

EXAMINATION OF FAST-CHANGING QUANTITIES IN ENGINE WITH COMMON RAIL INJECTION SYSTEM

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Abstract

The paper aims to present the results of investigations into the engine with Common Rail system that performs multi-phase injection. The scope of investigations included measurements and assessment of fast-changing quantities. The paper provides the research stand description and a block diagram of the system for taking measurements of fast-changing quantities, including the system measuring the intensity of the current that controls the injector operation. The experimental results discussed in the paper were derived from introductory investigations into measurements of the air-fuel mixture pressure in the engine cylinder and those of the injector needle lift, which were assessed on the basis of measurements of the intensity of the injector-controlling current. Tests were performed while the engine operated under external speed characteristics and under load characteristics at the crankshaft rotational speed $n=1200$ rpm and $n=3800$ rpm. During tests, depending on speed and load characteristics of the engine operation, the ECU performed different strategies of fuel injection. The fuel injection control system made it possible to complete three injection stages in a single work cycle of the internal combustion engine (pilot injection, pre-injection and the main injection). The maximum fuel pressure in the common rail amounted to 160 MPa. The engine was fuelled by commercial diesel oil.

Keywords: combustion engines, common rail, multi-phase injection, indicator diagram

1. Introduction

The dynamic development of piston internal combustion engines aims to achieve the lowest fuel consumption possible and minimize hazardous exhaust gases components emission into the atmosphere. One of the main factors which determine achieving this goal is providing a proper air-fuel mixture forming process and its combustion, which is presented in the form of the indicator diagram. The form and pressure values in the characteristic points on this chart are mainly dependent on the fuel injection process. The paper presents the results of selected fast-changing quantities in engine with common rail injection system that allows the distribution of fuel charge into 3 parts and their injection into the cylinder at a maximum pressure of 160MPa.

2. Research stand and testing and measurement equipment

The investigations were performed at the test bench consisting of a 1.3 MultiJet diesel engine, eddy-current brake, control and measurement cabinets used to control the stand and allowing for performance reading of brake and Bosch KTS 540 engine diagnostic equipment. Block diagram of the measurement system for fast-changing quantities and injector control current are shown in Fig. 1. The system consists of three measurement chains:

- cylinder pressure measurement chain,
- injector control current measurement chain,
- crankshaft rotational angle measurement chain.

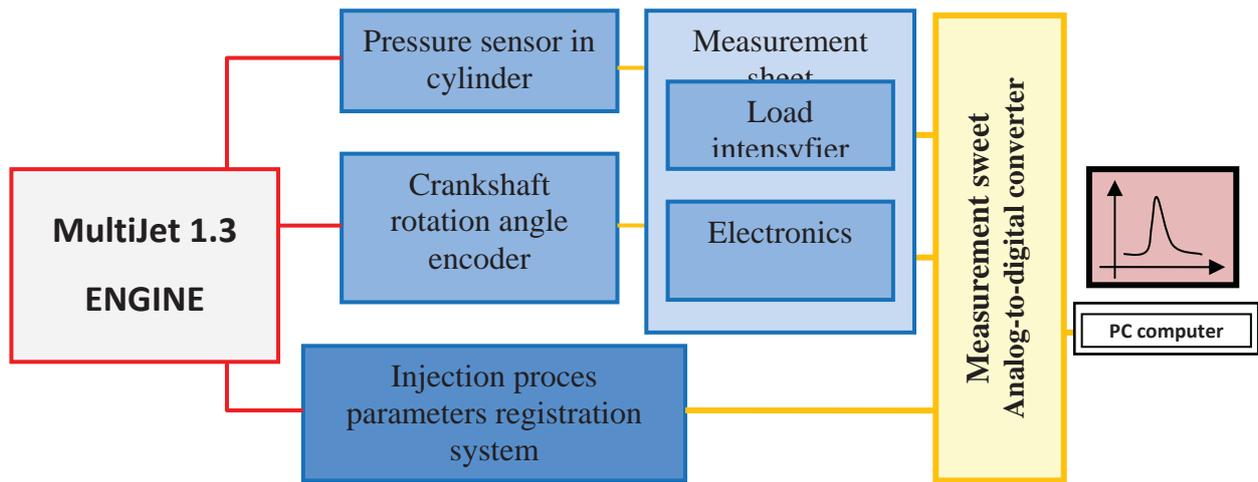


Fig. 1. Block diagram of the measurement system for fast-changing quantities in piston compression ignition internal combustion engine

