ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0012.4348

THE EVALUATION OF THE FIAT 0.9 TWINAIR ENGINE POWERED BY PETROL AND LPG GAS WORK CYCLES UNIQUENESS

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Abstract

The article describes the test results of the uniqueness of the work cycle of two-cylinder internal combustion piston FIAT 0.9 TwinAir engine, while being powered by 95 octane petrol fuel and LPG gas. The engine was working according to load characteristics. The engine mounted on the test bench was equipped with a sequential LPG gas fuel supply system. The gas fuels differ significantly from the petrol fuels in their physiochemical properties. In order to rationally utilize gas fuels to power internal combustion engines, the knowledge about basic fuel burning process of these fuels is required. The article shows the analysis of individual engine work cycles of the technologically advanced engine in order to evaluate the influence of powering by LPG gas fuel on the rate of uniqueness of its work cycles. The measure of uniqueness of the inter-cylinder processes are the work cycle uniqueness indicators, which are as follows: the maximum work cycle pressure uniqueness indicator, the average measured work cycle pressure uniqueness indicator, the measured pressure work cycle graph uniqueness indicator and the measured pressure work cycle partial graph uniqueness. The carried out research and its analysis has shown that powering the engine with LPG gas has an influence on the engine work cycles and its uniqueness. The burning process of the mixture consisting of air and LPG gas is quicker, which has an effect on the higher speed of pressure increase rate in comparison with the engine being powered by petrol fuel. Achieved maximum in-cylinder pressure values while the engine was powered by LPG gas were higher in comparison with it being fuelled with conventional fuel. This causes an increase of the gas lads on crank-piston system, which are influencing directly the piston with higher heat load, and the thermal load of the engine.

Keywords: *spark ignition engines, gas engines, gasoline engines, uniqueness of work cycle of internal combustion engine, indicator diagram*

1. Preface

Petrol is a conventional fuel used to power spark ignited combustion piston engines. Petrol fuels are a mixture of aromatic, naphthenic, paraffinic hydrocarbons and their derivatives with a boiling temperature in the range of 30 do 215ºC [3]. The fuels used to power spark ignited engines are required to have a high resistance to engine knocking. For this reason, it is beneficial for petrol to have a large content of iso-paraffinic and aromatic hydrocarbons, which are obtained in the reforming process. Petrol fuels also contains of unsaturated hydrocarbons, usually in the form of olefins. Because of the olefins presence in petrol, the storage time of this fuel is reduced due to formation of resins. In literature the most common [8] spark ignited engines petrol fuels development directions are decreasing the sulphur content, reducing the aromatic hydrocarbons content, decreasing the benzene content, reducing the olefin hydrocarbons content, decreasing the heavy hydrocarbons content, reducing the vapour pressure, increasing the oxygen based compounds content, introducing the new generation of cleaning additives.

Alternative fuels commonly used to power spark ignition engines are the hydrocarbon gas fuels like for instance: CNG – Compressed Natural Gas and LPG – Liquefied Petroleum Gas. Those fuels are forming the air-fuel mixture easily, which in effect means that a homogenous mixture is achieved very quickly. Furthermore, gas fuels have a large resistance to engine knocking, which is a required feature in the case of SI engines. Gas fuels are combusting smokeless. Wide ignition range of gas-air mixtures allows to combust lean mixtures [5].

In Poland LPG has found a wide range of application for the usage in spark ignition engines. LPG is a mixture consisting of two hydrocarbons: propane C_3H_8 and butane C_4H_{10}. It is obtained mainly in the refineries while the crude oil is being refined. It can also be acquired during the crude oil and natural gas extraction process. Besides from propane and butane it can also contain small amounts of other hydrocarbons like for instance: methane, ethane, pentane, propene, butane, isobutene and perchance some pollution.

The advantages of LPG fuel are high engine knocking resistance, the ease of mixing with air in the engine cylinder, no sulphur, benzene and polycyclic aromatic hydrocarbons content and decrease of CO – carbon oxide, CO_2 – carbon dioxide and HC – hydrocarbons emission while it is combusted [4, 12].

