EXTERNAL SPEED CHARACTERISTICS IN ENGINE WITH MULTI-STAGE FUEL INJECTION

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Abstract

Increasingly higher demands put on piston internal combustion engines are aimed at reducing their harmful impact on the natural environment. This refers primarily to nitrogen oxides, particulate matter and noise emissions. The reduction in emissions of noxious components of exhaust gases in engines is achieved by means of, among others, the use of catalysts decreasing nitrogen oxide emissions, particulate matter filters and oxidising catalysts decreasing carbon monoxide and hydrocarbon emissions. Common Rail injection systems make it possible to increase the engine power, and to reduce fuel consumption, exhaust gas toxicity and noise produced by engines. With Common Rail systems, the pattern of fuel injection process can be designed, consequently the combustion process can be controlled.

The paper presents the results of test bench investigations into a compression ignition 1.3 Multijet engine with multistage fuel injection, which is manufactured in Poland by Fiat-GM Powertrain Polska Company. The tests were conducted at a stand constructed at the Heat Engines Laboratory of the Kielce University of Technology. The scope of investigations included determining economic and energetic parameters of the engine work, and also environmental parameters, such as the concentration of nitrogen oxides NO_x, carbon monoxide CO and carbon dioxide CO_2 in exhaust gases, and exhaust gas smokiness. In tests, the engine operated under speed conditions and it was fuelled by two commercial diesel oils that had different physical and chemical properties.

***Keywords**: piston internal combustion engine, characteristics, engine work parameters, test bench investigations, engine fuels*

1. Introduction

Piston internal combustion engines are the most common and basic power source in various fields of human activity. They are most popular power source for cars and tractors, including agricultural tractors [1]. They are also used to drive work machines, locomotives, power generators and ships. Despite their high technical level, they still represent a construction of enormous development potential, requiring further intensive research and analysis. The previous period of the piston internal combustion engine development can be divided into three stages:

- construction development aimed at improving the effective indices of the engine operation and increase in durability and reliability,
- aiming to reduce fuel consumption,
- reduction of the engine's harmful impact on the natural environment.

The above-mentioned engine development stages result directly from the requirements which piston internal combustion engines should meet. In the initial stage of engine development, should the engines be widely used to drive cars, their design had to be developed to increase their power, durability and reliability as well as ease of maintenance. At this stage, fuel consumption and detrimental impact of the engines on the environment were not an issue. The crisis of the 1970s forced research and development of engines aiming to reduce fuel consumption. It has also become a spark for seeking alternative fuels for oil-derived hydrocarbon fuels: petrol and diesel. The third stage is the result of human attention paid to the detrimental impacts of the engine on the environment. More and more restrictive standards are being introduced defining acceptable levels of toxic components emitted by engines, adversely affecting the environment. It forced an intensification of research on engine design and improvement of its systems in order to reduce engines' detrimental effects on the environment. Currently, there is also a need to reduce carbon dioxide emissions, which is most conducive to the formation and worsening of the greenhouse effect. As for piston internal combustion engines fuelled by hydrocarbon fuels, it is possible by reducing fuel consumption and introducing alternative fuels.

The development of compression ignition piston internal combustion engines was limited by the possibility to increase the engine crankshaft rotational speed. It resulted from the relatively large angle of crankshaft rotation during the fuel compression ignition delay. Long compression ignition delay causes engine hard work and considerable impact loads. Compression ignition engines were characterized by high weight and work noise as well as lesser power generated from the displacement volume. For these reasons, these engines were mainly used in large trucks and smaller engines in cars. A solution to this problem was sought by taking measures to reduce the compression ignition delay period. Classic multi-sectional injection pumps and rotary pumps did not allow high-pressure fuel injection. The improvement in supply systems through the use of injection units as well as high-pressure common rail fuel pump and electronically controlled injectors allowed eliminating the drawbacks of existing compression ignition diesel engine. Modern diesel compression ignition engines are much lighter, less noisy and, above all, develop power and torque comparable to today's S.I. engines, while using less fuel. Due to these advantages, these engines became more popular in passenger cars. Currently, compression ignition engines of smaller displacement volumes developing 5500 rev/min are commonly used in passenger cars [2]. It is noticeable by a significant increase in the diesel engine cars sales share in the European market of new passenger cars.