Engine cylinder pressure measurement chain consists of the piezoquartz sensor type GH13G manufactured by AVL, connecting pipes and the load amplifier type CL 111 manufactured by ZEPWN Marki. Pressure measurement elements in the injection pipe are the following: measured current converter and KTS 540 diagnostic unit, connecting pipes and load amplifier type CL 111 manufactured by ZEPWN Marki. The applied piezoquartz pressure sensor converts the pressure signal to the electric charge. The measured quantities were recorded for the crankshaft rotation angle. The measurement is made possible by measurement chain of the crankshaft rotation angle consisting of rotary-pulse converter and crankshaft position marking and synchronization system. All the quantities measured were recorded in the computer. The test included 50 consecutive TSS cycles. There were 2,400 data points per engine cycle. This ensured the measurement resolution of every 0.3°OWK .

The test object was 16-valves, 4-cylinder compression ignition engines with Multijet common-rail system meeting emission the Euro 4 emission standards, with maximum power output of 90 PS (66 kW) and maximum torque of 200Nm. Engine technical data and physical and chemical properties of fuel are presented in [2, 3]. The engine incorporates multistage fuel injection as shown in Fig. 2.

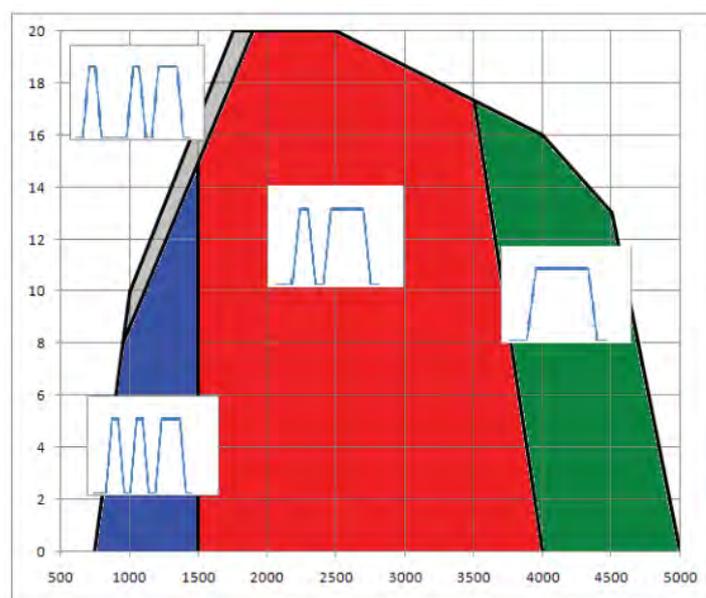


Fig. 2. Control of multi-phase fuel injection in MultiJet 1.3 engine with the maximum power output 66kW [4]

