pressure, the injector output was characterised in order to determine its opening time vs. injection pressure.

To this end, the injector was tested at an injector test stand. The test involved recording the fuel dose injected during a single injection depending on the injection pressure in the CR and on the duration of the injector opening impulse. The fuel temperature was also controlled during the injector testing to avoid an error resulting from the change of temperature-dependent fuel properties.

The characteristics of the injector output are shown in Fig. 3. They clearly indicate that the fuel dose is mainly affected by the injector opening time and fuel pressure.

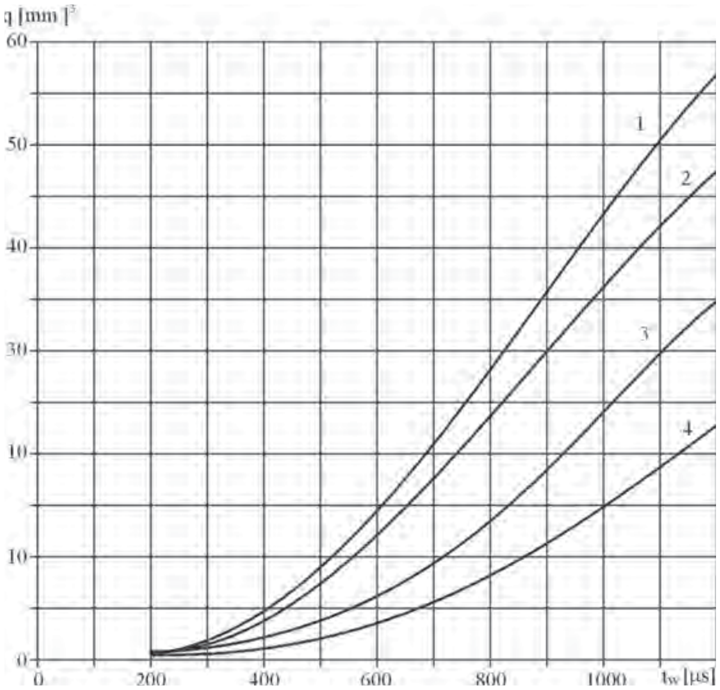

Fig. 3. Characteristics of the injector output depending on the injection pressure and duration of the injector opening impulse: 1 – p_w=100 MPa, 2 – p_w=80 MPa, 3 – p_w=60 MPa, 4 – p_w=40 MPa

In another stage of the study, the course of combustion pressure in the engine chamber was recorded. An example of the course of combustion pressure in the engine chamber is shown in Fig. 4. As stated earlier, 50 successive engine operation cycles were recorded and the pressure courses were subsequently processed and analysed. To this end, a procedure, developed in the MATLAB program, was applied to average and compare the pressure courses.

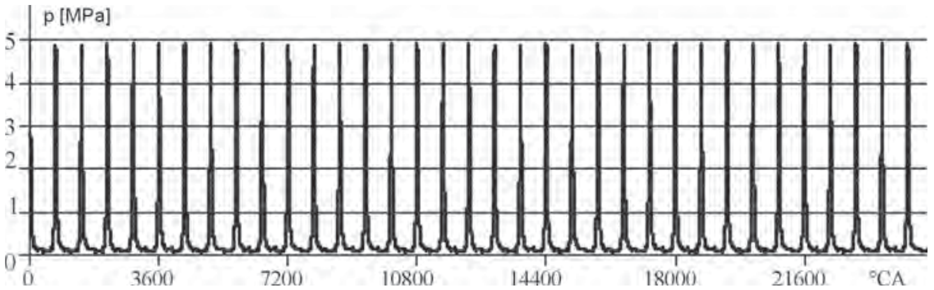

Fig. 4. An example of recorded pressure course in the engine combustion chamber

Figure 5 shows averaged pressure courses in the engine chamber at the revolutions of $n=1800\ rpm$ for an unloaded engine, fuel pressure in the Common Rail $p_w=100\ MPa$, duration of the injector opening impulse $t_w=390\ \mu s$ and variable fuel injection angle. The injected fuel dose per one cycle was equal to $q=4\ mm^3$.