Currently, the primary factor stimulating the development of piston internal combustion engines and decisive in their success is their small detrimental effect on the environment [6, 8, 10]. When designing the modern piston internal combustion engine, the following factors must be taken into account: low fuel consumption, low toxicity of exhaust gases, low noise operation and engine flexibility. Given these factors, the following development trends of compression ignition piston internal combustion engine can be highlighted [3, 5, 7]:

- common use of direct injection,
- the use of modern power systems with high-pressure injection, Common Rail systems or injection units,
- the use of multi-valve timing gear systems with controlled parameters of valve operation,
- development of turbocharged systems, the use of turbochargers, electrically assisted turbochargers, electric motor driven turbochargers, intercooled supercharged systems,
- the use of additional pulse charge with compressed air contained in a pressure tank during car acceleration,
- the use of electronically controlled exhaust gas recirculation (EGR) with cooling,
- electronic control of injection process parameters,
- the use of multistage fuel injection
- control of the working medium swirl and turbulence,
- concept development of the engine with an adjustable (variable) compression ratio, i.e. increased compression ratio at low rotational speeds and decreased at high rotational speeds,
- development of the particulate filters technology, the use of the Oxicat catalytic oxidation reactor (Oxidation Catalyst), reduction catalytic converters type DENOx, NO_x catalytic absorber or a combination thereof,
- on-board diagnostic development,
- the use of cooling systems with higher temperature coolant and faster engine heating after start,
- shaping the course of heat generation during the combustion process through the use of injection high pressure and modulating the fuel injection process in time,
- downsizing,
- production technology development of reformulated diesel fuel.

2. Research scope and methodology

The experimental tests were conducted at a stand constructed at the Heat Engines Laboratory of the Kielce University of Technology. The scope of research consisted of defining external speed characteristics of the Fiat 1.3 Multijet engine when fuelled by various commercial diesel fuels. In the tests, economic and energy as well as environmental indices of the test engine have been determined. The engine operated in the rotational speed range from 1000 to 4400 rpm. Measurements were performed under fixed engine operating conditions in steps of 200 rpm of the crankshaft. In the tests, the following measurements of the engine operation parameters were made: effective power N_e, effective torque M_o, hour fuel consumption G_h, engine boost pressure p_d, container fuel pressure p_d, basic exhaust components such as: carbon monoxide CO, carbon dioxide CO_2, nitrogen oxides NO_x and exhaust smokiness D.

The following paper presents selected test investigations into the winter and summer diesel-powered Fiat 1.3 Multijet engine. Basic physical and chemical properties of engine fuels are presented in Tab. 1. The Fuels exhibit considerable differences in low-temperature properties.

Tab. 1. Basic physical and chemical properties of engine fuels used in investigations

Parameter	Summer diesel fuel	Winter diesel fuel
Cetane number	52.4	52.1
Cetane index	53.6	52.6
Density at 15°C, kg/m^3	832.4	832.9
Kinematic viscosity at 40°C, mm^2/s	2.644	2.551
Flash point, °C	61.5	59.5
Cloud point temperature, °C	-8	-11
Cold filter plugging point, °C	-8	-25
Fractional composition - distillation to a temperature of 250 °C, % (V/V) - distillation to a temperature of 350 °C, % (V/V) - 95% (V/V) distillation to a temperature	 38.1 95.3 348.8	 39.5 95.7 347.4
Sulphur content, mg/kg	8.5	6.7
Water content, mg/kg	109	67
Solid impurities content, mg/kg	7	8
Carbon residue on 10% distillation residue, %(m/m)	0.01	0.02
Ash residue,%(m/m)	0.001	0.002
Polycyclic aromatic hydrocarbons content; %(m/m)	3.1	2.9
Fatty acid methyl esters (FAME) content;%(V/V)	4.8	4.7
Copper strip corrosion test; class	1	1

3. Test object and bench

The test object was the FIAT 1.3 Multijet engine manufactured by Fiat-GM POWERTRAIN Polska in Bielsko-Biala meeting the Euro IV emissions standards. The engine develops maximum power of 90 PS (66 kW) at the rotational speed of 4000 rpm and maximum torque of 200 Nm at rotational speed of 1750 rpm. The engine is an example of the automotive internal combustion engines trend known in the literature as “downsizing.” Tab. 2 presents the basic technical data of the engine tested.