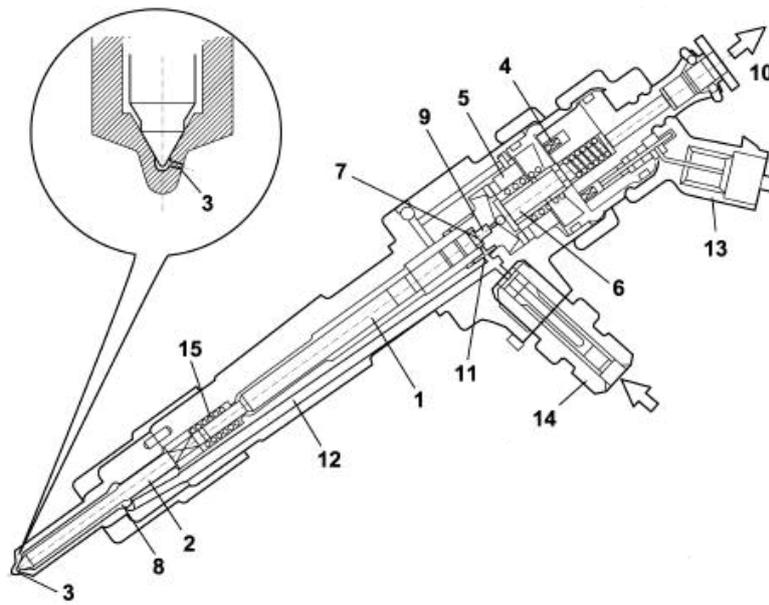


Fig. 3. Injectors building [5]: 1 - Pressure rod; 2 - Pin; 3 - Jet; 4 - Coil; 5 - Valve; 6 - Spherical plunger; 7 - Control area; 8 - Supply volume; 9 - Control volume; 10 - Fuel return - low pressure; 11 - Control duct; 12 - Supply duct; 13 - Electrical connection; 14 - Fuel inlet connector - high pressure; 15 - Spring

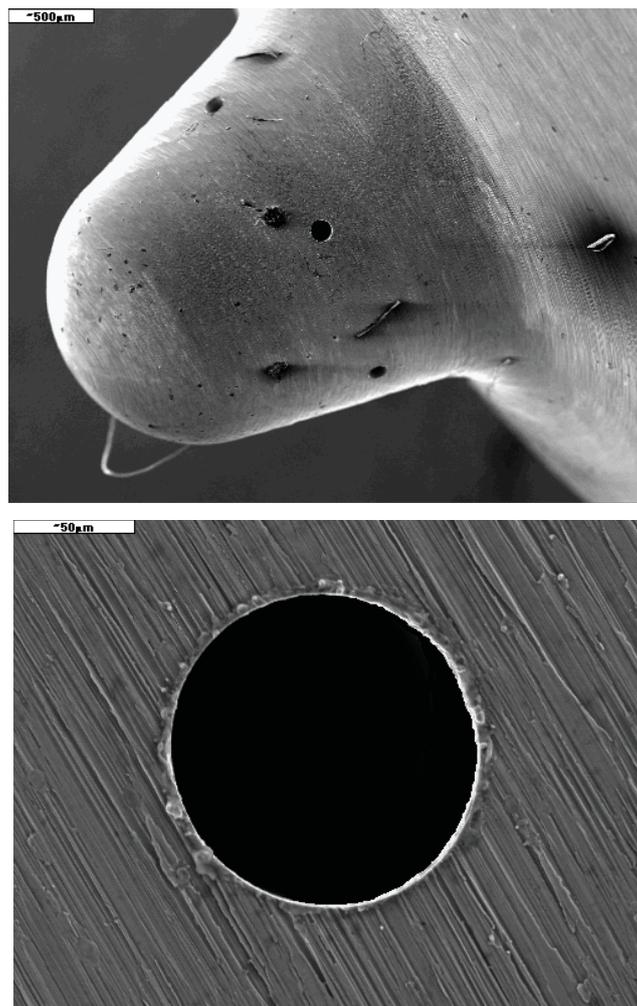


Fig. 4. View of orifices of electromagnetic injector in MultiJet 1.3 engine

Electronic high-pressure common rail injection system was adopted in the engine. Fuel flows from the high pressure pump to the collector busbar and then flows into the injectors mounted on the cylinder head controlled by the control unit. Spray nozzle orifice diameter was measured with a scanning scanner. The spray nozzle orifice diameter is 12 mm. The electro-injector design is shown in Fig. 3.