LPG fuel research octane number corresponds to around 100-110. This fuel has less coal than petrol fuel in its elementary composition; in effect, less carbon dioxide is produced in combustion process. Propane and butane mixture is condensing in the ambient temperature and under relatively low pressure. It is stored in the vehicle tanks in a liquid state, pressurized to about 3-20 bar. The disadvantage of the gas fuel is a lover calorific value of the gas-air mixtures, which in effect causes a higher operational fuel consumption. While powering the engine with LPG fuel there is no cooling the intake valves with fuel-air mixture effect. Besides that, there is a decrease of engine power and torque decrease possible and nitrogen oxides emission increase.

2. The test object

The unit under testing was a two cylinder FIAT 0.9 TwinAir engine with 875 cm^3 displacement volume. The engine is equipped with an indirect multipoint fuel injection system, which supplies fuel into the intake manifold. The engine assembled on the dynamometer is equipped with a turbocharger and reaches 62.5 kW of maximum effective power for the crankshaft rotational speed corresponding to 5500 rpm and 145 Nm of maximum torque for the crankshaft rotational speed corresponding to 1900 rpm. In the FIAT 0.9 TwinAir engine the exhaust valves are controlled mechanically by cams, however the intake valves are controlled by electro-hydraulic system combined with cam mechanism. The cam is transmitting movement only to the hydraulic system, which is equipped with electromagnetic valve. When the valve is closed, the timing is working like a typical mechanical cam timing system. While the electromagnetic valve opens, the oil is flowing out of hydraulic chamber, which controls the intake valves opening process [8]. The amount of air supplied to the FIAT 0.9 TwinAir engine cylinders is controlled by direct and flexible intake valves control. The basic technical data of the FIAT 0.9 TwinAir engine are shown in Tab. 1.

Tab. 1. Basic FIAT 0.9 TwinAir engine technical data [1]

Parameter	Unit	Value
Displacement volume	cm^3	875
Engine power	kW	62.5
Crankshaft rotational speed corresponding to maximum engine power	rpm	5500
Maximum engine torque	Nm	145
Crankshaft rotational speed corresponding to maximum engine torque	rpm	1900
Number of cylinder	–	2
Cylinders layout	–	in line
Timing system type	–	DOHC
Number of valves	–	8
Compression ratio	–	10:1
Cylinder diameter	mm	80.5
Piston stroke	mm	86

3. The FIAT 0.9 TwinAir LPG gas fuel supply system

The FIAT 0.9 TwinAir engine is equipped with a sequential injection LPG fuel supply system. The LPG gas fuel supply system consists of 60 litres portable gas fuel tank. The tank is connected to a single reducer with an integrated gas electro valve. From the reducer LPG gas under demanded pressure is supplied to the gaseous phase line filter and then to the set of injectors. In the injectors, set there is a gas temperature sensor installed. The electronically controlled STELLA I-Plus injectors are supplying gas fuel to the intake manifold through the calibrated nozzle, gas lines and nipples and then to the combustion chamber through the intake valves. In the gas system there is a gas pressure sensor installed after the injectors, it is connected to engines air intake system and the LPG gas pressure reducer. The work of LPG gas fuel supply system is controlled by the Elisa Stelle controller from Elpigaz Company. For the fuel usage measurement purposes, the Emerson flow meter was used, its operation is based on the Coriolis phenomenon.

4. The test station

The test was conducted on an engine dynamometer. Presented in Fig. 1 test station consists of: internal combustion piston spark ignition engine FIAT 0.9 TwinAir, the eddy current type brake Elektromex Centrum EMX 100/10000, a fuel mass dosimeter from Automex, temperature and pressure measurement sensors mounted in different engine systems and a test station control and data acquisition system. The tested engine, the eddy current brake and all necessary components were mounted on a single frame. The measurement system allows reading and archiving all the measured data and engine work parameters in real time [6]. While conducting research, the engine in cylinder pressure curves in the function of crankshaft rotational angle was measured. The measurements were obtained with the usage of indicated pressure measurement system AVL IndiSmart 612. The measurement system is equipped with a pressure sensor integrated with the spark plug, data measurement circuit consisting of shielded wires, signal amplifier, measurement card and a PC computer with AVL IndiCom Mobile software, which allows initial data treatment, and archiving the measured data.