Tab. 2. Basic technical data of the engine FIAT 1.3 MULTIJET

Fiat 1.3 Multijet SDE 90 PS compression ignition engine		
Parameter	Unit	Value
Cylinder Layout	-	straight
The number of cylinders, c	-	4
Injection type	-	Direct, multistage fuel injection (from 3 to 5)
Cylinder operation sequence	-	1 – 3 – 4 - 2
Compression ratio, ε	-	17,6
Cylinder bore, D	m	$69.6 \cdot 10^{-3}$
Piston stroke, S	m	$82 \cdot 10^{-3}$
Engine displacement, V_{ss}	m^3	$1.251 \cdot 10^{-3}$
Engine nominal power, N_e	kW	66
Rotational speed at nominal power, n_N	rpm	4000
Maximum engine torque, M_e	Nm	200
Rotational speed at maximum torque, n_M	rpm	1750
Rotational speed at idle speed, n_{bj}	rpm	850±20

The test bench at which the measurements were carried out consists of the following elements:

- Fiat 1.3 Multijet 90 compression ignition engine,
- Eddy-current brake type EMX - 100/10 000 manufactured by ELEKTROMEX CENTRUM,
- control cabinet for operation of engine and brake with control system manufactured by AUTOMEX,
- pressure measurement system of working medium in the cylinder by means of the GH13G12 AVL sensor,
- Fuel-flow meter type 730 Dynamic Fuel Consumption manufactured by AVL,
- SENSYFOLW iG thermal mass air-flow meter manufactured by ABB,
- PC computer allowing controlling the engine test bench with PARM version 1.7 software developed by AUTOMEX and engine diagnostics using the KTS 540 module and Bosch software.