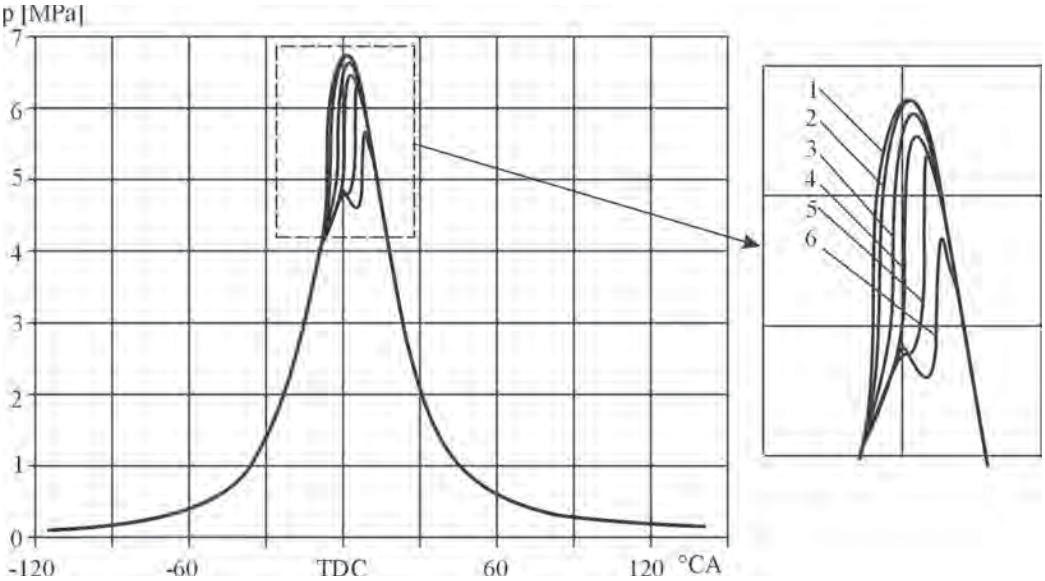

Fig. 5. Recorded pressure runs at a constant fuel dose of $q=4mm^3$, fuel injection pressure of $p_w=100$ MPa, duration of the injector opening impulse of $t_w=390$ μs and different fuel injection advance angle: 1 – 22.5°, 2 – 19.5°, 3 – 16.5°, 4 – 13.5°, 5 – 10.5°, 6 – 7.5° OWK

An analysis of the averaged courses of combustion, shown in Fig. 5 at the fuel injection advance angle ranging from *22.5* to *7.5°CA* before the TDC shows significant changes in combustion. Higher maximum combustion pressures were recorded at a greater fuel injection advance angle, but at the same time, more rapid pressure increases occurred ($dp/d\alpha$). On the other hand, if the fuel injection advance angle is too small (delayed injection), self-ignition is considerably delayed, which negatively affects the course of combustion due to a large decrease in the maximum combustion chamber pressure and a delay in its occurrence.

Figure 6 shows the averaged courses of combustion at a constant fuel dose of $q=4$ mm^3 and a constant fuel injection advance angle of $\alpha_w=17.5$ °CA before TDC, and different fuel injection pressures. In order to ensure a constant fuel dose, its decrease caused by pressure drop in the injection system during successive measurements was compensated for by an extended injector opening time. An analysis of the courses shown in the diagram shows a significant positive effect of fuel pressure on combustion chamber pressure. This is associated mainly with the total fuel injection time. The time needed to inject a specific fuel dose at a higher injection pressure is shorter, which favours quicker combustion of the entire fuel dose.

4. Summary

The results of the study have confirmed the application of the Common Rail system to power the HATZ 1B40 engine. The application of the system in further studies of powering the engine with methane will enable full control over the characteristics of self-ignition initiating dose supply.

The results of the study have corroborated the effect of the basic parameters of fuel injection, described in the literature, e.g. [4, 5]:

- fuel injection pressure,
- fuel injection advance angle,
- dose spread over the injection time,

on the combustion process which determines the engine performance.

The next stage of the study will deal with exhaust emission of a bi-fuel feed engine with methane injected to the suction manifold as the main fuel dose. The application of the Common Rail system to inject self-injection fuel oil dose may improve engine operation conditions and enable partial elimination of explosive combustion which occurs within certain engine load ranges.

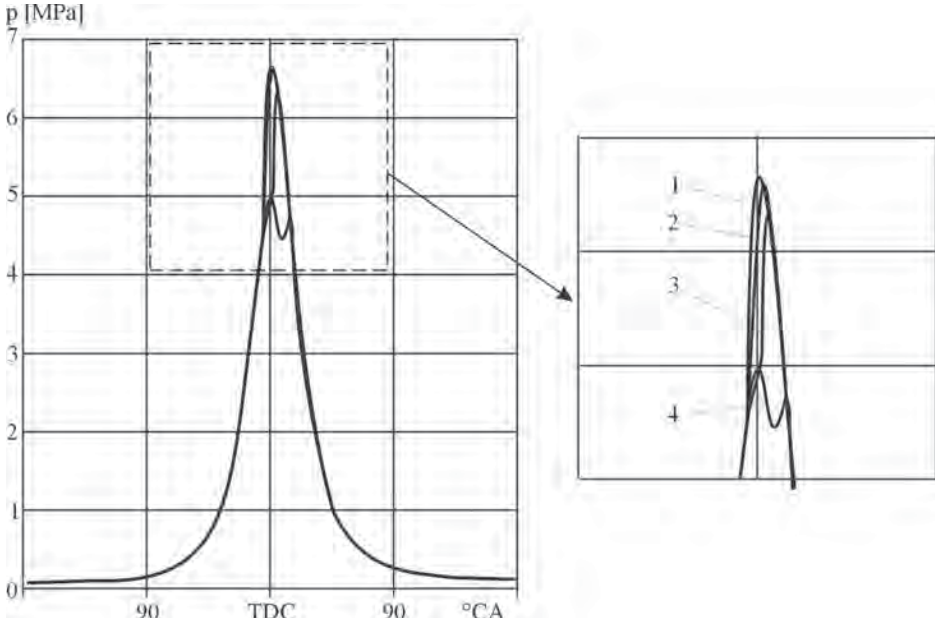

Fig. 6. The course of combustion process at a constant fuel dose of $q=4mm^3$ *and* $\alpha_w=17,5°$ *crankshaft rotations and at different injection pressure values* (p_w) *and injector opening times* (t_w): *1 –* $p_w = 100$ *MPa,* $t_w = 390$ μs, *2 –* $p_w = 80$ *MPa,* $t_w = 430$ μs, *3 –* $p_w = 60$ *MPa,* $t_w = 480$ μs, *4 –* $p_w = 40$ *MPa,* $t_w = 620$ μs

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