5. Test range and program

During research the engine under test was working according to load characteristic with crankshaft rotational speed n = 1900 rpm. The measurement was obtained for set engine loads in range of 10 to 130 Nm with a step of 10 Nm. Characteristics were obtained for test engine being fuelled with 95 octane unleaded petrol and LPG gas. The range of tests covered pressure measurement inside the engine cylinder in function of crankshaft rotation angle for set speed-load conditions. In each measurement point there were 44 engine work cycles in function of crankshaft rotation angle measured, the data was then analysed. Additionally fuel and air usage and engine thermal condition were monitored.

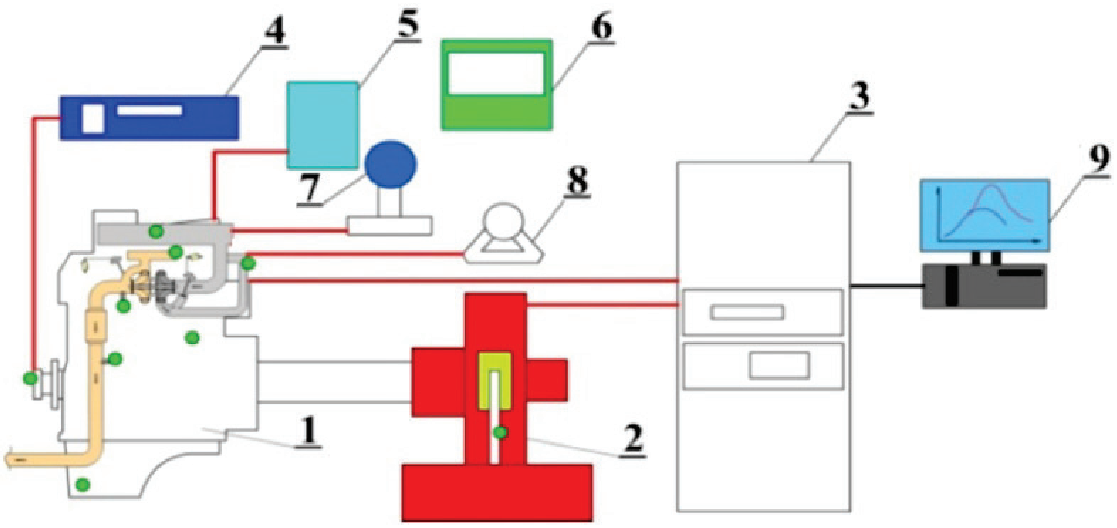

Fig. 1. Test stand scheme [2]: 1 – FIAT 0,9 TwinAir engine, 2 – eddy current brake Elektromex Centrum EMX 100/10000, 3 – control system, 4 – pressure measurement system AVL IndiSmart 612, 5 – gravimetric fuel meter ATMX 2040, 6 – diagnostic tester KTS 540, 7 – air flow meter ABB Sensy Flow, 8 – gas flow meter EMERSON Elite 9 – PC computer

6. Engine work cycles uniqueness indicators

Engine work irregularity is known as uniqueness of the measured engine work cycles [11]. The purpose of conducted analysis was to evaluate the influence of powering the engine with LPG gas on the uniqueness of the engine work cycles.

The evaluation of the engine work uniqueness is possible with the usage of engine work uniqueness indicators values. The basis of the analysis is engines indicator diagram, which is a source of many information concerning engine work indicators, especially the combustion process parameters [9]. There are many methods of evaluating uniqueness in existence; some of them are described in the papers [7, 11]. The engine work cycles uniqueness evaluation was conducted on the basis of real measured indicator diagrams. For each load characteristic point, the analysis on basis of 44 indicator diagrams obtained while the test engine was working being powered by petrol and then LPG gas was conducted. Exemplary developed indicator diagrams are shown in Fig. 2a. The analysis was carried out according to methodology presented in the article [7, 11]. For the calculation, purposes mean standard deviation: maximum combustion process pressure values, areas under the indicator diagrams and partial indicator diagrams and the deviation of average indicated pressure values of each cycles were used. Four engine work cycle uniqueness indicators were obtained: maximum combustion work cycle pressure uniqueness indicator, minimum average indicated pressure uniqueness indicator, indicator diagram uniqueness indicator and partial indicated diagram uniqueness indicator.