Fig. 1 shows block diagram of the test bench research stand with engine

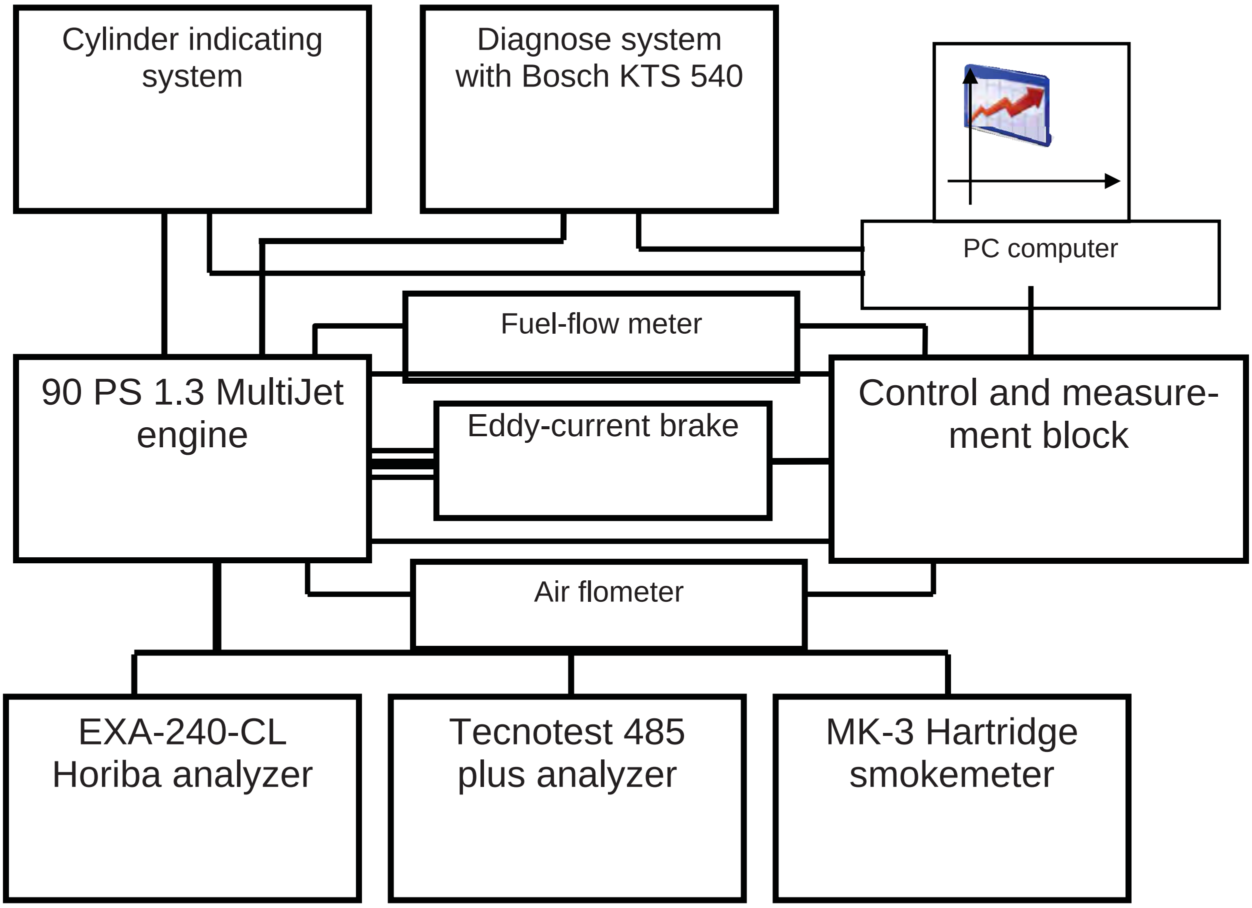

Fig. 1. Block diagram of the test bench research stand

5. Test results

The article presents the results of defining the Fiat 1.3 Multijet engine indices operating according to the external speed characteristics: effective power N_e, effective torque M_o, hour fuel consumption G_h, unit fuel consumption g_e, a fuel dose per engine cycle g_c, boost pressure p_d, fuel pressure in the fuel container p_w, concentrations in exhaust: carbon monoxide CO, carbon dioxide CO_2, oxygen O_2, nitrogen oxides NO_x and exhaust smokiness D.

The course of changes in basic effective and economic indices of the tested engine operation: effective power N_e, effective torque M_o, hour fuel consumption G_h, unit fuel consumption during operation according to external speed characteristics and fuelled by winter diesel oil is shown in Fig. 2. Fig. 3 shows graphic representation of the mentioned engine indices operating according to external speed characteristics and fuelled by summer diesel oil. The Fig. 4 shows the comparison of effective power N_e, effective torque M_o, hour fuel consumption G_h and unit fuel consumption g_e while fuelling the 1.3 MULTIJET with two commercial diesels of different properties depending on the operating conditions.

6. Summary

The article presents the preliminary results of the Fiat 1.3 Multijet 90 PS engine tests. The engine tested is one of the most modern compression ignition engines. It was developed by modifying the 70 PS 1.3 SDE engine which went into production in 2003. As compared to the previous model of this engine, its power has been increased from 70 to 90 PS and torque from 180 Nm to 200 Nm. It has been achieved mainly through the use of turbochargers with variable geometry vanes and by increasing fuel injection pressure from 1400 to 1600 bar.

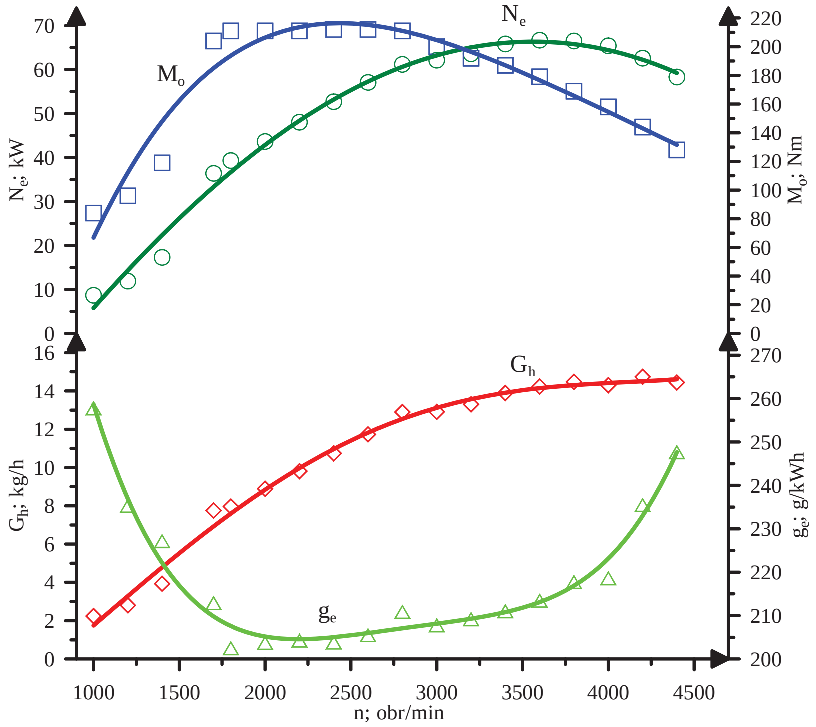

Fig. 2. External speed characteristics of Fiat 1.3 MULTIJET engine fuelled by winter diesel oil