3. Test results

The tested engine was fuelled by commercial diesel oil and operated under external speed characteristics. Engine controller coupled with the injection process parameter recording system controlled the operation of the engine electro-injectors under different load and speed conditions. The pre-injectors task performed prior to the main fuel injection is the increase in cylinder compression pressure, shortening compression ignition delay of the main fuel injection, reduction of the pressure rise rate in the combustion chamber and reduction of the maximum combustion pressure. Fig. 5 shows the injector controlling current intensity patterns averaged over 50 TSS cycles. Fig. 5A and 5B presents the current intensity pattern allowing the three-phase fuel injection process. Fig. 5C presents the current intensity pattern for the two-phase fuel injection process, while Fig. 5D shows the current intensity changes for the single-phase fuel injection process.

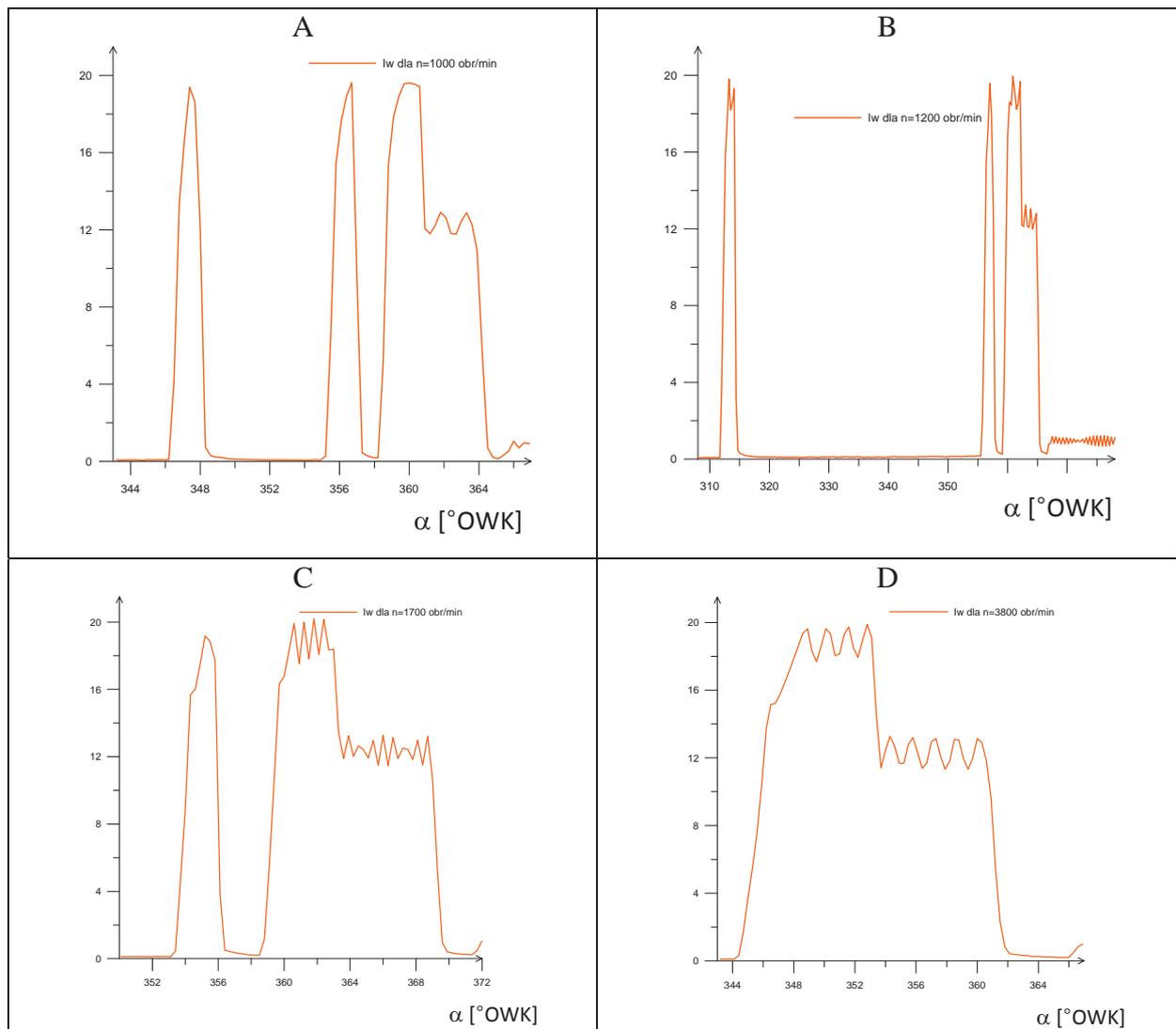


Fig. 5. Pattern of changes in the intensity of the injector operation controlling current in the MultiJet 1.3 engine performing different fuel injection strategies [1]: A and B - three-phase fuel injection, C - two-phase fuel injection and D - single-phase fuel injection