The maximum cycle combustion process pressure uniqueness indicator was calculated using the equation [7, 11]:

$$X_{p_{smax}} = \frac{\sigma_{p_{smax}}}{\bar{p}_{smax}} = \frac{\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}[(p_{smax})_i - \bar{p}_{smax}]^2}}{\bar{p}_{smax}}, \quad (1)$$

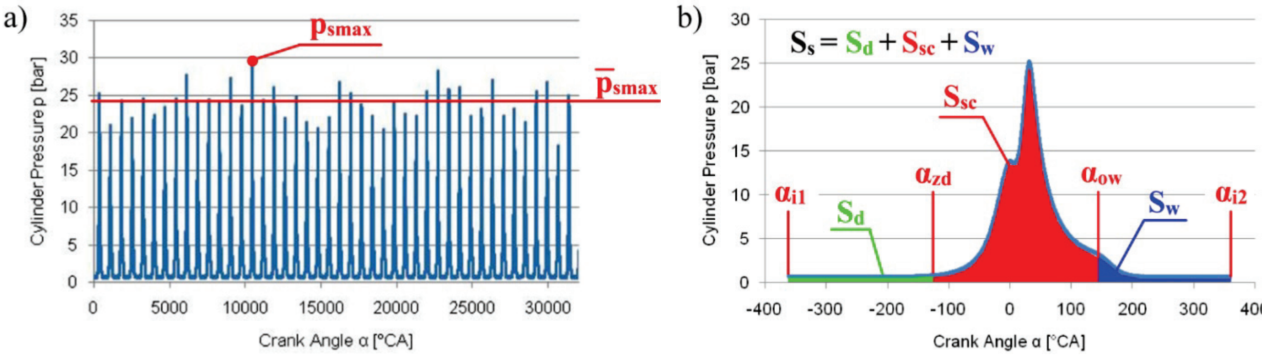

Fig. 2. FIAT 0.9 TwinAir engine indicator diagrams obtained for a chosen measurement point: a) for each work cycles, b) for a chosen work cycle; p_{smax} – maximum engine work cycle combustion process pressure, $\bar{p}_{smax}$ – average maximum combustion process pressure for each 44 measured engine work cycles, S_s – area under the open indicator diagram, S_d – area under intake curve of open indicator diagram, S_w - area under exhaust curve of open indicator diagram, S_{sc} – area under the open indicator diagram curve from the intake valve closure to exhaust valve opening α_{i1} – an angle corresponding to first point of engine work cycle, α_{i2} – an angle corresponding to last point of engine work cycle, α_{zd} – intake valves closure angle, α_{ow} – exhaust valves opening angle

where:
p_{smax} – maximum combustion process pressure of the number *i* engine work cycle,
$\sigma_{p_{smax}}$ – standard deviation of maximum combustion process pressure,
$\bar{p}_{smax}$ – average maximum combustion process pressure calculated from *N* following engine work cycles,
N – number of following measured engine work cycles.

The average indicated pressure uniqueness indicator was calculated using the equation [7, 11]:

$$X_i = \frac{\sigma_{(p_i)_i}}{\bar{p}_i} = \frac{\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}[(p_i)_i - \bar{p}_i]^2}}{\bar{p}_i}, \tag{2}$$

where:
$\sigma_{(p_i)_i}$ – standard deviation of average indicated pressure value,
$(p_i)_i$ – average indicated pressure value of the number i-cycle,
$\bar{p}_i$ – average value of average indicated pressure from the following *N* engine work cycles.

The indicator diagram uniqueness indicator was calculated using the equation [7, 11]:

$$X_s = \frac{\sigma_{(S_s)_i}}{\bar{S}_s}, \tag{3}$$

where:
S_s – area under open indicator diagram,
$\bar{S}_s$ – average area under open indicator diagram value, calculated from the following *N* engine work cycles,
$\sigma_{(S_s)_i}$ – standard deviation of areas under the curves of the following open indicator diagrams.