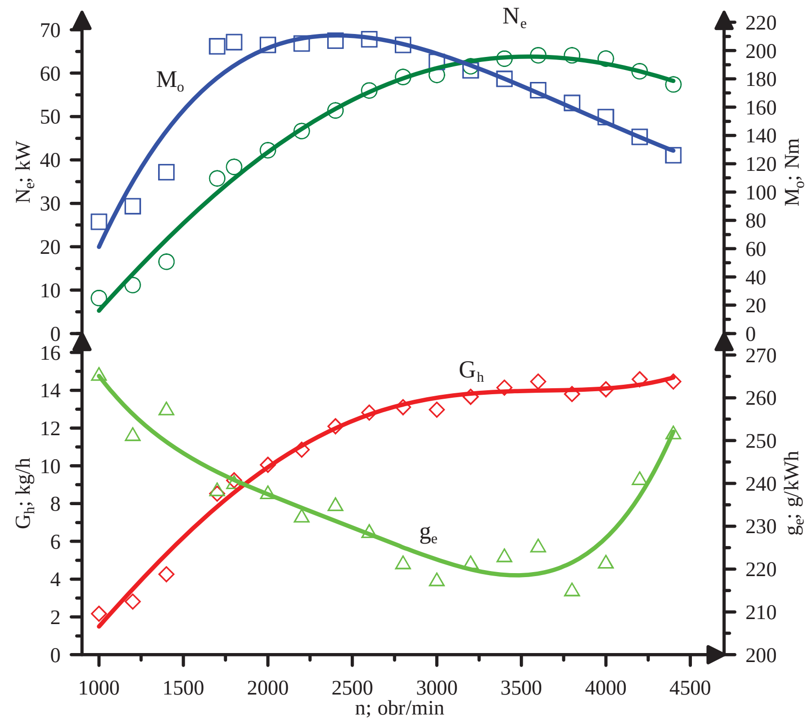

Fig. 3. External speed characteristics of Fiat 1.3 MULTIJET engine fuelled by summer diesel oil 3.

The research related to the determination of the test engine selected indices while operation according to the external speed characteristics and fuelled by two commercial diesel oils: summer and winter of different physical and chemical properties. The differences in values of basic operation indices of the engine tested when fuelled by particular diesel oils. When fuelled by winter diesel, slightly higher values of effective power and torque have been achieved as shown in Fig. 4. When fuelled by summer diesel oil, slightly higher hour fuel consumption and significantly

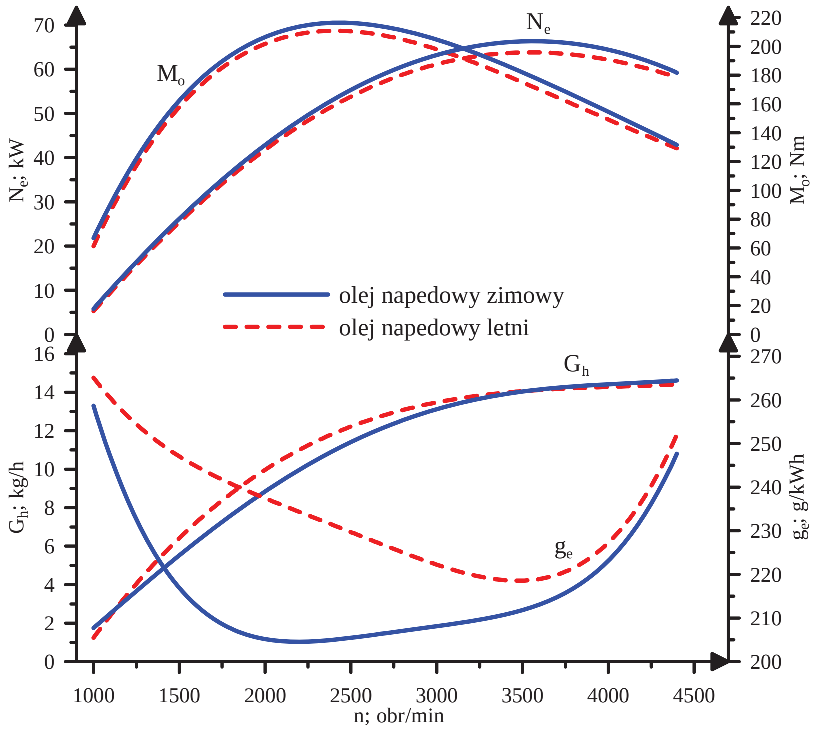

Fig. 4. Comparison of Fiat 1.3 MULTIJET engine work parameters

higher unit fuel consumption have been achieved. The graph of the unit fuel consumption curves when fuelled by the above-mentioned diesel oils is also radically different. The engine fuelled by summer diesel oil generated more nitrogen oxides. The differences in values of the analysed engine operation indices when fuelled by different diesel oils result probably from different physical and chemical properties of these oils.

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