Table 1 shows the basic parameters of the test engine operating under external speed characteristics.

Tab.1. Work parameters of MultiJet 1.3 engine operating under external speed characteristics at three different rotational speeds of the crankshaft

rotational speed n [rpm]	effective power N_e [kW]	effective torque M_0 [Nm]	hour fuel consumption G_e [kg/h]	unit fuel consumption g_e [g/kWh]	fuel charge g_c [mm ³ /cycle]	injection pressure p_w [MPa]	Excess air coefficient λ
1200	11.9	96	2.8	235	24.58	53.6	1.33
1700	36.4	204	7.75	213	45.70	88.3	1.27
3800	65.8	187	13.89	211	39.98	134.3	1.451

Figure 6 shows the actual cylinder pressure averaged over 50 TSS work cycles for three different approaches to the fuel injection process. Cylinder pressure pattern for three-phase fuel injection is marked in red (Fig. 5B), for two-phase fuel injection in purple (Fig. 5C), for single-phase fuel injection in blue (Fig. 5D).

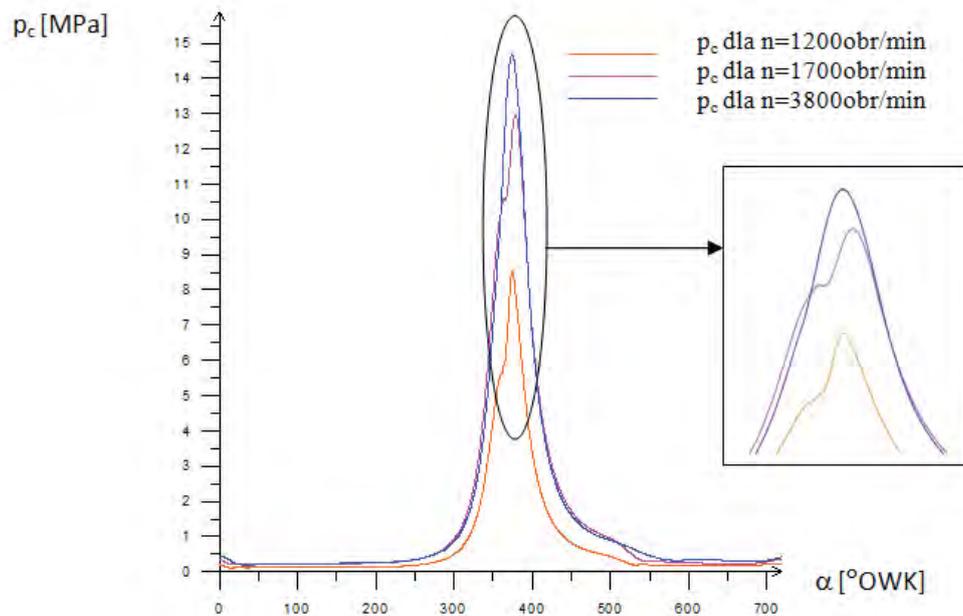


Fig. 6. Real pattern of cylinder pressure changes, averaged over 50 work cycles, in MultiJet 1.3 engine operating under external speed characteristics. Cylinder pressure pattern for three-phase fuel injection is marked in red (Fig. 5B), for two-phase fuel injection in purple (Fig. 5C), for single-phase fuel injection in blue (Fig. 5D).