The area under open indicator diagram was calculated using the equation [7, 11]:

$$S_s = \int_{\alpha_{i1}}^{\alpha_{i2}} p_s \, d\alpha, \tag{4}$$

where: α_{i1}, α_{i2} – the engine crankshaft rotation angle values corresponding to engine work cycle number *i* (markings are shown in Fig. 2b).

The partial indicator diagram uniqueness indicator was calculated using the equation [7, 11]:

$$X_{sc} = \frac{\sigma_{(S_{sc})_i}}{\bar{S}_{sc}}, \tag{5}$$

$$S_{sc} = \int_{\alpha_{zd}}^{\alpha_{ow}} p_s \, d\alpha, \tag{6}$$

where:

$\sigma_{(S_{sc})i}$ – standard deviation of the following areas under the open indicator diagram curve from the closure of the intake valve to opening of exhaust valve,

$\bar{S}_{sc}$ – average of the following N diagrams area value, calculated under the open indicator diagram curve from closure of the intake valve to opening of exhaust valve,

α_{zd}, α_{ow} – the closure intake valve angle and opening exhaust valve angle.

7. The test results

The FIAT 0.9 TwinAir engine real indicator diagrams while working according to load characteristics while being powered by 95 octane unleaded petrol and LPG gas test results analysis has allowed to obtain a following work cycles uniqueness values. On the basis of the following 44 measured engine indicator diagrams the following uniqueness indicators were obtained: the maximum work cycle combustion process pressure uniqueness indicator $X_{p_{smax}}$, the average indicated pressure uniqueness indicator X_i, the indicator diagram uniqueness indicator X_s and the partial indicator diagram uniqueness indicator X_{sc}. Obtained values of the above-mentioned indicators in the functions of engine load are presented in Figs. 3 to 6. Maximum pressure values measured among following 44 engine work cycles while working according to a load characteristics for crankshaft rotational speed corresponding to n = 1900 rpm and while being powered by petrol and LPG gas are shown in Fig. 7.

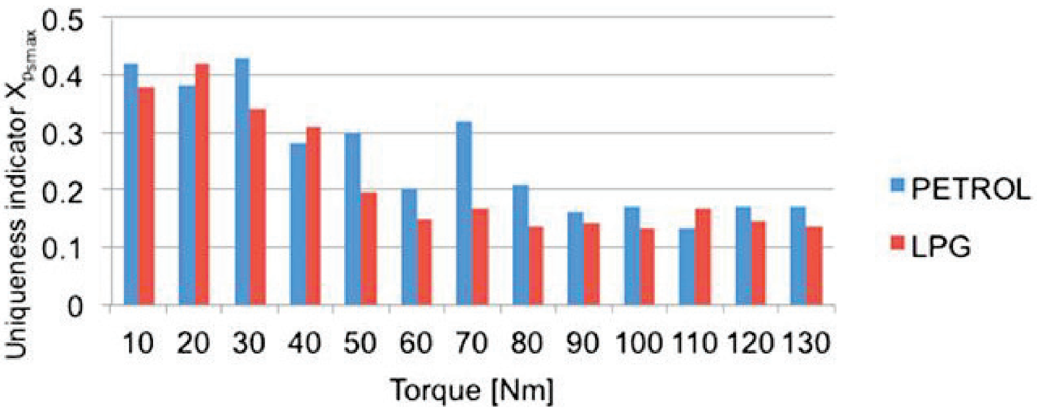

Fig. 3. The FIAT 0.9 TwinAir engine work cycle maximum combustion pressure uniqueness indicator values while being powered by 95-octane unleaded petrol and LPG gas and working in accordance with load characteristic for the crankshaft rotational speed corresponding to n = 1900 rpm