Figure 6 shows that the three-phase and two-phase fuel injection is accompanied by cylinder pressure change pattern collapse. The collapses are the result the different fuel injection patterns to the cylinder. In addition, Fig. 6 shows as the crankshaft rotational speed operating under external speed characteristics increases, the maximum cylinder pressure increases, too.

Figure 7 and 8 presents the averaged experimentally compiled cylinder pressure indicator diagrams of the engine operating under load characteristics, at the crankshaft rotational speeds at $n=1200$ rpm and $n=3800$ rpm respectively and for different injection processes and under different load characteristics.

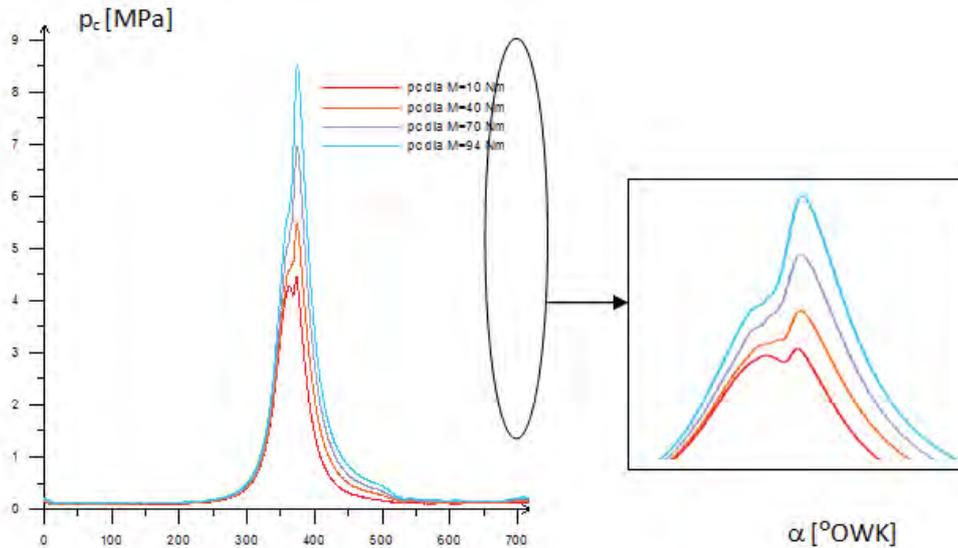


Fig. 7. Real pattern of cylinder pressure changes, averaged over 50 work cycles, in MultiJet 1.3 engine operating under load characteristics at $n=1200\text{rev/min}$ for three-phase fuel injection.

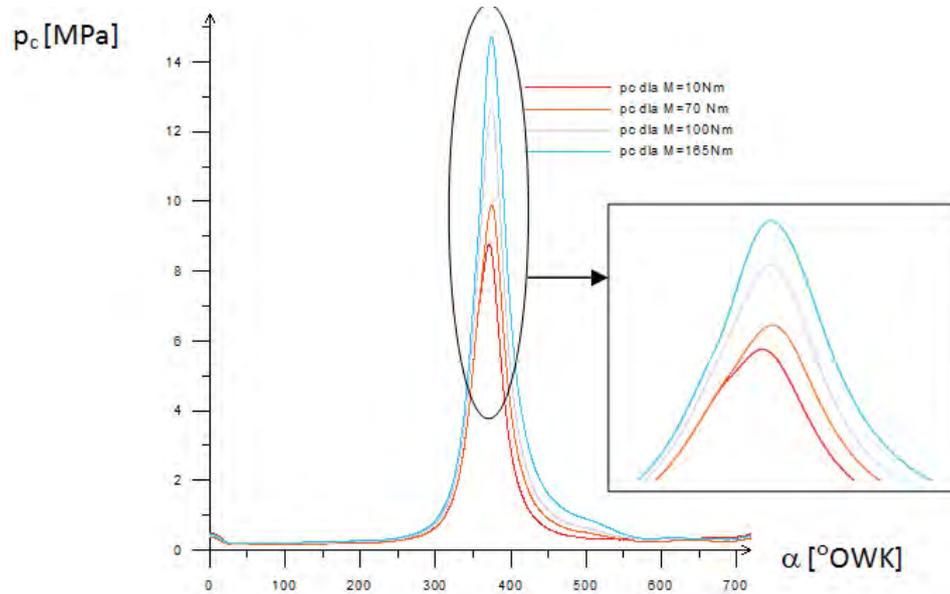


Fig. 8. Real pattern of cylinder pressure changes, averaged over 50 work cycles, in MultiJet 1.3 engine operating under external speed characteristics at $n=3800\text{rev/min}$ for one-phase fuel injection

Figure 7 and 8 shows that the engine operating under the above-mentioned two load characteristics, the increase in the engine load caused an increase in the cylinder pressure. The pattern of the cylinder pressure changes depended on the injection and fuel pressure in the busbar as well as on the exhaust gas recirculation rate. The gas recirculation degree was measured using the KTS 540 diagnostic device. The engine operating under the load characteristics at $n=1200\text{ rpm}$, the rate of exhaust gas recirculation ranged from 40 to 46%, while at $n=3800\text{ rpm}$, the exhaust gas recirculation has not been present.

Table 2 presents the basic engine work parameters operating under two load characteristics with the fuel charge per one engine cycle, injection pressure and exhaust gas recirculation. The three-phase fuel injection in the engine operating under load characteristics at $n=1200\text{ rpm}$ is shown in Fig. 5A and 5B. Injection pressure changed from 33.2 MPa to 55.8 MPa. However, one fuel injection was implemented for the engine operating under load characteristic at $n=3800\text{ rpm}$ (Fig. 5D). Injection pressure changed then from 33.2 MPa to 55.8 MPa.

Tab. 2. Work parameters of MultiJet 1.3 engine operating under two load characteristics at $n=1200$ rev/min and $n=3800$ rev/min

rotational speed n [rpm]	effective power N_e [kW]	effective torque M_0 [Nm]	hour fuel consumption G_e [kg/h]	unit fuel consumption g_e [g/kWh]	fuel charge g_c [mm ³ /cycle]	injection pressure p_w [MPa]	Exhaust gas recirculation rate EGR [%]
1200	1.1	10	0.68	618	6.67	33.2	46
	5.1	40	1.38	271	11.74	36.2	42
	8.7	70	2.1	241	15.92	41.6	40
	11.6	94	3.29	283	24.12	55.8	unavailable
3800	3.1	10	3.18	1025	8.59	82.9	unavailable
	27.9	70	6.56	235	18.57	114.3	unavailable
	39.3	100	8.68	221	24.5	132.5	unavailable
	65.6	165	14.58	222	37.62	150.9	unavailable

4. Summary and conclusions

Based on the test the following can be concluded:

- depending on speed and load operation condition, cylinder fuel injection is different. For low rotational speed - up to about 1500 rpm, three-phase fuel injection is implemented. For speeds from 1500 rpm to about 3500 rpm, two-phase fuel injection is implemented. Above 3500 rpm, only the main injection is implemented which means that single-phase fuel injection takes place,
- cylinder pressure pattern depends on the actual fuel injection pattern,
- during full engine load, as the rotational speed increased, cylinder pressures were higher and higher,
- during stable rotational speed, as the load increased, maximum cylinder pressures were higher and higher,
- exhaust gas recirculation took place only when engine was partially under load and at the crankshaft rotational speed smaller than 3400 rpm.

The results of experimental tests will be subjected to further processing and analysis focused on the determination of the average values of both compression and decompression polytrop exponents as well as heat emission characteristics during the period between the intake valves closing and the moment the intake valve open. The results of the analysis will be the subject of the consequent planned publications.

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