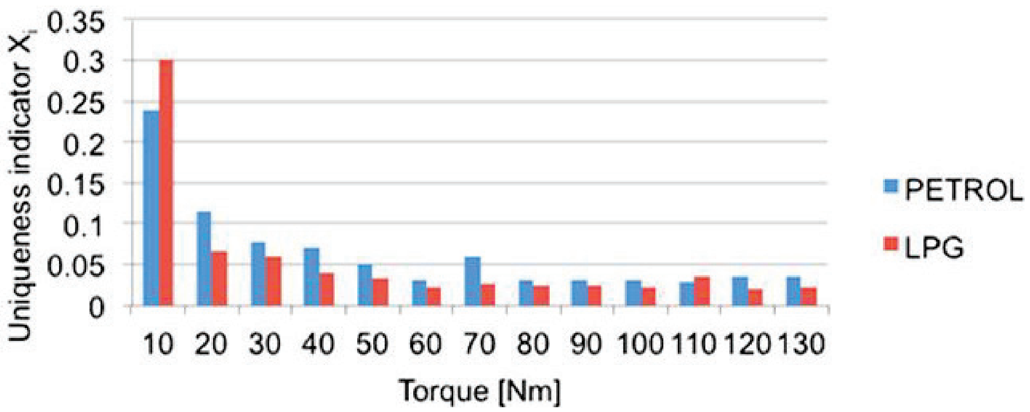

Fig. 4. The FIAT 0.9 TwinAir engine work cycle average indicated pressure uniqueness indicator values while being powered by 95-octane unleaded petrol and LPG gas and working in accordance with load characteristic for the crankshaft rotational speed corresponding to n = 1900 rpm

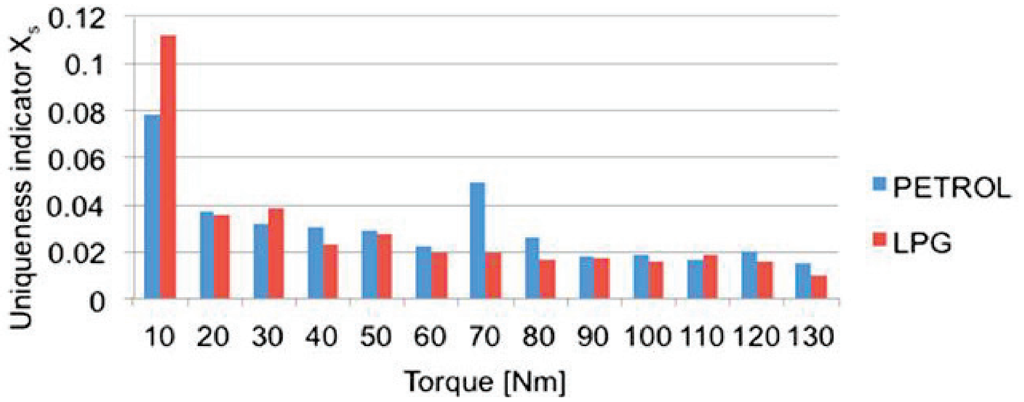

Fig. 5. The FIAT 0.9 TwinAir engine work cycle indicator diagram uniqueness indicator values while being powered by 95-octane unleaded petrol and LPG gas and working in accordance with load characteristic for the crankshaft rotational speed corresponding to n = 1900 rpm

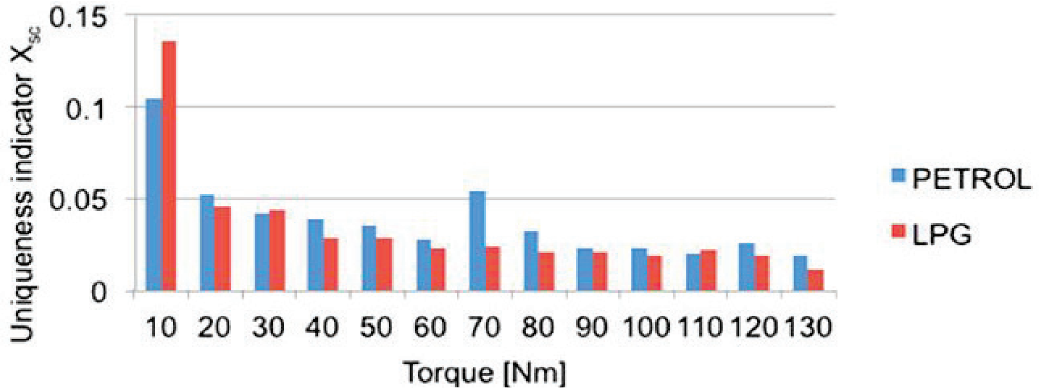

Fig. 6. The FIAT 0.9 TwinAir engine work cycle partial indicator diagram uniqueness indicator values while being powered by 95-octane unleaded petrol and LPG gas and working in accordance with load characteristic for the crankshaft rotational speed corresponding to n = 1900 rpm

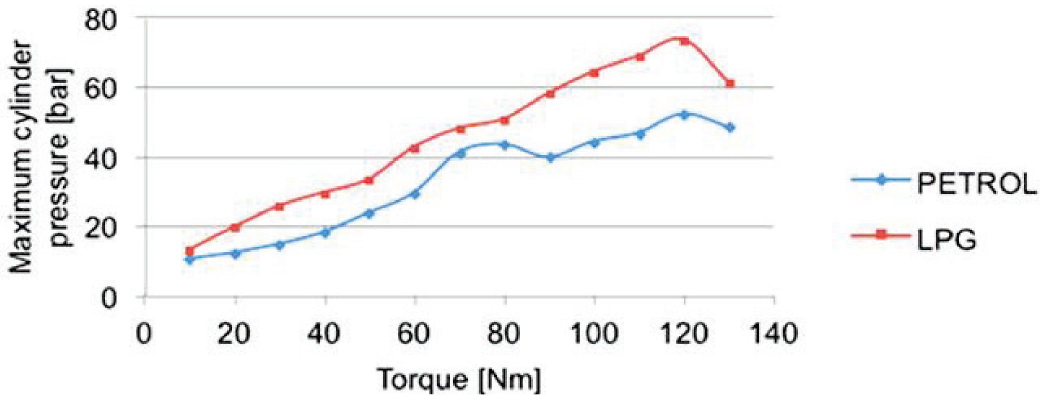

Fig. 7. The FIAT 0.9 TwinAir engine work cycle in-cylinder combustion process pressure uniqueness indicator values while being powered by 95-octane unleaded petrol and LPG gas and working in accordance with load characteristic for the crankshaft rotational speed corresponding to n = 1900 rpm

8. Summary

The analysis results of FIAT 0.9 TwinAir engine actual indicator diagrams while being powered by 95-octane unleaded petrol and LPG gas and working according to load characteristic allowed a comparison evaluation of engine work cycles uniqueness. The following uniqueness indicators were obtained: the maximum work cycle combustion process pressure uniqueness indicator $X_{p_{smax}}$, the average indicated pressure uniqueness indicator X_i, the indicator diagram uniqueness indicator X_s and the partial indicator diagram uniqueness indicator X_{sc}.The largest of above-mentioned work cycles uniqueness indicators values were obtained for the low range of engine load. More than twice bigger values of the average indicated pressure, indicated diagram and partial indicated diagram uniqueness indicators were obtained for the load corresponding to 10 Nm in comparison with other load values. The increase of load was causing the decrease of calculated following engine work cycles uniqueness indicators values, while it was powered by petrol as well as by LPG gas. While powering the engine with LPG gas fuel, smaller engine work cycle calculated uniqueness indicators were obtained in most of the measurement points. In the FIAT 0.9 TwinAir engine work cycle maximum combustion pressure uniqueness indicator values $X_{p_{smax}}$ have shown a large dispersion in maximum pressure values, while it was powered by petrol as well as by LPG gas, in the small and medium range of load. While evaluating the engine work cycles uniqueness determined by the indicator diagram uniqueness indicators and partial indicator diagram uniqueness indicators, very similar indicators values were obtained.

On the analysis basis of the 44 following open Fiat 0.9 TwinAir engine work cycles, there were cycles for which lower maximum combustion pressure values than compression pressure values were acknowledged. Those cycles were occurring while the engine was powered by petrol in the load range of 10 to 40 Nm and while it was powered by LPG gas in the range of 10 to 30 Nm. The biggest numbers of those cycles were detected while the engine was powered by petrol and for the load corresponding to 20 Nm. This was about 18% of following engine work cycles affected by this phenomenon. While the engine was powered by LPG gas there were about 6% of affected cycles.

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Manuscript received 28 May 2018; approved for printing 30 August 2018